Abbreviations

CAPEX	Capital Expenses (Investment Costs)
CHP	Combined Heat and Power
CLO	Compost-like output
GoL	Government of Lebanon
HR	Hazardous Residue
HWL	Hazardous Waste Landfill
MRF	Materials Recovery Facility
MSW	Municipal Solid Waste
N/HR	Non-Hazardous Residue
OPEX	Operational Expenses
RDF	Refuse Derived Fuel
SL	Sanitary Landfill
SRF	Solid Recovered Fuel
SW	Solid Waste
SWM	Solid Waste Management
T&S	Technologies and Systems
WWTP	Wastewater Treatment Plant

1 RAPID EVALUATION & ASSESSMENT OF ALTERNATIVE SW TREATMENT OPTIONS

1.1 Introduction

In aplanning processofsolid wastemanagementat the nationallevel, the development of alternative scenariosmay be related -more orlessstrongly- witha number of parameterswhichare not identicalin every countrynorin every season. Such parametersmay be:

- The existenceor notof establishedenvironmental commitmentsat state level(e.g.on emissions into theenvironment-air, soil, water) and, in particular, the character of thesecommitments(directive or indicative);
- The existenceor notof establishedsolid wastemanagement objectivesat state level(e.g.on the percentageof biodegradablediversionfromlandfills,the rate of sorted-at-source wastestreams, the rate of recovery of materials andenergy, etc.) and, in particular, the character of these goals(directive or indicative);
- The existenceor not of time-schedulingto achieve theobjectives,at state level, and, in particular, the nature of thisprogramming(directional or indicative);
- The suddenappearanceof variousunforeseensocial conditionsthat candecisively affectthe quantityofwaste generatedand the level ofserviceprovided(e.g.rapidurbanization, influxof additionalpopulation, etc.) and, therefore, determine imposedurgent options to addresscriticalcircumstances.

Onthebasisoftheseparametersthe decision-making process regarding the selectionof wastemanagement technologies and systems (T&S) is initiated. The criteria usedfordecision makingmay include:

- the degree of responsivenessof available T&S to achievethe statedcommitments and goals;
- theeconomicsof the available T&S (CAPEX, revenue– OPEX ratio, chargefees), with respect -from the one hand- to theavailability ofthe requiredresourcesand –from the other-to the affordability of households and enterprises;
- thelevel of socialacceptance oftheavailableT&S;
- the levelof familiarityof labor (technical andadministrative)to theavailableT&S;
- thetechnical/functional / operationalfeatures and theflexibilityoftheavailableT&Sinrelation to the natureand composition ofwasteto be managed;
- thedatafrominternationalexperienceontheefficiencyandapplicabilityoftheavailableT&Sinrelation to the natureand composition ofwasteto be managed.

The findings from theevaluation as to the abovecriteriajointly shapeasynthetic figure, the **applicability**of available T&S in the country concerned.

In thecase of Lebanon, the basic guidelinesare definedinaseries of legislativeframeworks, most recently with theCOM Decision no 1/2015,which states thatthediversionratefromlandfillthat must be achievedwithinthe next three yearsis 60%, which should reach75% in the years followingthe three year period.

The developmentof alternativesthat willbe advised to the competentLebanese authoritiesshouldthereforecomply withthe abovedirections.

In this context, in the present “rapid assessment”:

- firstly, schemespotentiallybeingfeasibletoapplyinLebanon areidentified (section 6.1.2);
- follows a briefoverview of the mainavailable solidwastetreatment/disposal T&S, internationallyapplicable (section 6.1.3);

- the identified schemes potentiallybeingfeasibletoapplyinLebanon are following presented in more details (section 6.1.4);
- then, these schemes are comparatively assessed to environmental, financial, technical, social and experience / applicability criteria (section 6.1.5), and;
- finally, evaluative comments and observations on critical issuesare stressed and coded, aiming to assist competent authorities in decision-making(section 6.1.6).

1.2 Identification of Potential SW Treatment Technologies and schemes in Lebanon

The alternative scenarios for MSW treatment and final disposal whichcantheoreticallybe drawnandcome up forevaluationare as many as the number of the single T&S families and of the combinations among them. These T&S canbe classified inseveral differentapproaches:

- as to the *typeofwaste*to be treated (mixed or sorted-at-source), whereby we can discern:
  - T&S for *mixed waste*, e.g. Mechanical – Biological Treatment (MBT), Bio-drying, Thermal Treatment, Sanitary Landfills;
  - T&S for *sorted-at-source waste*, e.g. Materials Recovery Facilities (MRF) for recyclables, Biological Treatment plants for biowaste, combined treatment plants for both recyclables and biowaste (MRF + Biological Treatment);
- as to the*biological process* applied for the treatment offermentablefraction and biowaste, whereby we can discern:
  - *aerobic* treatment process;
  - *anaerobic* treatment process;
- as to the *goal ofproduction*, wherebywe can discern:
  - T&S configured for recovery of recyclables;
  - T&S configured for production of cRDF for energy recovery (with in-situ incineration of RDF) or dRDF for disposal in other consumers (e.g. cement industry, power plants etc.), or
  - T&S configured for production of stabilat (SRF);
  - Sanitary Landfills with or withoutbiogascollection andrecovery of energy;
- as to the *labor intensity*, wherebywe can discern:
  - manual labor intensity T&S;
  - automation-intensiveT&S;
- as to the *type of thermalprocess*, wherebywe can discern:
  - Incineration - energy recovery T&S;
  - Pyrolysis - energy recovery T&S;
  - Gasification - energy recovery T&S.

Another –regardless of T&S- parameterthat should notbe omittedin designing of MSW scenarios, as it significantlyaffectsthe results of thefeasibility studyphase,is related to the*final disposalofbiostabilised material* that is produced in mixed wastetreatment plants,wherebywe can discernbetween utilization of the material (e.g. soils overlay, landscape/ landfillrehabilitation etc.) or burial.

Ifcountedallthe possible combinations among theabovecases,the number of possible(mathematically) scenarioscanreach 64. But manyof these combinationsmaybe excludedifaseries of logicalcriteriaapplied. Exclusion criteria are related to:

- Thefailure to achieve thetargetsofthe recovery rate-diversionfromlandfillwithinthe specified timeperiod, which have been setfor Lebanonby the directive Decision:
  - *“Recuperating 60% of the waste through separation, recycling and composting as well as energy regeneration in the first three years of the contract and 75% in the following years*

until we reach the stage of thermal disintegration (including RDF, or incineration or other) based on what will be decided later" ([1]).

- *…providing a landfill for every service area or at least in every Caza excluding administrative Beirut and its suburbs …" ([2]).*

- irrational combinations of simultaneous application, and at the same planning area, of competingtechnologiesthat mutually weakentheir scopes ofproduction, e.g. "clean" MRF scoping to recyclables (plastics, paper and cardboard) vs thermal treatment technologies scoping to energy recovery, since theoperationof the formersignificantlyweakens thecalorific value of theraw material in thelatter (especially in small size planning areas);
- irrational combination of simultaneous application of competing thermal treatment technologiesat the same planning area (incineration and pyrolysis and gasification at the same planning area);
- irrational combination of simultaneous application of competingtechnologies for the treatment of pre-segregated biowaste at the same planning area (composting and anaerobic digestion at the same planning area);
- irrational combination of simultaneous application of competing mechanical separation technologiesat the same planning area (mechanical separation for production of recyclables and mechanical separation for production of RDF).

Furthermore, consideringthefactthatthe Sorted-at-Source process neverandnowhereachievesthecollectionoftotal pre-segregated MSW streams(recyclableorbiowaste), achievingonlya portionof these, should be putfrom the outsetthatSorted-at-Sourcecan (and should) be consideredas a processparallel, coexistingandcomplementary tothemixed waste managing process and notas an exclusiveprocess for the management of total MSW quantity. This leads tothe additionof yet anotherrational criterion, under whichscenariosthat includeonlypre-segregated MSW treatment plants(without mixed MSW treatment plants) are excludedof the evaluation process.

By applying the aboverational criteria of exclusion, the number of finallypossible-realistic optionsis limitedto 19.

All combinationsarising from theaboveanalysis are presentedin the table of Annex …In this table theexcluded combinations arebeingmarkedwithredfontsingreycells while in the last column is provided justification for excluding specific schemes from the evaluation.

The schemesfinallyselected forevaluation inthis reportare givenin the table below. Forconvenience of the reader, in the second columnof this tablethe numberingof Schemesgivenin the table ofAnnex1is maintained.

Table 1: List of SW treatment schemes under consideration in Lebanon

No of Scheme	No of Scheme in Annex	Description of Scheme
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS		
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R. in H.W.L.
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal

[1]COM, Decisionno. 1 / 12-1-2015, paragraphI,first subparagraph.

[2]COM, Decisionno. 1 / 12-1-2015, paragraphI, second subparagraph.

No of Scheme	No of Scheme in Annex	Description of Scheme
		of H.R in H.W.L.
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.
10	8.f	Bio-drying. Metals / stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.
12		Landfills with recovery and combustion of biogas -energy.

b. PRE-SEGREGATED WASTE TREATMENT PLANTS		
b1. Separate Sorting-at-sourceof biowaste and dry streams		
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas -energy, disposal of residues in S.L.
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.
b2. Sorting-at-sourceonly biowaste		
17	10 et al	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.
18	13 et al	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of

		residues in S.L.
b3. Sorting-at-source only recyclables		
19	16.c et al	“Clean” MRF. Recyclables, disposal of residues in S.L.

1.2.1 An overview ofkey SW treatment methods, technologies and systems

1.2.1.1 Mechanical Treatment

Mechanical treatment process aims to increase purity of recovered Recyclables (mostly paper & cardboard, plastics, metals, as well glass whenever its recovery entails worthy selling prices) and make it feasible and worthy to divert them to the industry as secondary materials.

Mechanical separationinstallations and facilities are configureddepending on thepurityof the incomingwaste, whereby we candistinguish between:

- “Clean” MRF facilities, configured for treatment of sorting-at-source recyclables and;
- “Dirty” MRF facilities, configured for treatment of mixed MSW.

1.2.1.1.1 “Clean” MRF

A “clean” MRF receives recyclablesthat have been previously sorted-at-source.

Separation is achieved with use of manual and mechanical sorting techniques. Depending on the desired level of automatization, the mechanical separation process may comprise of conveyor systems, bag openers, magnetic devices, eddy current devices, air-separators, handpicking etc.

Recyclable materials are sold to the industry, whereas the remaining irrecoverable residues may be finally disposed of in landfills or fed in thermal treatment units.

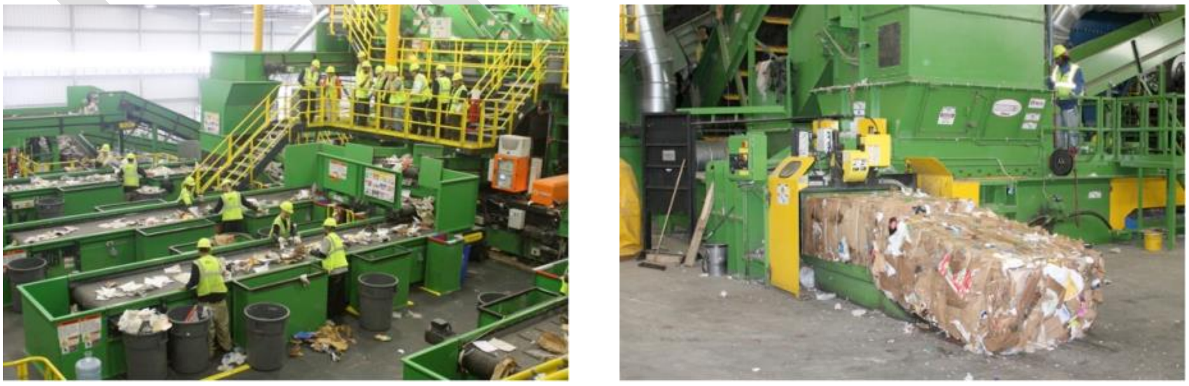


Figure 1: Handpicking and final products (paper and cardboard) in a “clean” MRF in the US (source: http://greenopolis.com).

Figure 2 gives a typical mass-balance diagram of a "clean" MRF. The recoveryrate is high (80-97% wt.) and depends on the sorting efficiency achieved upstream during street-cleaning and collection, which determines the quality of the incoming materials.

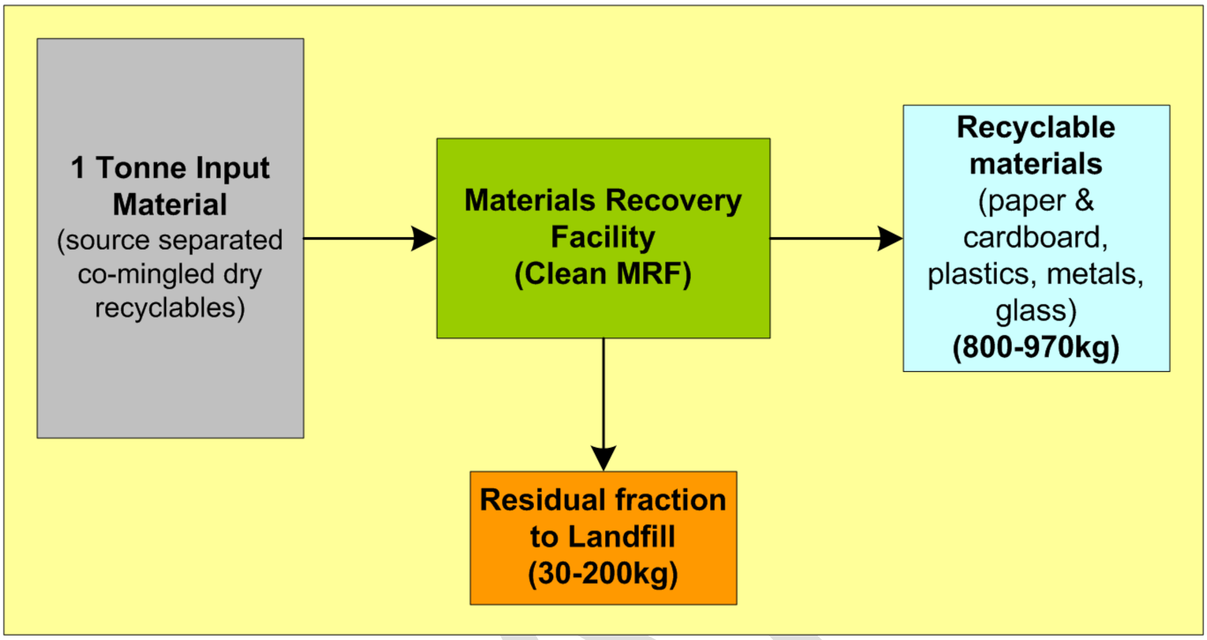


Figure 2: Indicative mass-balance diagram of a "clean" MRF.

"Clean" MRFs deploy readily available and proven technologies, and may operate as part of an integrated SW management system to recover recyclable materials out of the SW stream after the application of sorting-at-source initiatives.

Even though the combined "separate collection/"clean" MRF" system induces higher capital and operational costs (per ton equivalent) compared to the combined "mixed collection/"dirty" MRF" system, mostly due to the increased cost for separate collection of the various MSW fractions, it is easier to achieve cost recovery in the mid- and long-term, due to the higher purity and selling prices of the final products. Furthermore, the working conditions in a "clean" MRF are much better than in a "dirty" MRF.

- *Advantages & Disadvantages*

Techniques	Advantages	Disadvantages	Preceding Practices	Following Practices
“Clean” MFR	• Readily available an proven technology • High recyclables’ recovery efficiency • High quality and selling price of reclaimed recyclables • Simple technology implemented in small-, mid- and large-scale • Little requirements for experienced staff • High cost recovery • Prevents hazardous waste from reaching the landfill level • High public acceptance (higher than “dirty” MFRs) • Low environmental protection and H&S measures requirements	• Applicable only for pre-segregated recyclables (need for upstream recycling program) • No biowaste recovery when applied alone • Does not address non-recyclable materials which comprise large fractions of MSW • Intermediate energy needs per tonne	sorting-at-source of recyclables (all types)	need for a landfill or mixed MSW treatment facilities for residues

6.1.1.1.1 "Dirty" MRF

"Dirty" MRFs receive mixed MSW. Mechanical separation is achieved through similar techniques as in "clean" MRFs, mostly mechanical ones due to the increased hygiene risks for hand-pickers. In addition, "dirty" MRFs include a screening line (disc screens, trommel screens, etc.) for separating the fermentable fraction. The qualityof recycledoutput fromdirtyMRFislower than that of 'clean' MRF due to organic impurities in the incoming material, thus achieving lower selling prices.

A"Dirty" MRF may consist of the following:

a) Reception and Preparation Section

Enclosedbuilding wherethecollection vehicles(after weighing them)unloadin suitableplaces, which serve astemporarystorage space. Receptors are usually formedastanks(bunkers)whose"crowning" is at the levelofmaneuveringsquareofgarbage trucks, although there areplantswhere the landingis madedirectlyinthe square.

Vehiclesenterwhollytobuildinghostwhichhaselectrically drivengates, which are automaticallyclosedafter removalof the vehicle, as well as powerfulventilation. This procedureensuresthe minimizationof odorsin theenvironment.

For the collectionofwastefrom the receptorandunloadingto the feed hopper, cranesandgrippers are usuallyused. Thegripperis used bothfor transporting thewaste from thereceptor tothedownstreamreceivinghoppers, and forlayingwastewithin eachslot. By an appropriate operation of the grippers anybulky/undesirablewasteastires, chairs, bikes,etc., are removed. This waste isdivertedto storagespace (e.g.incontainer)forappropriate management. In thecase of landinginsquare, mobile equipment is usedin forthese procedures (loaders, vehiclesequippedwith crampons).

Thepreparationof wasteis the nextstep afterthe receptionand includestechnologies for tearingbags, reducingthe sizeandrecoveryof waste uniformity, described in the following table ([3]):

Table 2: Wastesizereduction technologies

Technology	Operation- Aim	Problems-Constraints
Hammer mill	Size reductionofwastewith swinginghammers.	Strain - wear of hammers, pulverizingglass/aggregates, unfitfor pressurizedcontainers.
Shredder	Rotatingbladesor discsrotate atlowspeed and hightorque.Theshearingaction ofripsorintersectsmost materials.	The largehard objectscan damagethe cutters, unfit pressurized vessels.
Rotating Drum	Agitationand homogenizingwaste.	Problemmay occurifwastewithhigh humidity
BallMill	Rotatingdrumswith heavyballsto sliceorpulverizingwaste	Strain-wearof balls, pulverizingglass/aggregates.
Wet rotating drums with knives	Byadding water, waste createslargeaggregates thatare brokenbythe cuttersupon rotationof the	Relatively small size reduction. Possibility of destruction of the cutter

[3]Bardos 2004, DEFRA 2005b, EA 2002b.

Technology	Operation- Aim	Problems-Constraints
	drum.	from large hard objects.
Plastic Bag splitter	It maybe ofa rotarycutter, orreciprocatingcomb or toothedchains	It does not reducethesizeof waste. Probability ofdestructionfrom largehard objects.

b) Waste SeparationTechnologies

This part of themechanicalprocessincludes technologieswhichachieve theseparationof the incomingwaste massinto two streams(organic and other materials), of which onecontainsa high concentration of the material to be recovered while the other islargelyfree of this material's presence.

The main separation technologies are given in the following table ([4]):

Table3:WasteseparationTechnologies

Technology	Separation Attribute	Target materials	Difficulties- Restrictions
Trommels and screens	Sizeanddensity	Oversized: paper, plastic Small: organic,glass,fine grains(fines)	Cleaning
Manual separation	visual examination	Plastic, impurities, oversized, foreign matter	Hygiene andlaborsafety, ethical issues
Magneticseparators	magnetic properties	ferrousmetals	
Separatorswithinductivecurrents	electrical conductivity	Non-ferrous metals	
Froth flotationseparators	densitydifferentials	Floating: plastic, organic. Sinking: stones, glass	Createsliquidwastestreams
Airseparators	weight	Light: plastic, paper Heavy: stones, glass	Requiredaircleaning
Ballisticseparators	Densityandelasticity	Light: plastic, paper Heavy: stones, glass	
Opticalseparators	Optical properties	Prescribedplastic polymers	Yield

Alternatively to recover recyclables, RDF could be produced in a “Dirty” MRF, consisted mostly of paper & cardboard, plastics and wood.

[4]Archer etal. 2005c, Bardos 2004, DEFRA 2005b, EA 2002b.

Figure 3 and Figure 4 provide typical mass-balance diagrams of those two options respectively. The high recoveryrates (75-95% wt.) should be noted.

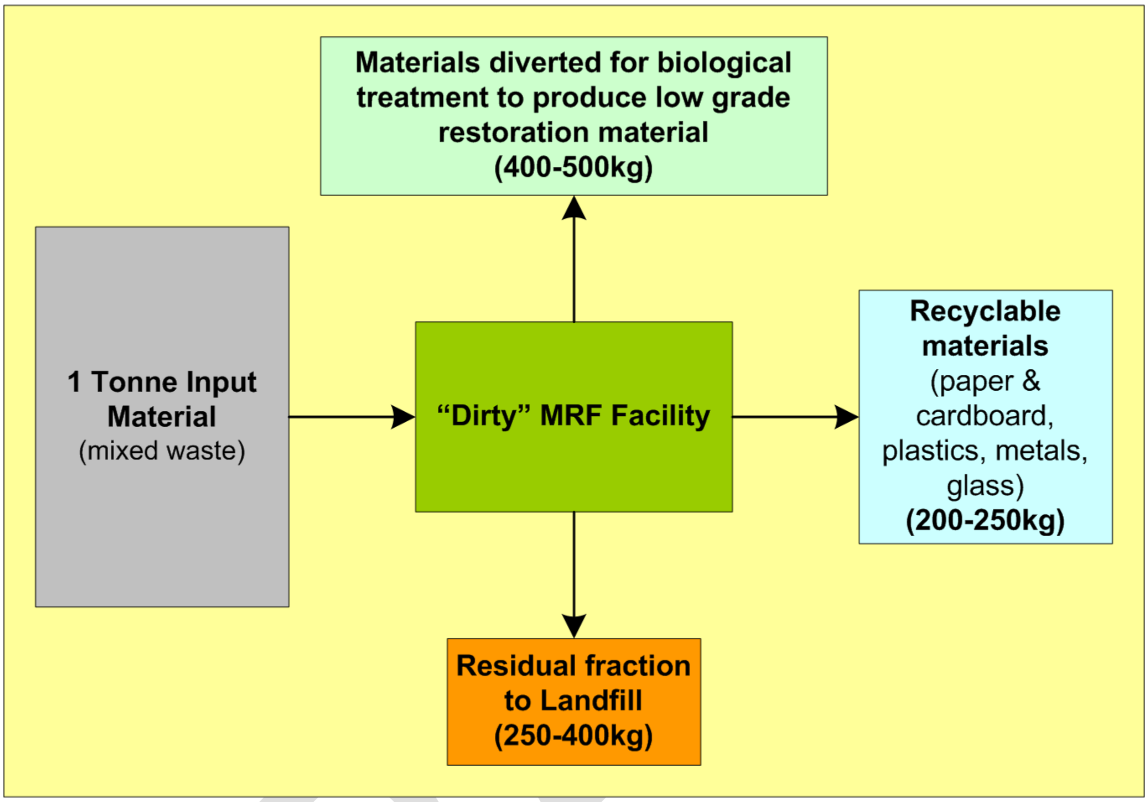


Figure 3: Indicative mass-balance diagram of a "dirty" MRF for production of recyclables.

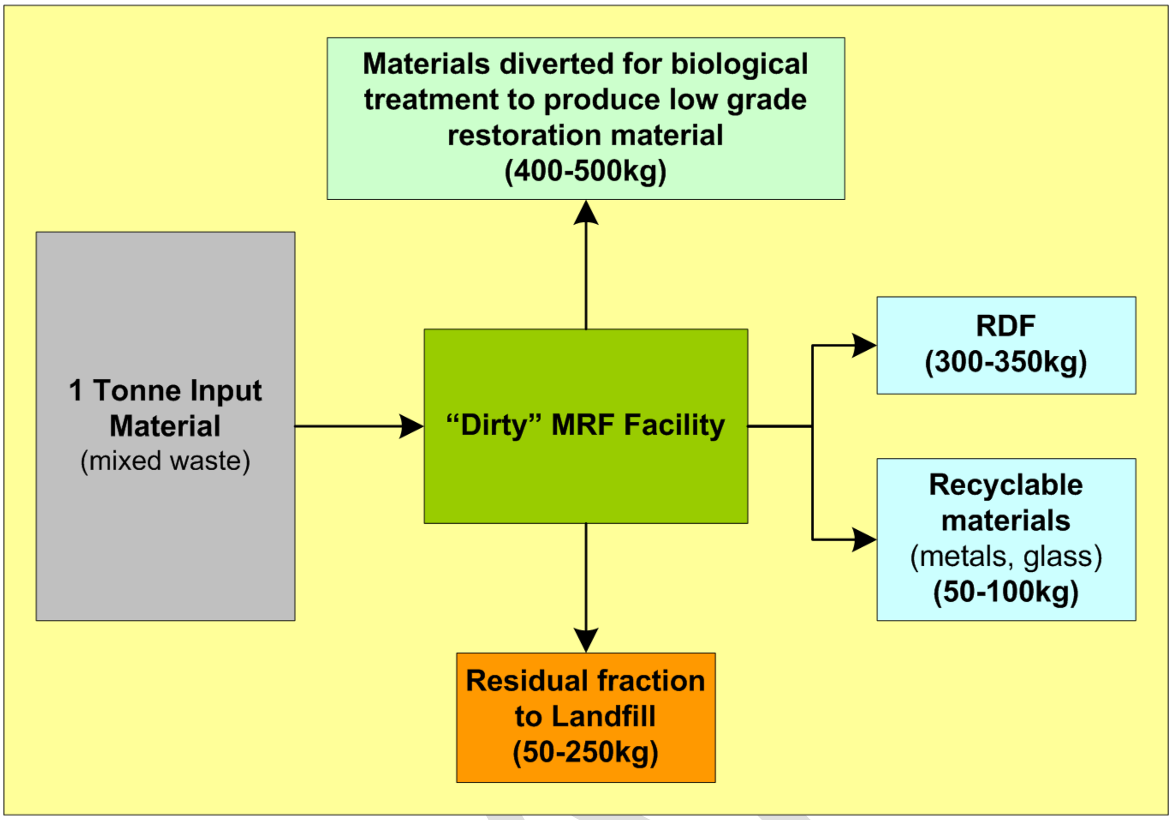


Figure 4: Indicative mass-balance diagram of a "dirty" MRF for RDF production.

Techniques	Advantages	Disadvantages	Preceding Practices	Following Practices
“Dirty” MFR	• Readily available and proven technology • Applicable for mixed waste • Potential for energy recovery through RDF production • Little requirements for experienced staff • Prevents hazardous waste from reaching the landfill level	• Intermediate recyclables’ recovery efficiency • No biowaste recovery when applied alone • Low quality and selling price of reclaimed recyclables • Need for securing final receptors of produced RDF (if this option is applied) • Implementation only in large scale • Intermediate cost recovery • Does not address non-recyclable materials which comprise large tractions of MSW • Lower public acceptance than “clean” MFRs • Intermediate environmental protection and H&S measures requirements • Intermediate energy needs per tonne	Mixed waste collection (all types)	need for final receptions RDF (if applied) need for a landfill for residues or RDF if final receptors are not willing to receive produced quantities

1.2.2 Biological Treatment

1.2.2.1 Aerobic Treatment – Composting

- Process description

Composting is the biological decomposition of organic waste ([5]) through aerobic microorganisms (bacteria and fungi) into carbon dioxide, water, and compost. It is very usual to co-compost organic MSW with dry sludge from WWTPs or other kinds of organic waste, such as pruning of agricultural origin.

In order to ensure effective composting, the following six (6) key factors need to be controlled: a) temperature, b) moisture, c) oxygen, d) pH, e) material porosity, and f) the carbon/nitrogen (C/N) ratio.

The systems implemented for the aerobic degradation of organic waste are divided into two main categories: *a. 'Open'* and *b. 'Closed'*. In the first, process takes place in the countryside in fully open or sheltered areas, while in closed systems the material degrades within bioreactors or enclosed buildings.

a. 'Open' systems are divided into static (Static Aerated Pile, Extended Static Aerated Pile, Turned windrow) and agitated.

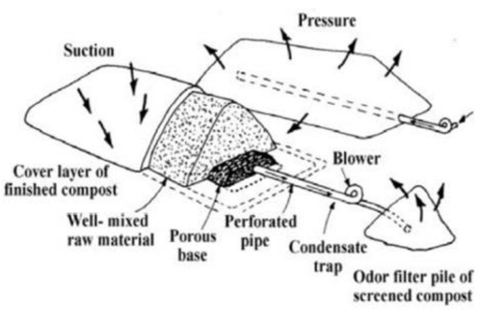
- *Static Aerated Pile*

In static systems the necessary ventilation is carried out by blowing and / or air aspiration.

In the absence of excessively high moisture content (desired moisture is between 40%-55%), aerobic conditions can be maintained at a satisfactory level in a static windrow, despite periodic brief interruptions of aeration. Because of the dependence of the option upon several variable factors, the specific requisite rate of air input for a particular operation should be determined experimentally.

Usually, the constructed windrow is covered with a 15-20 cm layer of matured (finished) compost. The cover serves to reduce releases odors and maintain the desired temperature. For the same purpose there are synthetic materials used alternatively. Experience has shown that continuous air supply is not essential to maintain aerobic conditions. In case of air suction it may be treated with biofilters before release into the atmosphere.

After the process completion the pile is dissolved and the material passes through a sieve.



(a)

(b)

[5] Organic waste mainly consists of biowaste (yard trimmings and food waste), cardboard, paper, etc.

Figure **5**: Aerated static windrow composting.

- *Extended Static Aerated Pile*

This method is used in cases where the volume of input material is very large.

The process initiates with the creation of a pile (as described in the preceding paragraph) with the difference that only the one side and the two ends of the pile are finally covered with mature compost.

To create the next pile a ventilation network and the bed is installed right next to the uncoated side of the first pile.

Save space is a key advantage of this method is to.

- *Turned windrow system*

In this method the pile is dissolved and the material is re-deposited. Agitation not only serves the ventilation needs but also ensures uniformity of degradation through exposure of all the organic material in the active inner zone of the pile.

The moisture loss observed is a disadvantage, but can be compensated by adding water whereas if the source material has increased moisture levels then the effect desired.

A significant factor is the surface area required for the agitation. There are stirring machines that carry out the deposition of the new material in parallel with the dissolution of the pile. Other machines deposit the material to an adjacent surface. The stirring frequency is primarily dictated by the oxygen consumption in the pile and the techno-economic characteristics of the unit. It is also affected by the humidity and the structural stability of the pile as well as by the objectives set by the site operator as to the degree of degradation.

For the creation of the pile asphalt surface is required to enable the leachate collection and better control of the material.

Figure **6**: Types of compost turners: (a) pulled-type, (b) self-powered.

b. 'Closed' systems

These systems are usually characterized by forced ventilation, with or without agitation, and achieve faster biochemical stabilization of organic material, better quality of its features and –mainly- capacity to control and processing of odors.

The main factor that influences the choice of the system is the initial investment costs and operating in conjunction with the requirements of legislation and the prevailing conditions in the product market.

Closed systems may be *horizontal* or *vertical* operating in closed reactors or buildings. The horizontal is further divided into Channel, Cells, Containers, Tunnel, Composting Table and rotating bioreactors.

Also, depending on the aeration process, the closed systems are divided into:

- systems with dynamic conditions wherein the aeration of the substrate is performed either by blowing air or aspiration or alternately, and
- systems with static conditions, wherein ventilation is done with regular stirring of the substrate.
- mixed systems (combination of the two previous schemes)

b1. Vertical systems

Vertical systems consist of reactors usually cylindrical or rectangular. The construction material is cement and steel and are thermally insulated. The volume begins the few cubic meters and may exceed 1500 m3. These reactors have a considerable height and can be of continuous or discontinuous operation, with or without agitation.

The continuous vertical systems without agitation include thermally insulated airtight closed configurations (of up to 9 m) made of steel and concrete. In order to avoid disrupting the biological processes there is no mechanical agitation and the process is difficult to control due to inability of homogeneous distribution of oxygen.

The vertical systems with agitation have internal stirrer bearing rotating bridge with worm screw at half of length.

Better aeration can be achieved with vertical discontinuous reactors, ie. with the material disposed in layers, not higher than 3 m, in superimposed levels. Such a reactor consists of a vertical cylindrical tower containing up to six levels. The different levels can be configured to work with an independent ventilation program according to the needs (oxygenation, temperature, humidity, etc.) of containing biomass.

Figure **7**: Vertical composting systems

b2. Horizontal systems

- *Channels*

The design of these systems is similar to the systems in windrows. The difference lies in the fact that the material is deposited between the walls of height 1-3 m and length 50m usually. To maintain aerobic conditions air is flowed through forced ventilation. Agitation is usually carried out in parallel. The channels are located in an industrial building for reducing emissions. The operation can be continuous or per load (batch).

Figure **8**: Composting system in channels

- *Biocells*

In this system the material is loaded into rectangle shape rooms hermetically closed. The conditions prevailing in the cell can be maintained at an ideal level as the space is fully controlled. Their operation is discontinuous. The cells can be constructed in-situ or prefabricated. The cells have insulation to maintain the desired temperature. Typical dimensions are 6 m * 4 m * 5 m (W * H * L).

Figure **9**: Composting system in biocells

- *Containers*

The containers have a rectangular shape with capacities between 20 and 40 m3 and are installed in groups (modules) of 6-8 containers of total capacity 3,000 – 5,000 tones.

Ventilation is done through nozzles installed in the floor. The discharged air passes from biofilter. Leachate discharged through perforations in the bottom of container. The length of stay is approximately 15 days.

Figure **10**: Composting system in containers

- *tunnels*

The tunnels are thermally insulated rectangular boxes, of typical dimensions 4 – 5 m * 3 – 4 m and up to 30 m (W*H*L), made of metal, concrete or brick. The movement of material is via a hydraulic piston or a moving floor. Record continuously moisture and oxygen and accordingly activated humidification and ventilation systems. The length of stay is approximately 15 days.

- *composting bays and extended beds*

The material enters in large buildings, designed in large "beds" where the material is placed in a continuous layer and partially reversed by appropriate machinery, comprising rotating drums, worm screws or other appropriate devices, usually remote controlled not requiring on-site operators. Treatment and movement of material are completed in 2 to 5 weeks. Usually, apart from agitation, the process includes ventilation provided through a perforated floor from where crossing ventilation channels or tubes.

Figure **11**: Composting system in extended bed.

- *rotating bioreactors*

This system consists of rotating cylinders of dimensions 45 m length and 2-4 m diameter. The humidity and oxygen conditions are monitored and maintained at an ideal level. The length of stay in space is approximately 1 week. Maturation of the material is necessary after leaving the bioreactor.

Figure **12**: Composting system in rotating bioreactors

In-vessel composting systems have some certain advantages over the others (windrows or aerated static piles) such as:

- shortening of the mesophyllic and thermophilic stages of decomposition of organic waste;
- achievement of higher process efficiency, which minimises space requirements;
- decrease of number of pathogens in the end product;
- easier control of odours and emissions;
- easier control of contact of animals (birds, rodents, etc.) with the decomposing material;
- better public acceptance due to the aesthetics of the composting site;
- less manpower requirements; and
- more consistent product quality.

However, it is important to note that all systems require final stabilization of the compost or CLO.

Disadvantages of the In-vessel method include:

- high capital and operational costs due to the use of computerized equipment and skilled labour. In-vessel composters are generally more automated than windrow or static pile systems, and can produce a top quality finished product on a consistent basis.

  - *Energy consumption*

Table 4: Specific energy consumption in aerobic processes ([6])

Type of aerobic process	electrical energy (kWh/tn)	Petroleum (Kj/Kg)
In-vessel aerobic degradation	27-65 ([b])	5
windrows	0	15
Various types ([a])	4-72 ([b])	5-132 ([c])

([a]) Various plants included with more or less modern gas treatment methods or no gastreatment.

([b]) Larger values correspond to processes with developed flue gas cleaning systems.

([c]) The largest oil consumption correspond to lower electricity consumption.

- *The product of aerobic composting*

Generally, the physical and chemical characteristics of compost vary depending on the original matter disposed of for composting, the conditions which prevailed during the process and extent of degradation. Compost has a dark color, fragile, earthy texture and odor resembling those of the soil. The physical form of the final product has nothing to do with that of the original organic material from which it was produced.

The good quality compost has been from pests and pathogens and can be used in agriculture, gardening-horticultural, restore damaged-overworked soils (artificial plants lakes, inactive quarries, saline soils), reforestation, artificial pasture lands and farming land.

Pure raw material collected through the separate collection (sorted-at-source) is more likely to satisfy the requirements for compost, thereby making it suitable for sale or use, bringing environmental benefits. The use of compost reduces the requirements for use of other soil conditioners (such as peat) for agricultural or horticultural activities.

The demand of this product varies mainly according to the needs in soil improvers and consumer confidence.

1.2.2.2 Anaerobic Treatment – Composting – Biogas

- **Process description**

Anaerobic Digestion (AD) is used to treat waste with a high organic content in closed vessels in the absence of air (oxygen), offering efficient containment and control of the waste treatment and products. A relatively homogenous feedstock is required, which often leads to requirements for pre-treatment, especially for organics sorted out from mixed waste stream (mixed collection).

The biochemical process of AD results in the formation of a carbon dioxide (CO_2) and methane (CH_4) mixture, called “biogas”. The proportions of CO_2 and CH_4 in the mixture are

[6]Dr Stuart R.B. McLanaghan, Delivering the Landfill Directive: The role of new & emerging technologies -Report for the Strategy Unit: 0008/2002, November 2002, pg.55

determined by the composition of the organic waste and the operating temperature of the system. Biogas can be used as a substitute of natural gas (secondary energy source), whereas it is usually utilised to generate electricity to run the AD unit.

Figure **13**: Anaerobic digestion unit in a Mechanical-Biological Treatment Plant in Germany.

The anaerobic digestion of organic fraction is taking place in closed mesophilic (30 - 40°C) or thermophilic (50 - 65°C) bioreactors, under controlled conditions in order to recover energy in the form of methane, reducing the volume of the MSW and biological stabilization. The most common methods used in anaerobic digestion are the "Wet" and the "Dry".

a) *"Wet" anaerobic digestion*

The feed liquor contains total solids 3 to 8%. To achieve such high dilution large quantities of water is required to add and heating, which must be removed after the digestion.

In the simplest case, the digestion is taking place in a single stage mesophilic reactor, which however presents serious operational problems. To solve these problems the use of two reactors in series was developed, in the first of which the organics are hydrolyzed and decomposed in acids while in the second methanogenesis is achieved. The total hydraulic retention time is 5-8 days.

b) *"Dry" anaerobic digestion.*

In this process the feedstock contains at least 25% solids and the digestion is taking place in single stage mesophilic or thermophilic reactors of continuous or periodic operation. The retention time ranges from 12 to 18 days.

- **Influent waste types**

AD is an alternative option against the composting, in order to achieve biowaste recovery. It is applicable in both sorting-at-source of biowaste and mixed waste collection.

- **Recovered products**

Apart from biogas, the AD process also produces a semi-solid by-product, whose quality may differ based on the purity of the incoming materials. This semi-solid by-product can be:

- the so-called *Digestate*, when the incoming material is of best purity, i.e. from sorting-at-source biowaste. Digestate can be used as a fertilizer or soil improver, and thus has a significant market value and can be sold;
- or a material similar to the CLO, which is produced in cases that the incoming organic material derives from mixed MSW collection systems.

1.2.3 Mechanical & Biological Treatment (MBT)

The term "Mechanical – Biological Treatment" (MBT) indicates the use of engineering techniques and biological treatment of waste.

This technology appears with different variations mainly determined by the method of biological treatment used. Thus there is a distinction between aerobic and anaerobic MBE with the first to make use of composting and the second of anaerobic digestion.

The input material can be either mixed waste or sorted-at-source biowaste. In the second case, however, the term MBT is not used, as the extent of the mechanical processing and the techniques used are limited and the units are referred to as "*Composting Units*" or "*Anaerobic Digestion Units*", indicating that the main part of the installation is the biological treatment.

The following sections present variants of MBT plants.

1.2.3.1 MBT – Aerobic for mixed waste

- **Process description**

The goals of mechanical processing, when used in combination with subsequent biological treatment stage are:

- Maximizing the recovery of materials such as metals (ferrous and non), plastic, glass, paper, etc.;
- Preparation of waste for the next stage of biological treatment (organic fraction);
- Remove undesirable components from the incoming waste.

The extent of mechanical treatment depends on:

- The types of incoming waste (mixed waste, pre-segregated biowaste);
- The proportion of recyclable on incoming waste;
- The required quality of output;
- The desired rate of recovery of recyclables.

Where the desired output of biological treatment stage is compost there is a mechanical treatment step following the biological treatment (sieves etc.) for the refining of the final product.

An installation of this type consists of the following units:

- *Vehicles' Control and Weighing unit*, including the guardhouse control and weighbridges;

- *Receiving and feed unit*, which includes trenches for unloading garbage trucks, gantries and grabs for transportation of waste, feeding hoppers with plate-straps for controlling supply and bags opening systems;
- *Mechanical sorting unit*consisting of manual separation system of bulky and undesirable objects, grating system with rotary sieves for removal of toxic and other small objects (1,5 - 2 cm), manual sorting of materials (paper, cardboard, plastic, glass, ferrous metals and aluminum) and baling systems, homogenization system with mechanical shredding, magnetic separation system of ferrous and aluminum, and air-separation system for receiving the light fraction that is led for composting. In modern plants, the homogenization and separation are achieved with rotary sieves for increased operational reliability;
- *Biodegradation unit*, which includes branches, grasses and / or biological sludge adding system in specific proportions, as well as a composting systemwhere, in the most common case, the organic fraction is diverted to an enclosed area and is placed in windrows, where it stays for 4 to 6 weeks under controlled conditions of moisture and aeration with mechanical stirring);
- *Maturation unit*, usually in a covered area, where the compost is placed in windrows for about thirty days for curing biological stabilization;
- *Refinery unit*, wherein compost, after been sieved, passes through an air-separation and ballistic separation system to remove impurities such as glass, hard plastic, etc.

  - **Recovered products**

a) Recyclables

The basic recyclable materials recovered during the mechanical treatment of mixed MSW are metals (ferrous and non-ferrous).Where the treatment plant is designed to allow maximum recovery of recyclables, the recovery of plastics, paper and glass is also possible by applying manual sorting or other mechanical techniques. These materials are not clean (as derived from mixed MSW) and therefore containing various impurities mainly organic material. Consequently, these materials -compared with the pre-segregated ones- are absorbed more difficult and at lower prices by the market of secondary products.

More specifically:

- *Paper*

The general requirements for acceptable paper in the market are to be pure fraction, free from impurities of other materials (plastics, gelatin, covers, binders, metals, organic or other materials) and free of moisture.

- *Ferrous metals*

In their entirety, the companies declare ability and desire to absorb all the recoverable quantity of scrap metal. The prices achieved on the market range at satisfactory levels, however it is stressed that prices are highly dependent on the type, degree of compression and the purity of the scrap. The requirements set by the companies concerned to absorb the recovered metals, focusing on:

  - The metals should be separated from each other and free of foreign matter (e.g. plastic, wood, soil, etc.).
  - The separation of recyclable ferrous metals in various categories is usually a prerequisite and also increases the selling price.

- *Non-Ferrous metals*

The main category of non-ferrous metal is aluminum. Thealuminumrecyclingmainlyconcernsbeverageandbeercans and can be recycled many times without the final product lacks in quality, as with the paper. It has very high price as scrap, which favors the high recycle rates, although the variation of recycled aluminum prices vary very often, according to the Metal Exchange. The requirements set by the companies concerned to absorb the recovered metals, focusing on:

- The metals should be separated from each other and free of foreign matter (e.g. plastic, wood, soil, etc.).
- Oftenthecompressionisnotdesired. Alternatively, it is desirable to lightly compressing into bales

- *Glass*

Glass may also be recycled many times without alteration. Recyclable glassconcernsbottles, glasscontainers, glazing, plates, heathigh-strengthglassesandcrystals. The recycled final product may be used in glass industry, glass wool, fiberglass, signals for roads etc.

b) CLO

The main product of the MBT processing is a low quality biostabilised material (CLO), which can hardly be absorbed in the market. The quality of this product depends on the particular MBT technology used. The potential uses of CLO are given in the table below:

Table 5: Potential uses of biostabilised material

Use	**Comments**
In forestry	Usually the end user requires compensation in order to use it
As a soil improver especially in arid areas or drylands, to improve the soil quality and to maintain its moisture.	Reduce the risks of floods, expansion of desertification and salinisation of soils. This option would be particularly interesting for areas of Mediterranean countries like Lebanon.
Forenergycrops.	Limitedpotentialusesinrapeseedcropsforbiodiesel, andwillowtrees
In curbs trunk roads - dikes, building construction.	Usually the contractors ask for a fee in order to use the material.
Filler in deodorization biofilters (EPA)	To reduce odors caused by organic compounds.
As a restorative material in quarries or old landfills / final cover in Landfills.	Great potential application although without expected revenue.

Ifnoneoftheaboveutilizationcapabilities is being possibletheCLOshouldendinLandfillforburial. In this case though the diversion of biodegradable materials from burial in a landfill is achieved, however the fact of placing large amounts of waste in landfill maintains the problem of finding, building and operating landfill sites.

The biggest obstacles in widespread use of CLO in various applications in soils are the low quality of the material, the strict requirements for application materials in soils, and the competition from other products. Verygoodqualitycompostproducts which are availableinthemarket and preferredby the farmers,comingfrom:

- The processing of biodegradable pre-segregated waste
- Theprocessingoflivestock and agricultural waste
- The processing of sludge from urban wastewater treatment plants
- Original fertilizers

Only with source separation is possible to achieve the standards required for producing good quality compost which improves and protects the soil. Thus it is considered that as most realistic solution for CLO that is produced by mixed waste MBT – Aerobic plants is placing it either in landfills or in uses not expected to generate revenue.

c) RDF

If the MBT installation is designed to produce RDF and not to recover recyclables, a secondary combustible material composed mainly of paper, cardboard, plastics and wood is then produced. This material can be produced in either cRDF (coarse rdf) type that is only suitable for direct use in a local installation, either in dRDF (dry RDF) type, following an additional energy intensive processing, which is suitable for storage and transportation in remote utilization points.

The quantity of the RDF produced per ton of treated mixed MSW amounts from 23-50 % wt of the treated MSW depending on the collection, processing and quality requirements of the final product.

The options of exploitation of RDF are:

- Incineration in a facility that was designed for this purpose
- Use as fuel in the cement industry
- Useasfuelinin power plants
- Use as a combustible material in other industries (paper, chemical industries, pharmaceutical, metallurgy, etc.)

The qualitative composition of the RDF and the calorific value is of particular importance since they are directly linked to the quality and quantity of air emissions produced during combustion. Other important parameters are the quality of the combustible material is moisture, ash content, chlorine and sulfur.

EURITS, the European association of thermal waste treatment companies, has issued quality criteria for incineration of RDF / SRF in the cement industry. However, representatives of the cement industry consider these prices very strict, particularly those mentioned in the calorific value (CV) of the material. This is the reason that the produced RDF in many MBT plants has specific quality requirements defined by the respective industrial unit that will use it as fuel. The use of RDF as a combustible material in such an industry should be further explored.

The main advantages of co-incineration of RDF produced in industrial plants are summarized as follows:

- TheutilizationoftheproducedRDFinindustrialunitspresentselasticitycomparedtothe in-situ combustion, since: a) enables the implementation of future recycling programs, b) the channeling of all the quantities produced in the units is not a prerequisite and compulsory, c) does not require the construction and operation of new plants that will result in additional investment cost;

- The use of RDF in power plants and cement industries has significant environmental benefits compared to burning it in mass incinerators.

More specifically:

- *Use of RDF in cement industry*

The installed furnaces used in the cement industry have characteristics that greatly favor the RDF incineration. High temperatures (-1500 0C) in combination with the relatively long dwell time in gas phase (4-5 sec), the high degree of mixing of the combustible materials in the kiln and oxygen-rich atmosphere result in minimizing environmental impact from the production of gaseous pollutants.

The main qualitative characteristics of RDF (except calorific) to be taken into account in the use of in the cement industry, are the organic ingredients and the concentration of metals. These two features can be so strong catalytic in both the combustion products and the quality of the produced clinker. In conclusion, there are no technical problems with the operation of the RDF in the cement industry to the extent that the environmental risk from the presence of toxic metals or other toxic organic substances has been taken into account.

- *Use of RDF in power plants*

The advantages and disadvantages in co-generation plants are shown in the table below.

Table 6: Pros and cons of co-generation of RDF in power plants

Method of co-generation	**Pros**	**Cons**
Direct	Low investment cost	Technical difficulties in mixing coal and RDF. The residual ash contains components of the RDF
Indirect	Separate storage of RDF. The residual ash is stored separately. The thermal exploitation of RDF is made separately from other fuels. The energy output is greater than the case of a mixture of carbon and RDF	High investment costs. Requiring continued feed gasification chamber with RDF.

- *Incineration of RDF in facilities designed for this purpose*

Thispracticeisverycommonmainlybecauseitoffersindependencefromthetrendsofthemarketfors olidfuels. On the other hand, the implementation of such a solution requires a high investment cost while the operation of such a plant may compete in waste reduction programs or recycling programs.

In general, the alternatives offered if adopted this practice are:

- Incineration of RDF in grate incinerators
- IncinerationofRDFinfluidized bed combustors

- Gasification of RDF
- Pyrolysis of RDF

From the above techniques, incineration in grate presents the worst behavior in terms of environmental impact.

In terms of investment and operating costs, all the above techniques are in the same range.

Substantialdifferencesexistintheamountandqualityoftheproducedash, fly and bottom. Due to greater uniformity in the distribution of temperatures in the fluidized bed, the gasification and pyrolysis of RDF, the quantity and quality of the produced ash is less and better than the case of incineration in grate. This results in reduced cost for the management of ash produced in these cases.

It should be noted that the gasification and pyrolysis techniques are applied more successfully in more homogeneous fuels such as RDF, rather than in mixed MSW.

Table 7: Pros and cons of possible uses of the produced RDF / SRF

Use	Pros	Cons
Incineration in a facility designed exclusively for this purpose	Independencefromthetrendsofthemarketforsolidfuels. Handling the total quantity of the produced RDF / SRF. The quality of the produced SRF/RDF depends on the operation of the installed combustor. Capable to incinerate other waste streams (e.g. tires, VELC* etc.)	High investment costs. Required specialized personnel for the operation of the unit. Possible reductions of the volume of incoming fuel will catalytic effect on the sustainability of the unit. Competitive in reduction and Sorted-at-Source programs. Low social consensus.
Co-incineration	Environmental benefits from substituting of conventional fuels. Achievability of producing gaseous emissions limits set by the Kyoto Protocol. Low operational cost. Steady supply of unit is not required. Can accept biomass as fuel and contribute to the development of the renewable energy market. Not conflict with MSW programs or programs to reduce the generation of waste. Incineration of other waste streams is possible (e.g. tires, VELC* etc.) is possible.	May require significant modifications to installed equipment. May be required storage space for RDF / SRF. Revision of the environmental operating terms of the unit required. Long-term contracts required for the use of the entire quantity of the produced RDF / SRF. The produced RDF / SRF must have specific technical and qualitative characteristics. Probability of imposing gate fee. In case of non-acceptance of the

Use	Pros	Cons
		produced RDF / SRF in units significant problems arise.

** Vehicles at the end of their life cycle.*

- *Operational requirements & complexity*

MBT plants have low operational requirements and complexity.

- *Ability to co-manage other waste streams* (yard trimmings, sludge, medical, industrial, agricultural, special waste)

MBT technologies can additionally treat only sludge in the biological part of the installation.

- *Flexibility for upgrade*

Aerobic MBT presents significant flexibility, since the function of the mechanical treatment can be adjusted to incoming amounts via reduction or operational rise time of each line, and finally operate at one or more shifts. The configuration of composting systems also allows them to easily adjust quantities fluctuations or future use for over pre-segregated organic in case of future extension of the sorting at source system.

- *water consumption*

Water consumption is too small in aerobic MBEunits in which water is only intermittently used for moistening during composting, if necessary.

- *employment*

In MBT units depending on the configuration of the mechanical sorting is possible to create new jobs especially if there is manual sorting.

Also, the existence of processing steps such as refinery and the laying of biologically treated organic in square for reaching maturity, also ensure more jobs.

- *land demand*

Aerobic MBT units require more land area. The organic drying units although based on the same technology require less space as compared to aerobic MBT due to the small dwell time of the waste in the biological part of the plant.

- *Existing international experience of adopted practices/techniques*

Aerobic MBT is a combination of mechanical and aerobic biological treatment, two proven techniques widely applied in Europe and with a large number of units in operation with a high degree of reliability.

Composting (aerobic biological treatment), in all its variations, is a proven and widely used technology for a wide variety of organic materials, including organic fraction of municipal solid waste, either after sorting at source or after mechanical sorting. There are over 50 manufacturers of different composting systems in Europe and North America, each with many units at his credit. Is characteristically mentioned that in the EU there are about 1800 large plants processing organic fraction of MSW after sorting at source, of which about 40% is processed only green waste. Their total capacity exceeds 19 mil. tn/y.

The systems used for the technical implementation of composting differ mainly as to whether the biological degradation takes place in open space, in enclosed buildings or enclosed reactors. Even when using the same systems the results on emissions, quality of compost and biological treatment time vary as the incoming material and the operation mode of the units differ.

In general, composting units in Europe operate successfully. Technical problems, however, occur in countries where biological treatment is not particularly widespread.

- *State and worldwide trends CST*

In new plants composting takes place indoors. Also, there is a tendency to produce large capacity units and be given greater prominence in the production of high quality compost by setting high technical standards during operation.

- *Advantages and disadvantages CST*

Composting is a relatively simple technique for MSWM. The simplicity of the technology enables implementation in small and large-scale applications. Composting units can be used for both pre-segregated biowaste and mixed waste; however the quality of final products and potential uses may differ significantly.

One major advantage of composting is that it achieves reduction of the volume of incoming organic waste, as well as its stabilisation. With regards to volume reduction, a rate of 25%-50% can be easily achieved. Based on the quality of the incoming materials, the following final products are produced:

- *Compost*, when the incoming material is of best purity, i.e. pre-segregated biowaste from sorting-at-source. Compost can be used as a fertilizer or soil improver, and thus has a significant market value and can be sold; and
- *Compost-Like Output (CLO)*, when the incoming material comes from mixed MSW collection systems. CLO can be used as a soil improver in degraded areas, as well as in several other uses, such as landfill/dumpsite rehabilitation, mines' rehabilitation, etc.

In both cases, mixing of biowaste with other organic waste (dry sludge from WWTPs, agricultural pruning) in a rate of 10%-30% regularly increases the final quality of compost or CLO.

Another advantage of the method is that it decomposes organic waste into carbon dioxide (CO_2) and water, instead of methane (CH_4) that would have been emitted at the landfill level, which is known to have a significantly higher global warming potential compared to CO_2.

On the other side, composting requires proper management of odours and leachate control that are produced from the process. Also, the method treats only the organic fraction of the waste, whereas the non-biodegradable portion remains intact. The process itself is sensitive to cross-contamination by glass and plastic, and therefore requires careful segregation beforehand.

Techniques	Advantages	Disadvantages	Preceding Practices	Following Practices
Composting	• Readily available and proven technology • Applicable for both pre-segregated biowaste and mixed MSW • High biowaste recovery efficiency • Significant diversion of biowaste from landfills • Simple technology implemented in small-, mid- and large-scale • Little requirements for experienced staff • High cost recovery when applied for pre-segregated biowaste • Addresses biowaste which comprise large fractions of MSW • High public acceptance • Reduces LFG emissions and leachate production at landfill • Low environmental protection and H&S measures requirements • Little surface requirement for in-vessel composting • High stabilization rate of biowaste	• No recyclables' recovery when applied alone • Need for upstream sorting of bio-waste to achieve good quality of compost • Need for securing final receptors of produced CLO when applied for mixed MSW • Low cost recovery when applied for mixed MSW • Intermediate energy needs per tonne • Significant surface needs for open systems (static piles /withdraws, turned withdraws)	sorting-at-source of biowaste and mixed waste collection (all types)	need for final receptors of compost of CLO need for a landfill for residues of CLo if final receptors are not willing to receive produced quantities

1.2.3.2 Composting Unit for pre-segregated biowaste

- *Process description*

Biowaste entering a composting unit after sorting-at-source are divided into the following categories:

- *municipalwaste*, includingdomestic, domestic – like commercial waste and green waste.
- Domestic waste contains a large percentage of organic matter, which in Lebanon exceeds 50%.
- domestic – like commercial waste includes waste that has approximately the same properties as the household. The organics originate from restaurants or flea markets.
- The green waste originate from gardening in parks or private gardens. They include mainly weeds, grass and twigs.
- *Sludgebiologicaltreatment*. The residues of biological treatments also contain a high proportion of organic substances, which must be stabilized. A deterrent is that if sludge is added in the composting bed then compost placing is prohibited for agricultural purposes.
- *AgriculturalWaste*. In this category belong waste from agricultural activities such as vegetable crop residues.
- *Industrialorganicwaste*. These are organic substances produced during industrial activities such as food processing.

The process steps include:

- ✓ Reception and depositing of raw materials. Pretreatmentwiththeuseofsieves, manual sorting, metal separators and air-separators as well as shredders. In large installations sieving is combined with magnetic separation, which is more about reducing heavy metals embedded in metals rather than the recovery of metals. In order to improve the physical characteristics of green waste they undergo a shredding to readily biodegradable and, in parallel, to gain structure material necessary to maintain air circulation during the phase of composting. If deemed necessary, other organic waste may also be shredded. In the final stage of pretreatment the biodegradable materials are mixed with structure material in order to achieve sufficient air flow during the biological processes in conjunction with moisture and the existence of ideal nutrients ratio. Mixing is done either by rotary drums or machines used during stirring.
- ✓ biological degradation of waste. It is a thermophile process with a duration of 5 - 10 weeks.
- ✓ Maturation of fresh compost in trapezoidal or triangular shape windrows, in temperature below 40 °C and duration depending on the sourced material, the technology used for the biological degradation and the desirable quality of final product.
- ✓ Refiningofcompostusingsieveswithaperture 10-25 mm, forremovalofnon-biodegraded organic materials such as wood, plastics, metals and stones, and also for sorting of the desired grain size fraction.
- ✓ Bagging – safe Storage

- *Indicative mass balance diagram*

The following diagram presents indicatively the production flow and the mass balance of a composting plant for pre-segregated biowaste.

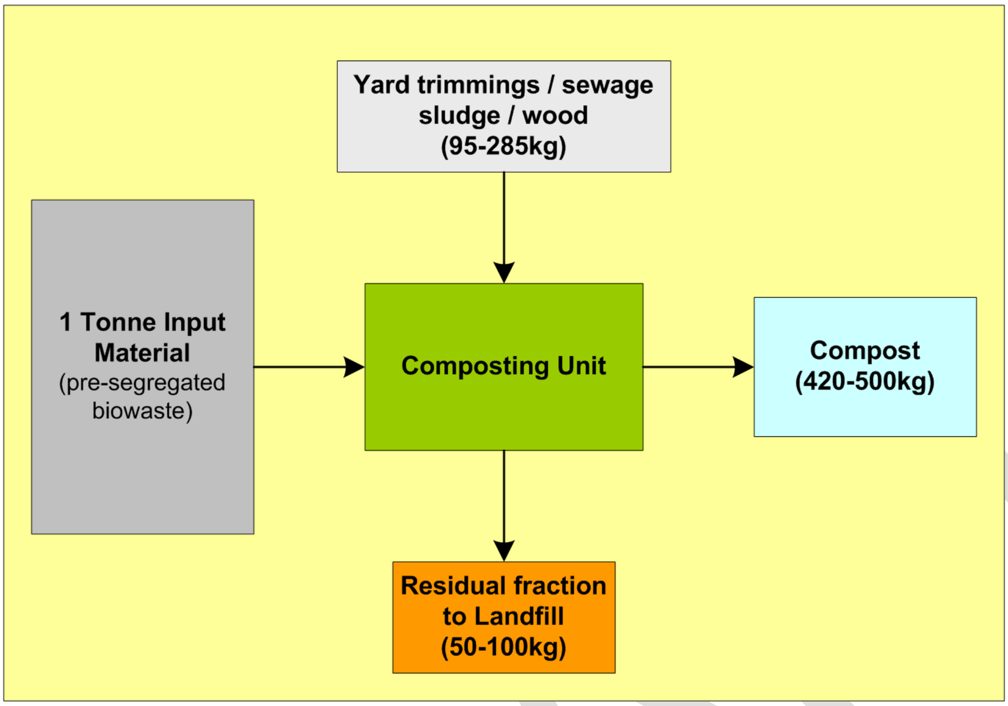


Figure 14: Indicative mass-balance diagram of a composting unit for pre-segregated biowaste.

- *The product*

Compost is rich in organic matter and nutrients. Its use increases the fertility of the soil and reduces the risk of corrosion. To successfully placed on the market should be removed materials such as glass and plastics that degrade the visual presentation. Chemically must ensure that the disposal of the ground will not cause damage to soil and plants that will later have impacts on humans. Finally, from a biological standpoint the destruction of pathogenic microorganisms during biological degradation is required.

1.2.3.3 MBT-Anaerobic for mixed waste

- *Process description*

An MBT – Anaerobic plant design depends on the type and the composition of feed material, the desired products to be recovered and the manufacturer's know-how. A typical MBT Anaerobic plant includes the following stages:

- Reception and depositing of raw materials
- Pretreatment aiming to:
  - removal of organic materials that cannot be degraded;
  - improve the physical characteristics of waste for τωvto facilitate their biological degradation
  - protect the machines used in the subsequent steps of the installation

    - removematerialswhichmayreducethequalityofthefinalproducts.

- Anaerobic digestion unit
- biogas exploitation unit
- leachates drainage

Instead of materials recovery a RDF recovery line may be configured, as in the case of aerobic MBT.

There may also be a biological sludge and/or agricultural and industrial waste adding system in certain proportions for co-processing with the organic fraction of MSW.

Oncompletionofanaerobicdigestionthesludgeisledtodrain. Thesolidoutputofthedrainage is ledtoaerobictreatment, while the liquid wastes are reused for the mixing of fresh substrate. Also they can be processed at a nearby biological treatment installation.

- *Recovered products*

For the recyclable materials (paper, carton, plastics, glass, ferrous metals and aluminum), the RDF, and the biostabilised material that is produced after mature and refine, the potential outlets are similar to those mentioned in the previous section for the MBT-Aerobic.

The partially biostabilised product of digestion can be placed directly into landfill. Alternatively, and in order to be used as soil improver material and/or as land remediation material or landfill cover, the product of digestion can undergo maturation and refining, a lengthy process that aims to reduce the moisture, to release of trapped methane, to eradicate the phytotoxic substances and to further stabilization of the product. In any case, the product of maturation contains high humidity, greater than 50%, which does not allow the bagged or even prolonged storage. To reduce the humidity moisture in the level of 35% to 45% (e.g. as required by the German legislation for bagging and storage respectively) filter presses are used while hot gas is used for even greater drying.

The biogas treatment comprises removing hydrogen sulfide and moisture content. Oftenremovedammonia also. Further separation and removal of CO_2 improves the characteristics of biogas into natural gas network levels. Biogasistemporarilystoredandusedforelectricityproduction. Part of the energy generated is used to maintain a constant temperature in the reactor and for the rest energy needs of the plant. Excess electricity can be allocated to activities outside the facility.

- *Residues*

The liquid fraction resulting from the above process is recirculated partially тoregulate humidity in the incoming waste, while the surplus is disposed of as wastewater after an advanced treatment, due to the increased concentration of pollutants it contains.

- *Indicative mass balance diagram*

The following figure presents an indicative mass balance of an AD unit that treats mixed organic waste following by composting of the produced sludge.

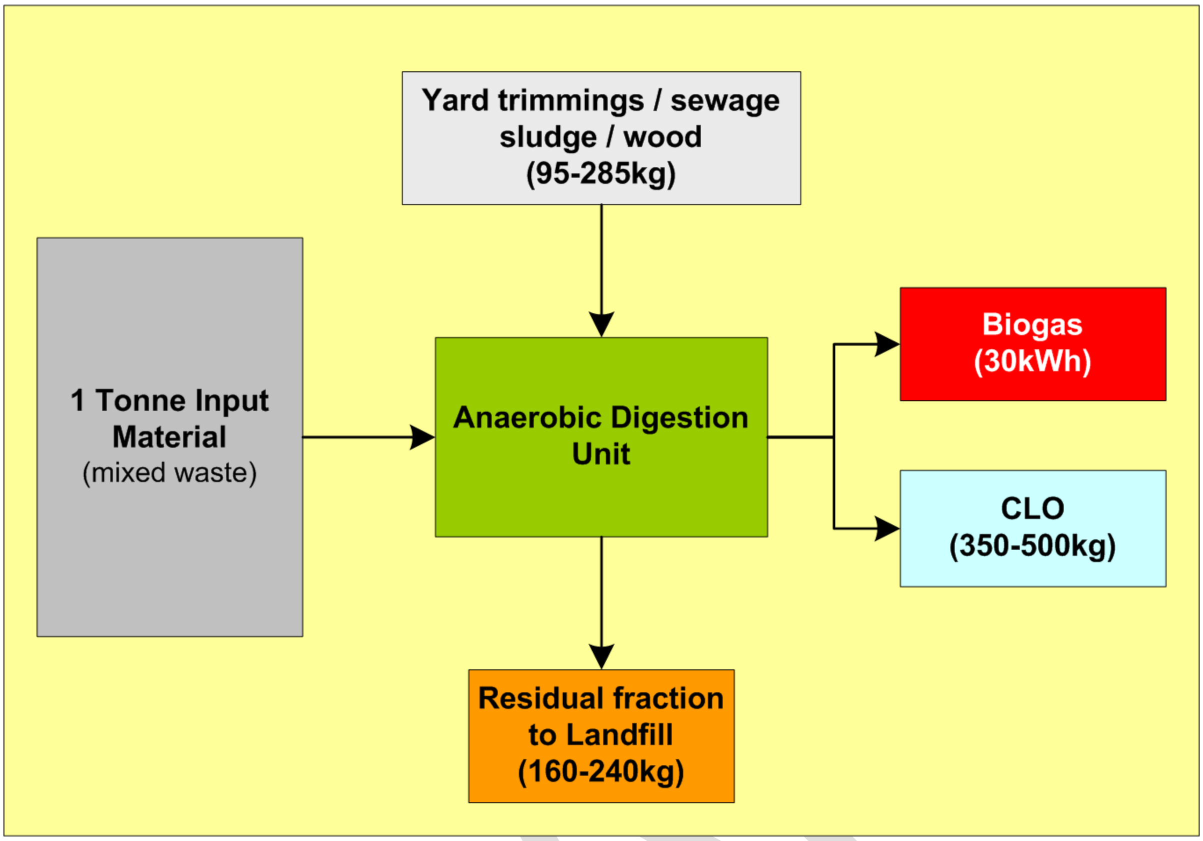


Figure 15: Indicative mass-balance of an anaerobic digestion unit for mixed waste

Instead of materials recovery process a RDF recovery process can be designed, as in the aerobic MBE case.

A system for adding biological sludge and/or agricultural and industrial waste in certain proportions there may also be included to co-processing with the organic fraction of the MSW.

- *Operational requirements & complexity*

Anaerobic MBT shows an increase in recent years. However, the method was originally developed for the treatment of net organic materials and a few of the technologies available in the market can support the treatment of mixed MSW. Also, specialized staff round the clock is also required for the operation of such a plant, due to its complexity.

- *Ability to co-manage other waste streams*

The MBT-Anaerobic technologies can additionally process only sludge in the biological part of the plant.

- *Flexibility for upgrade*

AD systems can be modular, so they can be sized according to local needs and be upgraded over time. However, their considerable construction cost make them inappropriate for “small” units with limited capacities (<10tn/d).

For the mechanical part of the anaerobic MBT apply the foregoing. The anaerobic reactors of continuous flow digestion (24 hour operation) must have a steady stream of incoming material for their effective functioning, while batch systems are not affected at all. This can be addressed effectively with the use of more than one reactors.

- *employment*

In MBE units depending on the configuration of the mechanical sorting is possible to create new jobs especially if there is manual sorting. Also the existence of processing steps such as refinery and the laying of biologically treated organic in square reaching maturity ensure more jobs.

- *Existing international experience of adopted practices/techniques (High / Low)*

Anaerobic digestion is on a worldwide scale, a proven technology for the treatment of sludge from sewage treatment plants of urban waste water, and animal wastes.

In anaerobic digestion, due to the "sensitivity" of the method, the "transition" from the treatment of organic waste to treatment of the organic fraction of MSW after mechanical sorting was done at a lower rate. For this reason the use in the organic fraction of municipal waste is relatively more recent, but there are now several units and installed capacity in the EU to be seen as a safe option. So the situation in the EU is as follows (Barth, 2005):

- There is an increase of the installed capacity for anaerobic digestion for commercial and household food waste, especially in countries like Germany and Austria, which provide subsidies for the produced renewable energy. Also of considerable interest for the technology exists in Spain, where there are efforts to produce a marketable product from anaerobic digestion of mixed MSW
- In total the installed capacity amounts to 3.5 million tons
- The trend is to constructing larger units (capacity of over 50,000 tons / year). Among existing systems, 45% apply "dry" and 49% "wet" anaerobic digestion.
- Sweden only supports the production of fuel from biogas rather than energy production
- Denmark aims to process the sorted at source household biowaste in existing anaerobic digestion sites of agricultural waste

Thegreatervarietyofsystemsthatmakeuseofalmostallavailable bioreactors technologiesforanaerobicdigestion, with morethan 40 independentmanufacturers, is recordedinthedigestioncategoryofsortedatsourcebiowaste. However, four systems seems to have prevailed, for various reasons, in the market and have been doing most of the constructed plants: DRANCO, VALORGA, KOMPOGAS and BTA.

By the end of 2006, there were 124 anaerobic digestion plants with a capacity of more than 3.000 tn / year, of which incoming or part of the incoming waste was mixed A.S.A. or pre-segregated organic material. Compared to 2000 the total capacity of units has quadrupled while the number of units has doubled which is indicative of the increasing use of anaerobic digestion.

Generally, the current trend in the application of technology provides for the construction of large capacity reactors. The average capacity of the units constructed in the period 2001-2005 was 43.000 tn / year.

Despite the increasing use of AD technology, only about 3% of biodegradable waste in Europe undergoes anaerobic treatment. Aerobic composting remains the main method of biological treatment by treating approximately 7% of household organic waste. In 2006, Spain, Belgium, Holland, Switzerland and Germany had the largest per capita capacities of anaerobic treatment.

90% of installed capacity in Europe is comprised of one-stage systems while only 10% of two-stage systems (Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste, California Integrated Waste Management Board (2008). Fromtheonestagesystemsthe 60% usesthedrydigestionmethod.

ThetablebelowpresentstheAD technologieswiththewider commercial application for organic material derived from MSW.

Table 8: AD technologies with wide commercial application

technology name	**Number of units in operating status (*)**	**Capacity**	**Number of processing steps**		**Percentage of dry matter**	
			1	**2**	**<20%**	**>20%**
AAT	8	3.000 – 55.000	x		x	
Arrowbio	4	90.000 – 180.000		x	x	
BTA	23	1.000 – 150.000	x	x	x	
Biocel	1	35.000	x			x
Biopercolat	1	100.000		x		x
Biostab	13	10.000 – 90.000	x		x	
DBA – Wablo	4	6.000 – 60.000	x		x	
DRANCO	17	3.000 – 120.000	x			x
Entec	2	40.000 – 150.000	x		x	
Haase	4	50.000 – 200.000		x	x	
Kompogas	38	1.000 – 110.000	x			x
Linde – KCA/BRV	8	15.000 – 110.000	x	x	x	x
Preseco	2	24.000 – 30.000				
Schwarting – Uhde	3	25.000 – 87.600		x	x	
Valorga	22	10.000 – 270.000	x			x
Waasa	10	3.000 – 230.000	x		x	

Source: Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste, California Integrated Waste Management Board (2008).

(*) Includes planned or units in operation treating one of the following materials: MSW, organics from kitchen, food residues, parks and garden waste. Not including industrial waste treatment plants from food or sewerage treatment units. Also not including pilot operation units.

Following presented units in operation of three

Follows the presentation of units of the three largest companies that make use of the dry process and have over 10 units in operation.

Table 9: AD units in operation of DRANCO

	Location	Capacity (tn)	Input
1	Brecht I - Belgium	20,000	Organic pre-segregated
2	Bergheim – Austria	20,000	Organic pre-segregated
3	Aarberg-Switzerland	11,000	Organic pre-segregated
4	Kaiserslautern- Germany	25,000	Organic pre-segregated
5	Villneuve- Switzerland	10,000	Organic pre-segregated
6	Brecht II - Belgium	50,000	Organic pre-segregated
7	Leonberg - Germany	30,000	Organic pre-segregated
8	Rome- Italy	40,000	Organic pre-segregated
9	Pusan – S. Korea	70,000	Organic pre-segregated
10	Terassa – Spain	25,000	Organic pre-segregated
11	Bassum—Germany	105,000	Mixed waste
12	Hille—Germany	100,000	Mixed waste
13	Munster—Germany	80,000	Mixed waste
14	Vitoria - Spain	120,000	Mixed waste

Source: Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste, California Integrated Waste Management Board (2008), www.ows.be.

Table 10: AD units in operation of Valorga

	Location	Capacity (tn)	Input
1	Gadiz- Spain	115,000	
2	Engelskirchen- Germany	35,000	Organic pre-segregated

	Location	**Capacity (tn)**	**Input**
3	Freiburg- Germany	36,000	Organic pre-segregated
4	Calais-France	27,000	Organic pre-segregated
5	Geneve-Switzerland	10,000	Organic pre-segregated
6	Tilburg - Netherlands	52,000	Organic pre-segregated
7	Amiens - France	85,000	Mixed waste
8	Beijing - China	105,000	Mixed waste
9	La Coruna - Spain	100,000	Mixed waste
10	Hannover - Germany	100,000	Mixed waste
11	Barcelona - Spain	240,000	218,000 tn mixed and 22,000 tn organic pre-segregated
12	Shanghai - China	268,000	227,000 tn mixed and 41,000 tn organic pre-segregated
13	Mons - Belgium	59,000	23,000 tn mixed and 36,000 tn organic pre-segregated
14	Tondela - Portugal	35,000	30,000 tn mixed and 5,000 tn organic pre-segregated
15	Bassano - Italy	52,400	44,200 tn mixed and 8,200 tn organic pre-segregated
16	Varennes - Jarcy	100,000	70,000 tn mixed and 30,000 tn organic pre-segregated

Source: Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste, California Integrated Waste Management Board (2008), www.**valorga**international.fr.

Table 11: AD units in operation of Valorga

	Location	**Capacity (tn)**	**Input**
	Switzerland		
1	Oensingen	16,000	

	Location	Capacity (tn)	Input
2	Klingnau	20,000	
3	Utzenstorf	12,000	Organic pre-segregated
4	Langenthal	4,000	
5	Ottenbach	16,000	
6	Aarberg	16,000	
7	Pratteln	12,500	
8	Jona	5,000	
9	Lenzburg	5,000	
10	Oetwil am See	10,000	
11	Volketswil	5,000	
12	Niederuzwil	20,000	
13	Otelfingen	12,500	
14	Samstagern	10,000	
15	Bachenbülach	12,000	
16	Rümlang	8,500	
	Germany		
17	Flörsheim - Wicker	45,000	
18	Rostock	40,000	
19	Amtzell	18,500	
20	Ilbenstadt	18,500	
21	Regen	18,500	
22	Weissenfels II	24,000	

	Location	Capacity (tn)	Input
23	Passau	39,000	Organic pre-segregated
24	Weissenfels	25,000	Organic pre-segregated
25	Frankfurt	30,000	
26	Azley – Worms	26,000	
	Other countries		
27	Roppen – Austria	10,000	
28	Lustanau – Austria	10,000	
29	Montpellier – France	100,000	Mixed waste
30	Botarell – Spain	54,000	
31	Rioja – Spain	75,000	Mixed waste
32	Kyoto –Japan	20,000	Organic pre-segregated
33	Martinique – Caribbean	20,000	Organic pre-segregated
34	Doha - Qatar	274,000	

Source: Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste, California Integrated Waste Management Board (2008), www.**kompogas**.ch

The second category, the anaerobic digestion of the organic fraction of mixed waste, until recently was not so widespread, but it is constantly increasing. Although the biological digestion process has operated satisfactorily and for mixed A.S.A., impurities can cause technical problems and damage that adversely affect the economics of the plant. On the other hand, the anaerobic digestion of mixed waste presents some advantages compared to the composting, as the slurry phase of waste allows some additional processes for the separation of the organic fraction of the contaminants, thereby leading to a slightly better quality final product. Additionally, the produced biogas can be exploited regardless of the quality of the solid residue.

Finally, the third category includes plants that gather a variety of organic waste from various sources, mainly from livestock farms. TheMSWusually do not exceed 10% of the plant's feed, thus improving its finances due to high gate fees without particularly affect the quality of the soil improver. Such units are situated in many countries of central Europe, wherein Denmark (where this approach is very widespread) is the main representative.

- *Advantages and disadvantages*

Anaerobic MBT has comparatively lower reliability, as it is more appropriate for clean organic waste while the separated by mechanical pretreatment organic fraction of mixed waste has increased percentage contaminants.

Techniques	Advantages	Disadvantages	Preceding Practices	Following Practices
Anaerobic Digestion	• Readily available and proven technology • Applicable for both pre-segregated biowaste and mixed MSW • High cost recovery when applied for pre-segragated biowaste • Energy recovery through biogas utilization • Significant diversion of biowaste from landfills • High cost recovery • Addresses biowaste which comprise large fractions of MSW • High public acceptance • Reduces LFG emissions and leachate production at landfill • Low environmental protection and H&S measures requirements • Low energy needs due to energy generation by the facilities • Little surface requirement in relation to open composting • High stabilization rate of biowaste	• No recyclables' recovery when applied alone • Need for upstream sorting of biowaste to achieve good quality of digestate • Need for securing final receptors of produced CLO when applied for mixed MSW • Implementation only in mid-and large-scale • Low cost recovery when applied for mixed MSW • Sophisticated technology with requirements for experienced staff	sorting-at-source of biowaste and mixed waste collection (all types)	need for final receptors of digestate or CLO need for a landfill for residues or CLO if final receptors are not willing to receive produced quantities

1.2.3.4 MBT-Anaerobic for pre-segregated waste

The production stages of this method are described below.

Reception and dropping raw materials

In the reception portion waste weighed and a first visual check is made as to their composition. Mayneedtotemporarilystoredforuptoleadtotreatment. The temporary storage area must be sealed to prevent leakage and can be either roofed or open depending on the amount, type of waste and frequency of rainfall.

The generated leachate must be collected. The time of the temporary storage should be limited due to the nature of this waste.

- *Pretreatment*

The pretreatment aims:

- To remove non-organic materials that cannot be degraded
- To improve the physical characteristics of the waste to facilitate biological degradation
- To protect the machines used in the subsequent steps of the process
- To remove materials which may reduce the quality of the final products

The extent of pretreatment depends on the system selected for anaerobic treatment and the composition of original material. High solids systems have small requirements in pretreatment and the same is true for organic waste from sorting at source. Unlike to mixed waste that requires complex mechanical pretreatment prior to enter the reactor. At the end of this, unacceptable contaminants are removed and the remaining material entering the reactor wherein the anaerobic fermentation takes place.

In pretreatment are mainly used sieves, hand-sorting, metal separators, blending machines with water and shredding machines.The effectiveness of pretreatment has an impact on production of biogas since removing the contaminants saves space in the reactor and improves the biological degradation.

- *Anaerobicdigestion*

Inthisstepthebiologicaldegradationofwaste is performed. Through the supply system waste are pumped or transported by conveyor or loader in the reactor and remain there for a period of 15-20 days.In the course of their stay biogas and sludge are produced.

- *Biogas recovery unit*

The amount of biogas produced is dependent on the selected technology as well as on the purity of starting material. Usually it amountsto 100-200 m^3 / t. A large proportion of non or hardly biodegradable organic substances in the reactor results in reduced production of biogas. The energy generated is primarily used to cover the plant installations needs.

- *Draining*

Oncompletionofanaerobicdigestionthesludgeisledtodrain. The solid products of drainage are driven to aerobic treatment.The liquid wastes are reused for blending of fresh substrate. Also they can be processed at a nearby biological treatment in.

  - *Indicative mass balance diagram*

The following figure presents an indicative mass balance of an AD unit that treats sorted-at-source organic waste following by composting of the produced sludge.

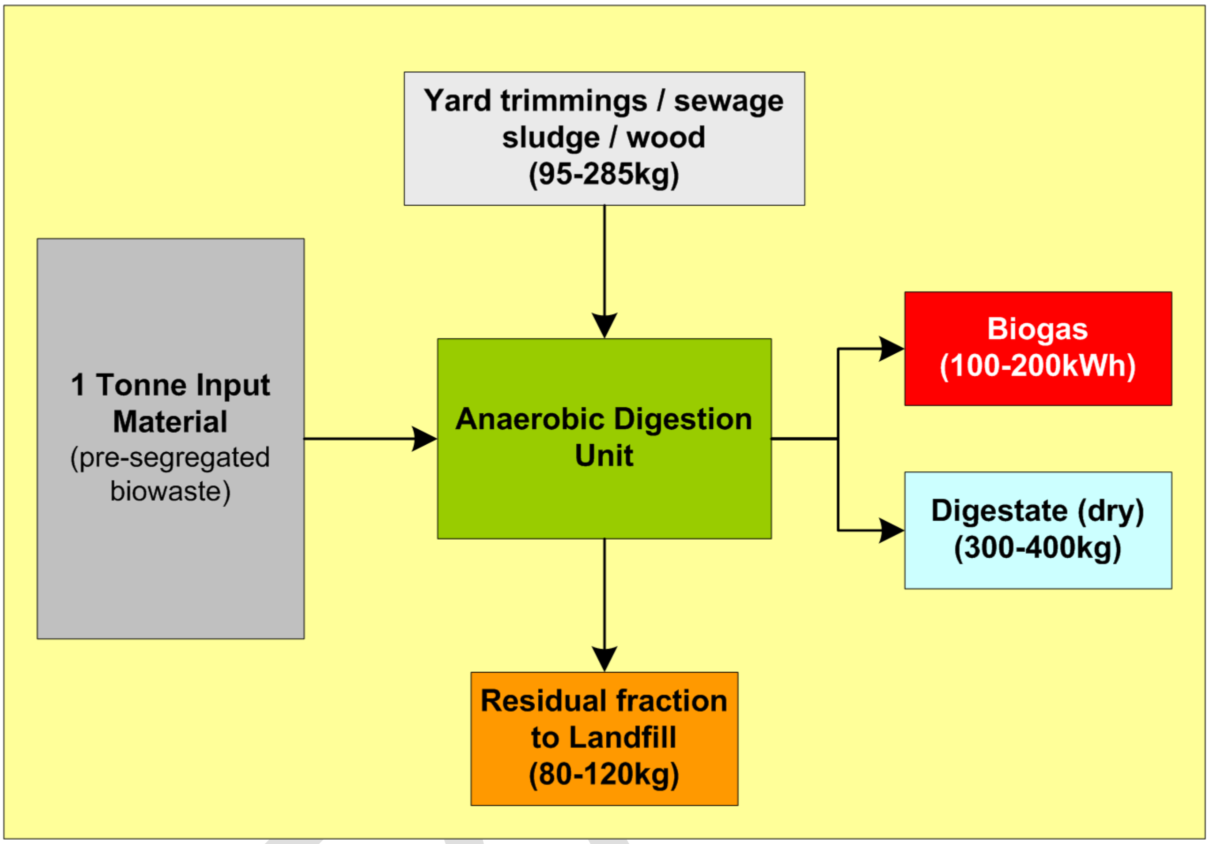


Figure 16: Indicative mass-balance of an anaerobic digestion unit for pre-segregated biowaste.

Techniques	Advantages	Disadvantages	Preceding Practices	Following Practices
Mechanical – Biological Treatment	• Readily available and proven technology • Applicable for mixed waste • Little requirements for experience staff when composting is applied • Potential for energy recovery through RDF production • Significant reduction of volume and weight of MSW ending up to landfills • Addresses the majority of MSW • High public acceptance • Reduces LFG emissions and leachate production at landfill • Prevents hazardous waste from reaching the landfill level • High stabilization rate of biowaste	• Intermediate recyclables' recovery efficiency • Low quality and selling price of reclaimed recyclables and compost • Need for securing final receptors of produced RDF (if this option is applied) • Implementation only in mid-and large-scale • Intermediate cost recovery • Difficult prevention of hazardous waste from reaching the landfill level • Intermediate environmental protection and H&S measures requirements • Intermediate energy needs per tonne • Sophisticated technology with requirements for experienced staff when anaerobic digestion is applied	mixed waste collection (all types)	need for final receptors of RDF (if applied) need for final receptors of compost, digestate or CLO (respectively of the type of MBT) need for a landfill for residues of RDF or CLO if final receptors are not willing to receive produced quantities

1.2.3.5 Biological Drying

- *Process description*

The biological drying, while belonging to the family of MBT technologies, due to the techniques used, in fact is quite different from the above technologies. Although, there is much in common between biodrying and composting, the essential difference is the process goal. Composting aims at fully decomposing the biomass, removing odours and killing pathogens., as the biological stage of the installation precedes of mechanical processing and the purpose of the unit is exclusively the production of secondary fuel. Biodrying, on the other hand, aims at removing as much moisture as possible in the shortest time. The biological drying is a pretreatment method scoping mainly to upgrade MSW to make them more suitable for thermal recovery.

More specifically, because MSW contain high humidity and the heat content is low, the biological drying aims to:

- Reduction of moisture of MSW in 12 to 15% by weight;
- Separation of recyclable ferrous metals and aluminum;
- Production of SRF (Solid Recovered Fuel), a material suitable for thermal recovery with lower calorific value of about 15 MJ/kg.

Drying is achieved through energy generated by the aerobic degradation of a limited percentage of the organic materials of MSW.

Biological Drying consists of two processes:

1. The aerobic waste process (usually shredded previously to reduce the size) with oxygen supply, but without adding water to waste (unlike to the conventional composting);
2. The mechanical post-treatment processes (with combinations of mechanical equipment as in the standard mechanical sorting) for removing metals and generally reduce non-combustible materials (stones, glasses, etc.).

Airflow is a critical factor that should be controlled properly during the biodrying process. Low aeration rates may result in decomposition without significant moisture removal. Higher values of aeration rates may quickly cool the material down and stop microbial activities. It is important to adjust appropriately the aeration levels for biodrying. To do so, biodrying systems usually use fans to force air through the organic matter.

The process duration varies with the waste material type and the system setup, but it typically should last between 2-3 weeks. Composted material can be used as a fertilizer or soil amendment while bio-dried material has potential value for bioenergy production.

As shown in Figure 17, a membrane cover separates the waste material from ambient conditions, allows water vapour to be released but retains bio-aerosols and reduces odour emissions. These membrane covers are impermeable for rain. Rain water runs off the covers and is collected separately between the bays. The aeration pipes provide the necessary oxygen for the microorganisms, the air to remove the moisture in this aerobic process and in parallel act as drainage for the little amounts of leachate water arising during the first few days of the drying process. The pipes are connected to the leachate water collection system via a water trap. The drying process is controlled via a specialized software using process data as temperature profile, air flow, etc. to control the process according to the requirements. A winding device is used to remove the cover from the drying material before shifting and covers it after the heap filling is completed.

Figure 17: Aspect of a biodrying unit

After drying, the end material is passed through mechanical treatment systems (shredders, sieves, magnets, eddy current separators, hand-picking, air-separation, etc.), in order to reclaim as more metals as possible (~70% w/w of metals contained in the MSW) and a waste-derived fuel consisted by combustible materials (papers, plastics and organic waste), the so-called Solid Recovered Fuel (SRF).

There are three basic biological drying systems applied, which differ mainly in the configuration of the drying area:

i. *Biological Drying in Industrial Building within a single tank*, implemented by two Italian firms.

Figure 18: Department of reception, shredding and biological drying of waste

ii. *Biological Drying in covered Piles*, implemented by several firms in Germany, Austria and Italy. It is a simple and relatively inexpensive system, mainly applied to small-scale plants or in waste that has been subject to some degree of sorting. These systems are often installed within the landfill and do not include building infrastructure, except perhaps basic premises (e.g. guardhouse). Shredder and piles installations are situated in open, non-covered area configured as "square". If screening mechanical equipment is desired, then it will be roofed (e.g. a metal building with industrial floor).

1. Control system
2. PC
3. Restraint of membrane
4. Temperature sensor
5. O_2 / temperature sensor
6. Placement system
7. Air generating station
8. Air supply pipelines 'on floor' type
9. Membrane
10. Leachate drainage
11. Ventilation channels 'in floor' type

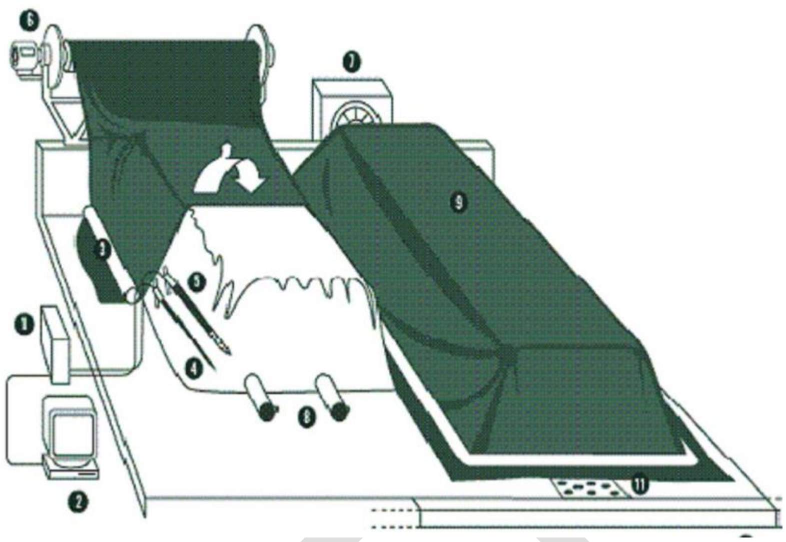


Figure 19: Biological drying in covered piles

iii. *Biological Drying in industrial building within Compartments (boxes)*. This method is similar to the process in an industrial building, with the difference that drying does not take place in a tank, but in concrete or metal compartments - boxes which is able to receive material of a day. The boxes are placed either in fully covered area or in roofed asphalted square, depending on the conditions and requirements of the authorizing environmental authority. The method is applied by two German companies, but on a different scale with regard to the capacity (one deals with small and medium-sized units of no more than 50,000 tons per year, while the other can supply full range of systems).

Closed bio-box	Open bio-box

Figure 20: 'Boxes' applied by the German company Herhof (Juniper, 2005)

Newer boxes added	Initially installed boxes

Figure 21: ‘Boxes’ applied by the German company Nehlsen (Juniper, 2005)

- *Recovered products*

Ferrous metals and SRF can be produced by a biological drying unit.

- *Indicative mass balance diagram*

Around 55% wt of the MSW is being transformed into SRF. A residual fraction also remains at the output of biodrying units (~16.5% wt of initial MSW mass), consisted of inert and non-combustible materials (incl. glass, remaining metals, etc.). A schematic diagram of inputs and outputs of a MBT is given in the following Figure.

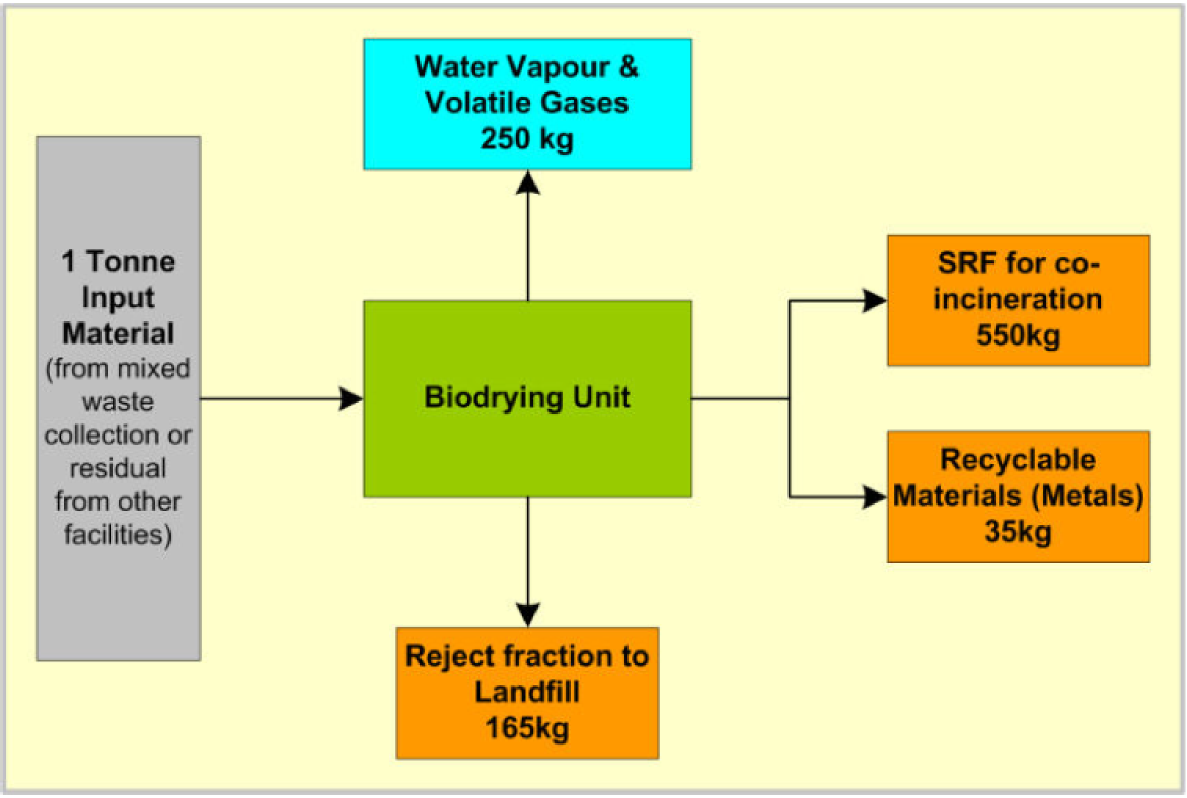


Figure 22: Schematic diagram showing the inputs and outputs of a typical biodrying unit.

- *Flexibility for upgrade*

The biological drying can respond to a lesser extent from aerobic MBE in quantity changes as the round the clock biological treatment that is the first step in treatment has a specific capacity and increased volumes should be absorbed from the reception area provided that it has been properly sized.

- *Energy*

The literature states that the SRF has a lower calorific value between 15 and 17,5 MJ / Kg. For waste as those produced in Lebanon, with lower calorific value 8 MJ/kg and a mass balance as was described earlier, the energy balance requires that the lower calorific value of SRF cannot exceed 8 * (1000/550) = 14,5 MJ/Kg.

- *Water consumption*

In bio-drying method, where the aim is to remove moisture from the waste to increase the calorific power, not additional water is used.

- *Aesthetic burden*

The annoyance from biological drying units varies depending on the system gas treatment (thermal oxidation or biofilter) while some anaerobic digestion technologies operate with horizontal reactor.

- *employment*

The biological drying is a process with a relatively high degree of automation.

- *Existing international experience of adopted practices/techniques*

The biological drying is a variant of aerobic MBE and what has been aforementioned is applied.

14 out of 80 MBT plants operating in 2004 were biological drying plants. The total capacity of these plants amounted to 1.165.000 tn/year, representing 13.7% of the capacity of all MBT plants. Existing biological drying factories in EU can process around 830.000 tn MSW per year and produce approximately 830,000 x 0,55 = 460.000 tn SRF per year.Three firms have successfully built plants with variants of this technology, by the end of 2004.

The German company Herhof GmbH specializes in the construction and operation of similar units, since it has built eight plants in Europe with the technology of biological drying to produce a secondary dry fuel (Dry Stabilat), as well as 43 units worldwide by the process of aerobic composting on special type of enclosed bioreactors (In-Vessel Composting). The following table presents a summary report of facilities in operation that use for several years this technology.

Table 12: Biodrying units in operation of Herhof GmbH

	Location	**Capacity (tn/y)**	**Year of completion**
1	Asslar, Germany	140,000 15,000	08/97 08/99 (extension)
2	Rennerod, Germany	100,000	04/00
3	Dresden, Germany	85,000	05/01

	Location	Capacity (tn/y)	Year of completion
4	Fusina, Italy	150,000	02/02
5	Geel, Belgium	150,000	08/05
6	Osnabruck, Germany	90,000	02/06
7	Niederlehme, Germany	135,000	09/06
8	Trier, Germany	220,000	03/07

- *Advantages and disadvantages*

Biodrying is commonly applied as another version of MBT, so in many cases it is referred to as an MBT option.

Additional **benefits** of biodrying include the reduced potential for odors, since the resulting material is well aerated and partially stabilized. Finally, the resulting SRF with its lower moisture content is more suitable for energy production through incineration.

On the other hand, biodrying does not greatly affect the biodegradability of waste and hence is not completely stabilised. Biodried waste will still break down in a landfill to produce landfill gas and leachate, hence potentially contributing to climate change.

Techniques	Advantages	Disadvantages	Preceding Practices	Following Practices
Biodrying	• Readily available and proven technology • Applicable for mixed waste • Potential for energy recovery trough SRF production • Significant reduction of volume and weight of MSW ending up to landfills • High quality and selling price of reclaimed recyclables (metals) • High public acceptance • Low environmental protection and H&S measures requirements	• Low recyclables' recovery efficiency • Need for securing final receptors of produced SRF • Implementation only in mid-and large-scale • Intermediate cost recovery • Difficult prevention of hazardous waste from reaching the landfill level • Partial stabilization rate of biowaste • Partial reduction of LFG emissions and leachate production at landfill • Intermediate energy needs per tonne	mixed waste collection (all types)	need for final receptors of SRF need for a landfill for residues or SRF if final receptors are not willing to receive produced quantities

1.2.4 Thermal Treatment methods

The "industry" of solid waste management and disposal is constantly growing driven by the need for new legislation which promotes recycling, and the development of sustainable technologies and continuously removed from the technical landfill and disposal of solid waste without treatment.

Thistrendofcontinuouschangeespeciallyhelpsandsupportsthegrowthofsolidwastethermalproc essingmethods. The key to the promotion of such processes is the need to shift from conventional solution of combustion (as now seen in Europe) in "best" thermal processing methods.Theemphasisisoncreatinglessresiduesandemissions (flyash, gasemissions, etc.).

The thermal treatment of waste technologies can be defined as solid waste conversion processes in gaseous, liquid and solid products, with simultaneous or subsequent release of thermal energy. The most basic methods of thermal treatment, categorized according to their requirements in air are the following:

- *Incineration* (complete combustion) is defined as the rapid conversion of chemical energy into thermal by oxidation of the organic matter of the municipal solid waste, under conditions of excess oxygen, to carbon dioxide and water. The inorganic components of the waste remains in the resulting solid residue. Incineration can be performed either with the required stoichiometric air ratio (stoichiometric combustion) or with excess air (excess - air combustion).
- *Pyrolysis* is defined as the degradation of the organic substances of the waste, in absence of oxygen (or minimum quantities). The products of pyrolysis are solids, liquids and gases and their composition depends on the functional characteristics of the unit, such as temperature and dwell time of the waste in the pyrolysis chamber.
- *Gasification*isdefinedasthepartialoxidation (withairoroxygen) oftheorganicmatterofthewaste, whichisconvertedtoamixtureofgases (e.g. carbonmonoxide, hydrogenandmethane). At all stages of this process are produced gases, solids and thermal energy, which is needed for the realization of chain reactions. Therefore, gasification requires strict stoichiometric ratios between waste - air to achieve incomplete combustion of waste and to produce gas of CO, H_2 and hydrocarbon gases (which in turn is fuel).

1.2.4.1 Incineration - Combustion

Incineration or -most common- combustion of solid waste represents a number of old and widespread process which comprises the development of high temperatures (850-1500°C), in the presence of a flame for oxidation of the components of the waste, i.e. their compound with oxygen.

The process aims to evaporation, decomposition and / or destruction of the organic components of the waste, in presence of oxygen (either in a stoichiometric ratio or in excess) and the reduction of the volume destined for final disposal.

Important role in the economic efficiency of thermal treatment plants plays the possibility of utilizing of steam after the turbine, either by passing to neighboring plants or to use for tele-heating of urban centers, where local conditions are favorable. If it is not possible to exploit the latent heat of steam, then it must be liquefied, so that the water can be recycled to the steam boiler. In this case the heat of liquefaction is not utilized, but ends up in the environment. For the utilization of generated heat and for the recovery of energy, modern incinerators allocate specific boilers, by the help of which the heat is used to produce steam. Then, the generated steam is used as either a heat source or as a means of producing electric power using steam turbines and generators.

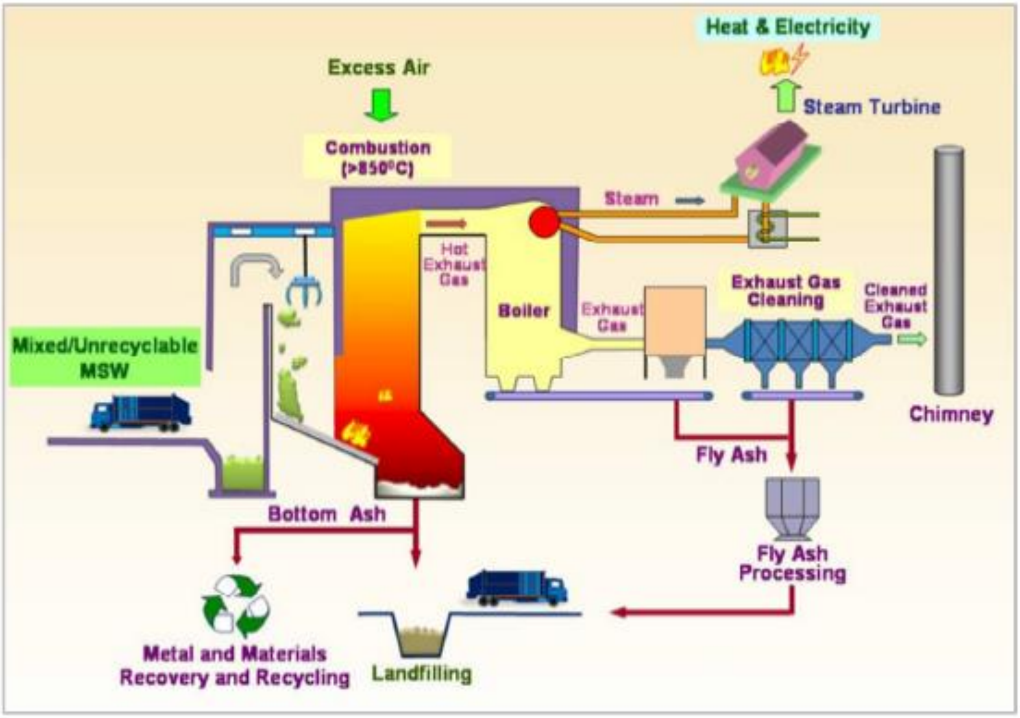


Figure 23: Typical incineration flow chart (source: www.epd.gov.hk)

After their passage from the steam boiler, the flue gas traveling through their purification plant and then discharged into the atmosphere. In cleaning systems apply various, proven and safe technologies to remove suspended solids, acids, nitrogen oxides, dioxins and others.

The emission control systems include various devices such as scrubbers, electrostatic filters, cyclones, fabric filters, etc. the selection of which is based on the composition of flue gases for treatment and on the emission limits for the whole installation.

Types of incineration plants

Broadly there are two types of conventional incineration units:

- units that require minimal pretreatment of waste (**mass-fired**), and
- units operating **with treated RDF** (refuse - derived fuel) as fuel.

The *mass-fired* are the majority of installed units. Their big advantage is that the waste enters without any pretreatment in the combustion unit, making operation more "convenient". This also entails risks for plant operation (e.g., introduction of bulky or particularly hazardous waste) which are treated with a strict supervision of incoming waste and allowing manual interruption of waste entry, whenever considered necessary by the supervisor.

It is clear that fluctuations of the energy content of waste in mass-fired units are huge and depend on climate, the time period, the composition of waste etc. Consequently, mass-fired units fit with a relative difficulty in a power recovery system.

The *RDF-fired* units are clearly less than the mass-fired as the former require the operation of a RDF plant. The RDF-fired units have certain important advantages, compared with the mass-fired plants:

- Fit easily in energy recovery and distribution network because the RDF has higher calorific value compared to untreated waste) and much smaller fluctuations of energy content.
- Control of a RDF-fired unit is clearly easier.
- The space required is much less, than a mass-fired unit.
- Finally, the pretreatment of the waste for the production of RDF allows removal capacity of a series of waste categories, such as PVC, the metals etc. which contribute to the creation of dangerous pollutants transported by the gases of the incineration plant.

The aim is the final mixture has a high calorific value. Specific requirements that must be met by RDF are defined for this purpose. Indicatively[7]:

- lower calorific value = 4.000kcal / g (16.744MJ / kg)
- moisture content <20%
- paper and plastic> 95% (dry weight).

The whole process takes place in special incinerators, whose capacity may vary from 8 to 25 Mg/h (Vehlow, 2006). The type of these also varies, since various types of incinerators have been developed at times, each with different advantages and disadvantages. The most common types of incinerators are:

- moving grate incinerator,
- rotating furnace incinerator,
- fluidised bed incinerator.

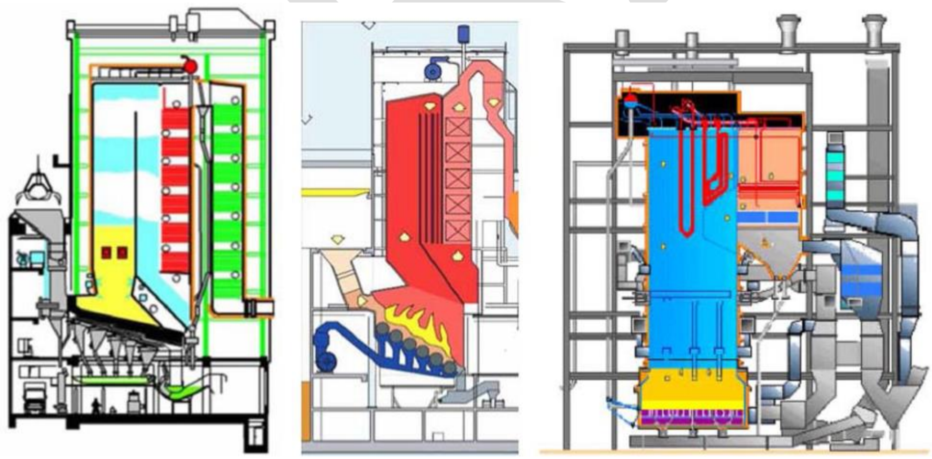


Figure 24**:** The three types of incinerators: (a) moving grate, (b) rotating furnace, (c) fluidised bed (Finbioenergy, 2006)

[7] As they are defined in Greece bytheJoint MinisterialDecision No 114218/1997.

The *moving grates*incinerator is the oldest technology, and - traditionally - the most widely applied for the thermal treatment of any type of waste. The basic steps in operation are:

- Drying: The incoming waste receives heat by radiation from the flame and by convection from the hot air. The result is evaporation of the moisture contained in the waste and of the volatile components.
- Pyrolysis: With the increase of temperature the more volatile components evaporated.
- Ignition: The heat required to ignite the fuel is imparted to the waste by radiation from the flame and the walls of the combustion chamber.
- Gasification and combustion: The large increase of temperature due to the full ignition of the waste causes the gasification of a variety of materials, contained therein.
- The remaining carbon is completely oxidized, while the waste gases generated by the phases of pyrolysis and gasification are burned in the combustion chamber.
- Completion of combustion: The completion of the combustion yields a fairly inactivated (inorganic) solid residue at the end of the grate.

A *rotating furnace* incineratorprocesses successfully many types of waste and pollutants that other technologies cannot cope.
It consists of a rotary kiln, an afterburner and one emission control system of the generated gaseous. Basic operating parameters of such incinerator are:

- the outlet temperature of the rotary furnace and the afterburner, which should result in a complete incineration of waste,
- the internal pressure of the furnace, which should be negative in order to avoid gaseous and particulate emissions to the atmosphere,
- the rate of supply of air (oxygen) and waste, so that the burner operating conditions being optimal.

The waste residence time determines their degree of mixing within the furnace since it is rotated, as well as their processing time.

The composition of the flue gases is a performance index of the furnace and since it works with excess oxygen, flue gases should contain low concentrations of CO and hydrocarbons and reduced quantities of incineration residues.

The *fluidised bed* incinerator uses a layer of sand or alumina (bed), on which the waste entering. Beneath this layer air is fed with such a supply so that the entire bed to be in suspension and at a temperature equal to the ignition temperature of the existing pollutants. The supplied oxygen, the intense mixing conditions and elevated temperature result in evaporation and destruction of the organic pollutants.

Basic functional parameter for this type kind of incinerators is the temperature, which is defined according to the feeding of waste, flue gases generated and an auxiliary combustion material. Its value ranges between 750 - 880°C, lower than in the other incineration technologies, due to good mixing of the waste to be treated.

The required combustion oxygen and the waste residence time are also important operating parameters of a fluidized bed incinerator, which are determined based on the feeding rate of waste to be treated.

The main advantages of a fluidised bed incinerator are:

- avoid the occurrence of local temperature differences and therefore reduce pollutant gaseous emissions, which are a result of incomplete combustion due to temperature differences,
- possibility of energy utilization of difficult fuels, with a high moisture and ash content,
- increasing the degree of conversion of the fuel and more efficient utilization of the combustion air, which leads to a smaller excess air requirements (in this case about 55% compared to conventional 100%).

Residues

Three types of residues arise from the incineration process: gases, liquids and solids. Of particular importance are the gases, for the purification of which a large amount of investment is required.

Gases

During incineration appr. 4 - 5.000 m^3 flue gases per tonne of waste are generated with a temperature at about 1000^oC. The temperature drops sharply at 350 ^oC during the first phase of flue gases cleaning and the heat resulting from the cooling can be used in various purposes.

The gases generated by combustion contain nitrogen and excess of oxygen, dust particles, typically combustion products (CO, CO_2, H_2O, NO_x, SO_2), and a number of other harmful substances, which depends on the composition of the waste. Most important of these are the HCl, HF, heavy metals and polycyclic hydrocarbons (dioxins, furans). Fly ash and suspended solids contained in the waste gases are also of particular significance for the gases cleaning systems. The maximum allowable limits of gaseous pollutants from municipal waste incineration plants are defined in legislation.

Of the most dangerous exhaust gases pollutants are the dioxins, also referred to as polychlorinated dibenzodioxins (PCDD), and equally the furans (PCDF). The creation of dioxins and furans takes place in the gaseous phase in almost all combustion processes, in small quantities, in a temperature of 300^oC. The hazardousness and toxicity of these substances is in line with indications for their contribution in carcinogenic processes in humans.

Liquids

Liquid waste contains suspended particles, as well as inorganic and organic in solution. The product is corrosive and it often requires processing before disposing of sewage system. The most common wastewater treatment methods are decanting and then adjust the pH.

Solid

The solid residues from the incineration of waste are distinguished into the following categories:

- Fly ash. The ash consists of the lightest part of the ash drifting from the exhaust gases and collected by special filters. This ash has high concentrations of heavy metals.
- Bottom ash. This is the residue which is gathered in the bottom of the furnace.
- Boiler ash (ash from boilers).

- Filter dust (dust from cleaning filters).
- Solid residues from waste gases' cleaning process.

If the bottom ash is not to be used it can be disposed like household waste without any problem, having first undergone a conventional mechanical pretreatment.

Under development is the technology of inactivation the fly ash, which is considered as hazardous waste, which converts it into useful material for road construction, structural applications, etc. The use of ash in road construction - road surfacing is very common in Europe.

It should be noted that in recent years modern pollution control technologies have been developed, which reduce significantly and effectively the generated pollutants. These include deposition chambers, wherein removed 40% of the suspended particles, wetting screens (efficiency 95%), cyclones (efficiency 60-80%), liquid absorber towers (efficiency 80-95%), electrostatic precipitators (efficiency from 99 to 99.5%) and sack filters (efficiency 99.9%).

For the treatment of dust of the filters various systems are used such as thermal (high temperature). The purpose of processing at high temperatures is to melt the dust and convert it into material that is in glassy state, which may be allocated to various purposes or disposed of as inert.

Besides the removal of suspended solids, often becomes necessary to remove other pollutants, e.g. acid gases, if their content is above the allowable limits mentioned above.

Particularly great importance is the HCL generated mainly from the combustion of PVC, and the oxides of nitrogen, sulfur, phosphorus. In this case only effective and appropriate way is the function of liquid and dry absorption towers (scrubbing). The liquid absorption towers are necessary in any case, for the combustion of toxic waste.

The process of liquid absorption is based on the absorption of gaseous pollutants by use of a selected washing liquid (solvent). The effectiveness of the process depends primarily on the available surface of the solvent, which controls the transition of the mass from the gas in the liquid condition. For this purpose, various techniques are used, such as:

- Venture type scrubbers
- filling Towers
- Towers with discs
- film type absorption tower (thin layer)

The technology of *liquid absorption* is a common strategy in most Central European incineration plants, a process which is performed in two phases units, an initial acid absorption phase and a second at neutral or slightly alkaline environment.

This device of acid absorption is often injection type or venturi and in this phase a reduction in the temperature of flue gas from 180-200^{o}C at 63-65^{o}C is achieved. For the second phase (neutral or slightly alkaline) filling towers are mainly used.

Commercially available *scrubbing systems* operate with or without waste production. Such two-stage systems are quite effective in removing hydrides halogen, HF, HCl, HBr, mercury and SO_2 from waste gases of incinerators. With this technology, the initial concentrations of the above components in the flue gas are reduced well below statutory limits.

The *towers of dry or semi-dry absorption* are simpler and lower-cost technologies and operate in many facilities in the world. In most cases the adsorbent is injected either directly into the flue gas conductor or via injection tower in a dry or semi-dry form. The products of the absorption are removed in a second phase through a hymen filter device. The absorption process may be carried out with various reagents (limestone, $CaCO_3$, calcium oxide, CaO, lime, Ca (OH) 2 etc.).

Nowadays, the Dry Absorption Towers technology that uses $CaCO_3$ is being phased out, as it does not comply with the strict statutory limits.

- *Indicative mass balance diagram*

The following diagram presents the mass balance for a typical incineration plant. The figures depend, as is normal, on the composition of waste, but also on the composition of the emissions control system used.

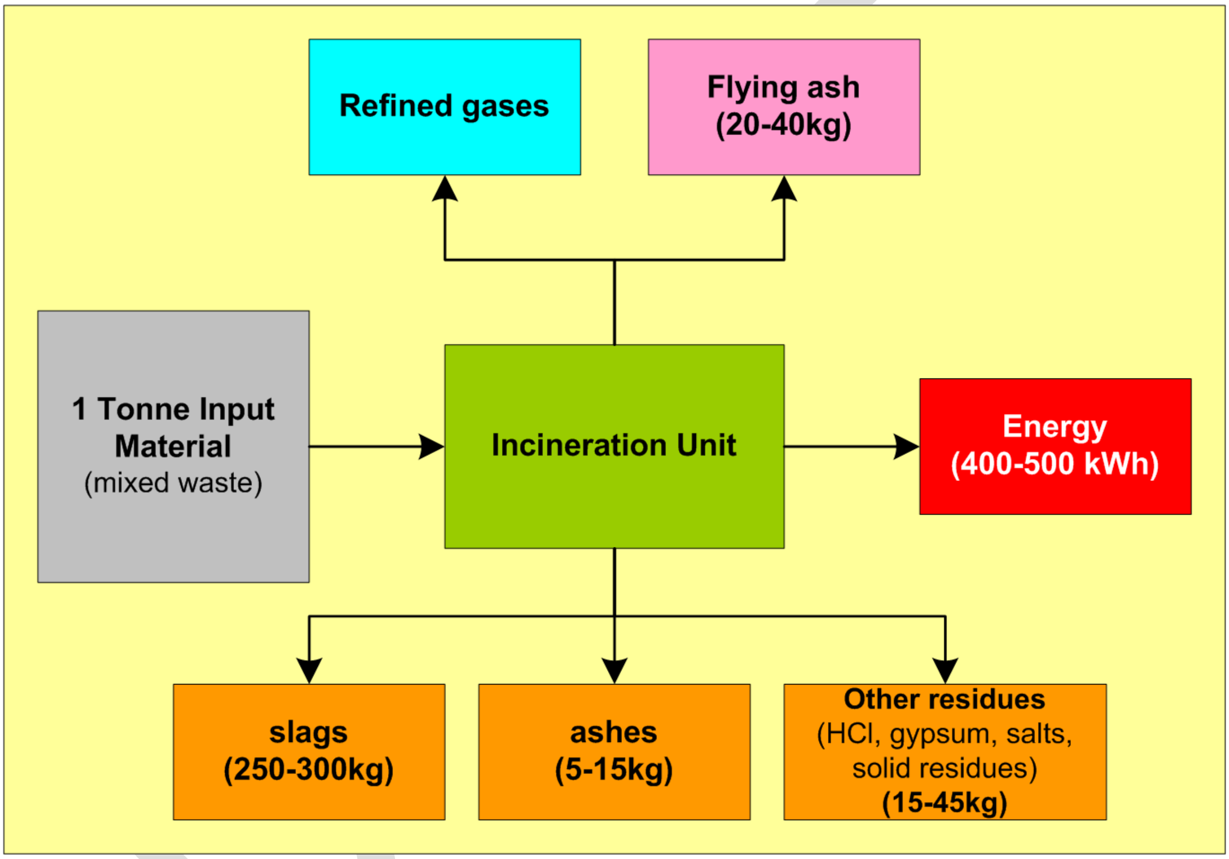


Figure 25: Indicative mass-balance of an incineration unit

- *Operational requirements & complexity*

Incineration is a proven method which is used worldwide for several decades. The operation of such a plant is complex, it requires 24-hours employment and specialised staff. Emphasis should be given to the effectiveness of the gas treatment system.

- *Ability to co-manage other waste streams*

Incineration has the greatest flexibility with regard to the admission of other waste streams such as sewage sludge, tires.

- *technology flexibility*

In the thermal treatment units, the quantity of incoming material should be kept constant, so that the combustion is performed with high yield. Reducing input quantity has a direct impact on the production of electricity and hence the viability of the plant.

- *recovery of materials and products*

In thermal treatment plants recycling takes zero although there is practically metal recovery system, but which cannot be estimated.

- *residues to landfilling*

Thermal treatment plants achieve greatly diversion as the total organic is incinerated.

- *Existing international experience of adopted practices/techniques*

The experience and knowledge gained over the years, as well as the emergence of major environmental problems (eg, soil and groundwater pollution, air pollution, reducing fossil fuel reserves, increasing energy needs, etc.), which necessitated the imposition of strict standards and limitations in managing all types of waste and in human activities in general, significantly changed the character of so-called Thermal treatment MSW.

Leading countries in thermal treatment methods are Switzerland, Sweden, Holland, Denmark and Germany (Bilitewski B., 2006a).

- *Denmark*: Denmark was one of the leading countries in the field of application of thermal treatments (at least in Europe). In the course of 100 years of application of these methods, the Danes saw the incineration plants of MSW to be converted from waste "destruction" spaces in "environmentally friendly" and reliable power plants. According to recent data, Denmark has a total of 30 power plants (heat and electricity) from MSW, which operate with very high performance levels and cause minimal environmental disturbance.
- *Germany*: Germany is also one of the first countries that adopted the thermal treatment for MSW. According to 2004 data, the power plants from thermal treatment A.S.A. amounted to 61, a figure that is expected to increase in the future as Germany is probably the only country, which completely banned the landfill of waste.

One of the relatively new MSW incineration plants in Germany is that of the city of Hamburg. The construction was completed in 1998 and operates with two parallel processing lines, of capacity 21,5 Mg / h, each. Unit's flue gases produced amount to 180.000 m3 / h, while the generated steam and electricity is 137Mg / h (45bar / 425 0C) and 58 MW, respectively. Has suitable processing units of waste gases (chlorine scrubber and gypsum production, bag filters, etc.), while the solid residue of the whole process (ash) is further processed to be used as construction material.

Figure 26: A view of the MSW incineration plant of Hamburg (www.bildarchivhamburg.de/AGB)

- *United Kingdom*: The United Kingdom, although it was the first country in Europe which implemented the incineration of MSW, is not still to be leading in this sector as the units available are only 15, while a percentage of produced MSW higher than 70% is managed through the landfill.

The available units show considerable disparities in their capacity. For example, the unit operation in the city Lerwick with capacity 26.000 tn MSW/year, produces small amounts of heat and electricity, while another unit in the city Edmonton, processes 600.000 tn MSW/year, producing 30 MW electricity (UK Parliamentary Office of Science and Technology, 2000).

The latest achievement demonstrated by the United Kingdom on the production of energy through thermal treatment is the new incineration plant in Allington Quarry, which started its operation in 2007. This unit has a capacity of 500.000 ton / year, operates a fluidized bed incinerator and produces 43MW / h of electrical energy which is distributed directly to the existing network. The cost amounted to 150 million. British Pounds and operates in compliance with the most stringent national and European environmental constraints.

Figure 27: A view of the MSW incineration plant at Allington Quarry

- *USA*: The United States does not show particularly high application rates of thermal treatment for MSW. According to 2005 figures, from 245.7 mil. tons of MSW produced in the US, 23.8% was recycled, 8.3% was composted, 13.6% was thermally treated to energy production facilities, and 54.3% was landfilled (EPA, 2006), which might also be due to the large availability of land.

Nevertheless, in large urban centers such as New York, the available land for landfill has been reduced significantly, making it necessary to find alternative solutions, including thermal treatment.

A characteristic MSW thermal processing unit in the US is a fairly large incineration plant 400km from New York (Onondaga County), which operates since 1994 with three different incinerators, of capacity 990 ton A.S.A. daily. It features weighing scale, special radioactivity control of incoming waste, temporary storage of waste, flue gas treatment systems (scrubber and bag filters), water - vapor recirculation system, and ferrous materials recovery unit from the produced ash.

Figure 28: View of MSW incineration plant in New York.

Since the starting operation of this unit has processed more than 3 million tons of waste, while producing more than 2 billion KWh for the state of New York. The equivalent savings of fossil fuels is estimated at 3.8 million barrels (www.ocrra.org).

- *Japan*: Japan, as already mentioned, is showing considerable growth rates in MSW thermal treatment methods A.S.A. and in particular in specific methods that at least in Europe are not very widespread (e.g. pyrolysis). This development can be considered expected and almost imposed by the high population density, the large quantities of MSW produced and the low availability of land.

Illustrative is the example of the city Osaka, which features a total of 10 different thermal treatment units for MSW with energy production in order to satisfy the needs.

Table 13: Thermal Processing Units for MSW with energy recovery in the city Osaka, Japan (www.city.osaka.jp).

Facility	Capacity	Construction period	Use of heat
Morinomiya	300 tn/d, 3 units	1966-1968	Steam supply in nearby facilities
Minato	300 tn/d, 2 units	1974-1977	Energy production (2.750 Kw)
Nanko	300 tn/d, 2 units	1974-1977	Energy production (3.000 Kw)
Taisho	300 tn/d, 2 units	1976-1980	Energy production (3.000 Kw)
Suminoe	300 tn/d, 2 units	1985-1988	Energy production (11.000 Kw) and supply in nearby facilities - Hot water supply
Tsouroumi	300 tn/d, 2 units	1987-1990	Energy production (12.000 Kw) and supply in Tsouroumi park
Nishiyodo	300 tn/d, 2 units	1990-1994	Energy production (14.500 Kw)

Facility	Capacity	Construction period	Use of heat
Yao	300 tn/d, 2 units	1991-1994	Energy production (14.500 Kw) and supply in landfill Yao
Maishima	450 tn/d, 2 units	1996-2001	Energy production (32.000 Kw)
Hirano	450 tn/d, 2 units	1998-2002	Energy production (27.400 Kw)

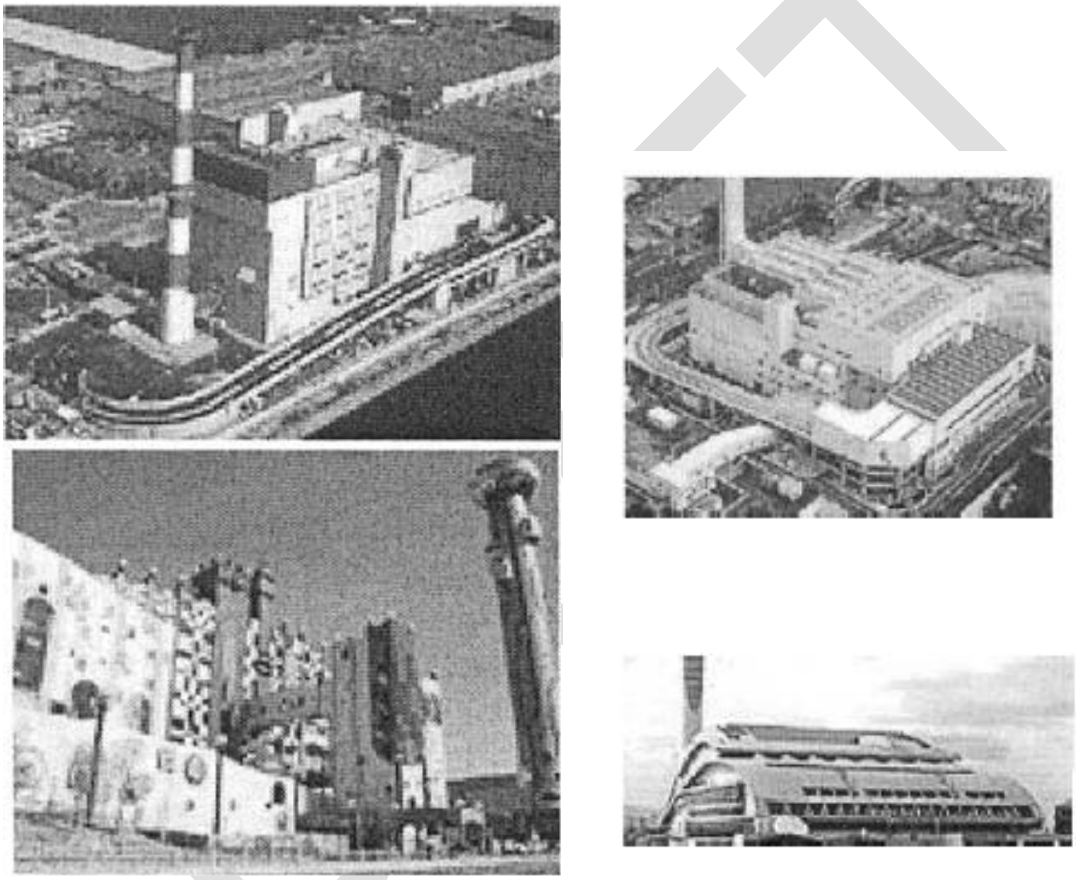


Figure 29: View of thermal treatment facilities for MSW in Osaka. (a) Nanko, (b) Suminoe, (c) Maishima, (d) Hirano

- *Advantages and disadvantages of incineration*

The basic utility of incineration is to drastically reduce the volume of waste, which reaches up to 90% of the initial volume and the possibility of energy recovery from waste. Therefore space scarcity and significant energy needs, combined with difficulties in power supply, "facilitate" the operation of incineration plants. Note that in each case one incinerator must be accompanied by appropriate landfill for hazardous waste for the disposal of hazardous solid residue, which is a small fraction of solid residues of an incineration plant.

It is a precondition for the application of incineration that the waste have a minimum calorific value of 6 MJ / kg in all seasons of the year and an average annual minimum calorific value at least 7 MJ / kg. For waste with a lower calorific value of about 8 MJ / kg the total electricity production is estimated at 520 kWh / ton. If the own consumption of the plant, which is 70 kWh / ton of waste, is subtracted, the excess electricity that can be disposed of to others, is around 450 kWh / ton.

Table 14: Advantages and disadvantages of incineration of MSW

Advantages	Disadvantages
• Widely proven technology • Long term solution as it significantly reduces volume of combustible waste • Limited and manageable risks • Total investment cost (civil engineering costs, risk mitigation funds, insurance, project financing costs, pretreatment costs etc.) is lower than pyrolysis and gasification • High potential of energy recovery	• No recycling potential • Low in the Integrated MSWM practices hierarchy • Conventional incineration has lower energy recovery efficiency than pyrolysis and gasification • Requirement for post-management of hazardous by-products (landfilling, trans-boundary transport etc.)

1.2.4.2 Gasification

o Process description

Gasification is the conversion of a solid or liquid feed fuel into gas through thermal treatment. Essentially, the fuel is subjected to partial oxidation (sub-stoichiometric conditions), which is achieved by regulating the supply of the oxidizing agent. While the physicochemical processes that take place vary considerably, the gas is formed mainly at temperatures above 750 °C. For organic feeders (fuel), as is most of urban waste, the final gas is mainly a mixture composed of carbon monoxide and carbon dioxide, hydrogen, methane, water, nitrogen and small amounts of high hydrocarbon.

The produced gas has typically relatively low calorific value of about 10 MJ/Nm3 (compared, mention that the calorific power of natural gas is about 39 MJ/Nm3). The produced gas can be used as fuel in boilers, internal combustion engines or gas turbines.

As an oxidizing agent either air, or oxygen enriched air or pure oxygen is used. When air is not used, the final produced gas (synthesis gas) has a higher calorific value (from 10 to 15 MJ/Nm3) compared to that formed by use of atmospheric air.

The gasification process which has the greatest evolution in recent years is the gasification in fluidized bed, whereby the first production facility was built and put into operation in Greve-in-Chianti (Italy).

Figure 30: fluidized bed gasification unit in Greve-in-Chianti (Italy)

The produced gas can be exploited in several ways, including:

- Combustion for steam production. The advantage compared to incineration, is that the gases are purified before combustion, thus enabling functioning of steam boiler at higher pressure and the steam superheater at higher temperatures in order to achieve improved performance in electricity generation, which can be approaching 30%.
- Power supply of internal combustion engine that drives generator. The yield of Electricity can exceed 40%, taking in account that a very good cleaning of gases prior to feeding the machine is required.
- Drive gas turbine and steam production in combined cycle. This method which also requires a very good cleaning of gases prior to feeding, can result in yields of about 40% to electricity.
- Channeling in the city gas network. Good cleaning and constant quality are necessary conditions.
- Supply of gas to the industry, such as cement industry for direct burning in fireplace. In this case cleaning requirements are significantly reduced
- Supply of gas to industry for use in steam production. The cleaning requirements depend on the operating conditions of the steam boiler.

Plasma technology

The plasma units are used for years primarily for the treatment of ash from incineration plants, while in recent years the technology has been tested for the waste treatment and energy recovery.

The process includes the following: the waste is fed as raw material while a quantity-controlled air is provided. The waste is fed into the furnace plasma, wherein two products are produced under the influence of an electric field. One is the crude synthesis gas (containing H_2, CO, CO_2, H_2O, HCl traces, H_2S) and the other an inert molten slag (melting at 1,600 °C). The molten slag is a glassy material with very low leachability (this is why sometimes solid residues of combustion are treated with plasma technology, without of course the production of synthesis gas). The glassy material is considered as usable material, and has come in applications such as e.g. coating roads.

The crude gas is purified, thereby to produce the pure synthesis gas (syngas) composed almost solely of H_2, CO, CO_2. The pure gas is led to the burner and electricity and heat is produced. The conditions (high temperatures in a reducing environment) prevent the formation of dioxins and furans.

Generally the unit is smaller, since it uses about 8 times less air than that of incineration, and arises 4 times smaller quantity of gases for cleaning, and thus much smaller amount of gaseous emissions to the environment. On this basis, the unit is very small volume and small size.

The amount of energy produced depends greatly on the composition of MSW as moisture content, presence of paper and plastics, etc. For a typical composition of MSW, the energy produced is estimated to be at the level of 2-3 MW for a 200 tn/d unit capacity.
One drawback of the method is that it has been implemented to date mainly in special waste (radioactive waste, solid waste of combustion units, etc.), but its application in MSW (which have extremely heterogeneous composition) is very limited and there are very few data from the operation.

o Indicative mass balance diagram

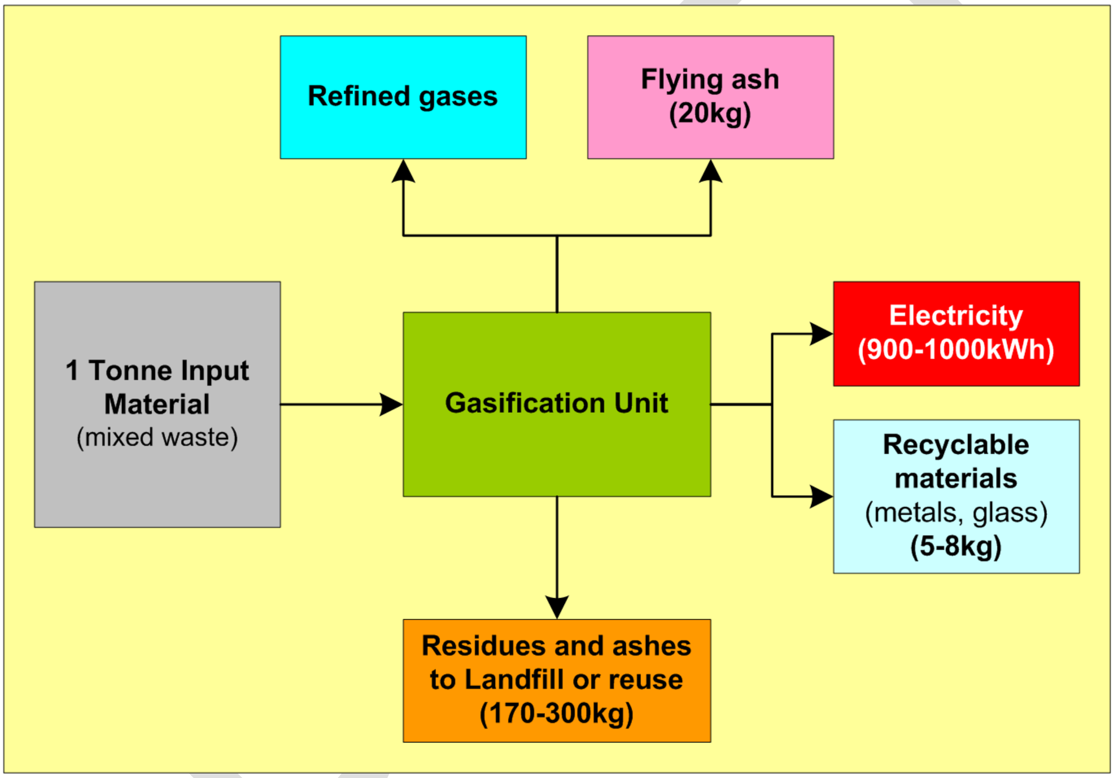


Figure 31: Indicative mass-balance of a gasification unit

o Emissions (contribution to the greenhouse effect, toxic air emissions)

Gas emissions in the process of gasification are very different from those occurring in incineration. The base gas generated in the processes of pyrolysis and gasification is rich in hydrogen, carbon monoxide and carbon dioxide, hydrocarbons, etc. (depending on the initial composition of the waste), and is further used as fuel. Pyrolysis and gasification produce lower amounts of flue gas due to the use of zero or at least minute amounts of air oxygen.

Also, important is the fact that in these processes a large number of pollutants (e.g., sulfur, heavy metals, etc.) remain in the ash produced without being transferred to the gas phase and burdens the quality of the atmosphere. This fact, coupled with the fact that the produced gas is further used as fuel, often restricts the number and type of required antipollution technologies.

Regardless of the amounts emitted, many of the gaseous components of waste gases resulting from the various thermal treatment methods are common and include dioxins, heavy metals, nitrogen oxides, etc. In any case, the permissible values of emissions generated during gasification are identical to all the thermal treatment technologies and apply the aforementioned in combustion – incineration method. Gaseous emissions which require special treatment include suspended particulates, acidic chemical compounds and nitrogen oxides. The measures to tackle emission are similar to them mentioned for incineration.

o Existing international experience of adopted practices/techniques

Gasification and Pyrolysis technologies are promoted as environmentally friendlier than combustion. Through gasification the energy content of waste is converted to synthetic gas (syngas) which can be used in the chemical industry or for energy production. Pyrolysis produces biofuel and syngas (syngas) from waste. Although the technologies of pyrolysis and gasification have been widely used in the petrochemical industry, their use in the treatment of MSW is limited. About 80 units of gasification, pyrolysis or combination of two technologies are reported, which have been developed for the management of MSW and RDF. The development stage of these units varies from pilot to commercial scale, with the majority being in the pilot phase.

The main negative factor for the adoption of these technologies for processing waste is the limited experience and a low degree of flexibility compared to the technology of combustion.

The following tables present existing gasification plants in Europe (Juniper 2001).

Table 15: Key technologies and suppliers of gasification and pyrolysis processes in Europe

Supplier / Trade name of Process / Country	Type of process	Main product	Commercialitystage
Compact Power / UK	Pyrolysis+Gasification+ Combustion	waste gases	Testing
Ebara / TwinRek / Japan	Gasification + Combustion + Melting	waste gases	Commercial
Enerkem/Biosyn/Canada	Gasification	Syngas	Semi-commercial
Foster Wheeler / Finland	Gasification	Syngas	Commercial
Graveson / GEM / UK	Gasification	Syngas	Pilot
JND / UK	Gasification	Syngas	Underdesigning
Lurgi / BLG / Germany	Gasification (slagging)	Syngas	Testing
Organic Power / Norway	Gasification + Combustion	waste gases	Semi-commercial
PKA / Germany	Pyrolysis + Gasification + Melting (optionally)	Syngas	Commercial

Supplier / Trade name of Process / Country	Type of process	Main product	Commercialitystage
RGR / Ambiente / Italy	Gasification + Melting	Syngas	Pilot
Serpac/Puroflam/Belgium	Pyrolysis+Gasification+ Combustion	waste gases	Testing
Texaco	Gasification (slagging)	Syngas	Commercial (refinedwaste) Testing (mixed plastic waste)
Thermoselect/Switzerland	Pyrolysis+Gasification (slagging)	Syngas	Semi-commercial
Thide/Eddith/France	Thermalgasification+Combustion	waste gases	Testing
TPS/Sweden	Gasification	Syngas	Semi-commercial
WasteGen/Pyropleq	Gasification	Syngas	Commercial

Table 16: Gasification units treating RDF in Europe

Supplier / Trade name of Process / Country	Type of process	Main product
Lanti/Finland	Foster Wheeler	50 Mw unit operating since 1998 for syn-gasification of **RDF and industrial waste**
Varkaus/Finland	Foster Wheeler	40 Mw unit designed for gasification of **carton** and recovery of aluminum
SVZ Schwarze Pumpe/Germany	Lurgi	Large-scale 'fixed bed'unit for **syn-gasification** of various types of waste with carbon for the production ofelectricity(50 Mw) and methanol (120,000 tn/y). Processing ofpelletizedRDF from MBTs of Dresden
Aalen/Germany	PKA	Operating since 1999 converting 25,000 tn/y of **mixed waste** into electricity withgascombustionengines
Rotterdam, Holland	Texaco	The PAX is designedfor gasification of 40,000 tn/y of **mixed plastic waste** and production of syngas to be used in a neighboringchemicalplant. According to Texaco, the delayof the projectis due economic reasonsandmarket conditions.
Greve-in Chianti	TPS	Operating since 1992 for gasification of **RDF**. Thesyngasproducedis soldto thecement industryorburntin situ togenerate steam

o Advantages and disadvantages

Table 17: Pros and Cons of plasma gasification technology for SW

• Increased recycling potential • High potential of energy recovery • Reduced waste stream volume sent to landfill • Production of valuable by-products (oils, solid char, stable granulate, H2) • High energy recovery efficiency • More flexibility of scale	• Not widely proven technology • Possible risks of failures • High requirement for pretreatment of the MSW input, leading to extra costs • High maintenance requirements and cost • High tar content of pyrolysis gases that may cause failures • Significant potential of lower calorific value and quantity of produced gases than designed • Requirements for post-management of hazardous by-products (landfilling, trans-boundary transport, etc.)

1.2.4.3 Pyrolysis

o Process description

Pyrolysis is defined as the thermal decomposition of a material in absence of oxidising agent (e.g. air or oxygen). In practice, the total elimination of the oxygen is difficult, so it always prevailing partial oxidation conditions. The difference between pyrolysis and gasification is that -in the first- the gas is produced by thermal treatment of waste, in absence of air.

Usually pyrolysis process takes at temperatures of 400-800 0C and its action breaks down the complex molecules into simpler. This process results in the production of gas, liquid and tar generation. These products may have multiple uses, the nature of which depends on the nature of the initial fuel. However, for fuels based on urban waste the most frequent use of gas is as fuel for power generation.

The relative proportions of the produced gas-liquid-solid, depend on the the temperature at which the material is subjected, the time exposed to this temperature and the nature of the material itself. Continuous exposure to low temperatures maximizes the production of tar.

A pyrolysis plant consists of:

- The reception and pre-treatment space (shredding, sieving)
- The pyrolytic reactor
- The energy utilization of gas
- The anti-pollution system

In the case of municipal solid waste the material is milled and the inorganic is separated by sieving, while the 200 mm fraction is led to the pyrolysis.

Regarding the pyrolytic reactor there are various types as shown in the following table.

Table 18: Types of pyrolytic reactor

Rotaryfurnace.	Operatesat temperatures300-850°C. It can processwastesized upto200 mm. The furnaceis heatedexternally andthewaste is fedon one sideof the furnacewhich rotatesgeneratingoscillation. In this manner is achieved the constant touch of the wastewith theheated surfaceand the gasesin the furnace.
HeatedTube	The tubesare heatedexternally andtemperatures of800^{O}C are grown. The wastepass throughthetubeat a specific speed.

contact surface	It can managesmall-grainedwaste.The processoperatesat high temperatureand the smallsizeof thewasteensures highyield.

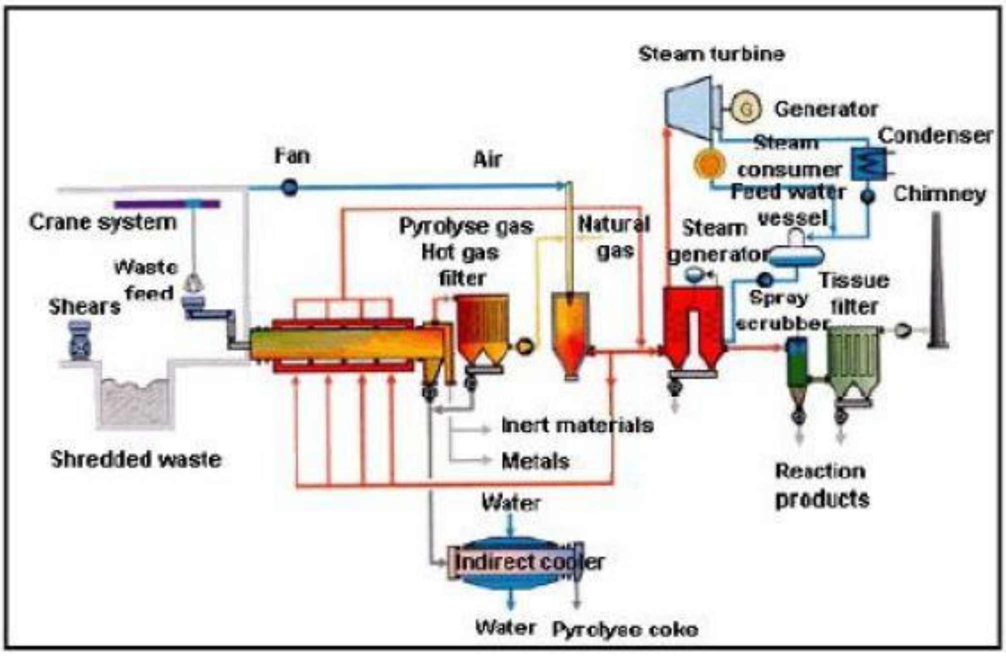


Figure 32: Indicative pyrolysis flowchart

o Indicative mass balance diagram

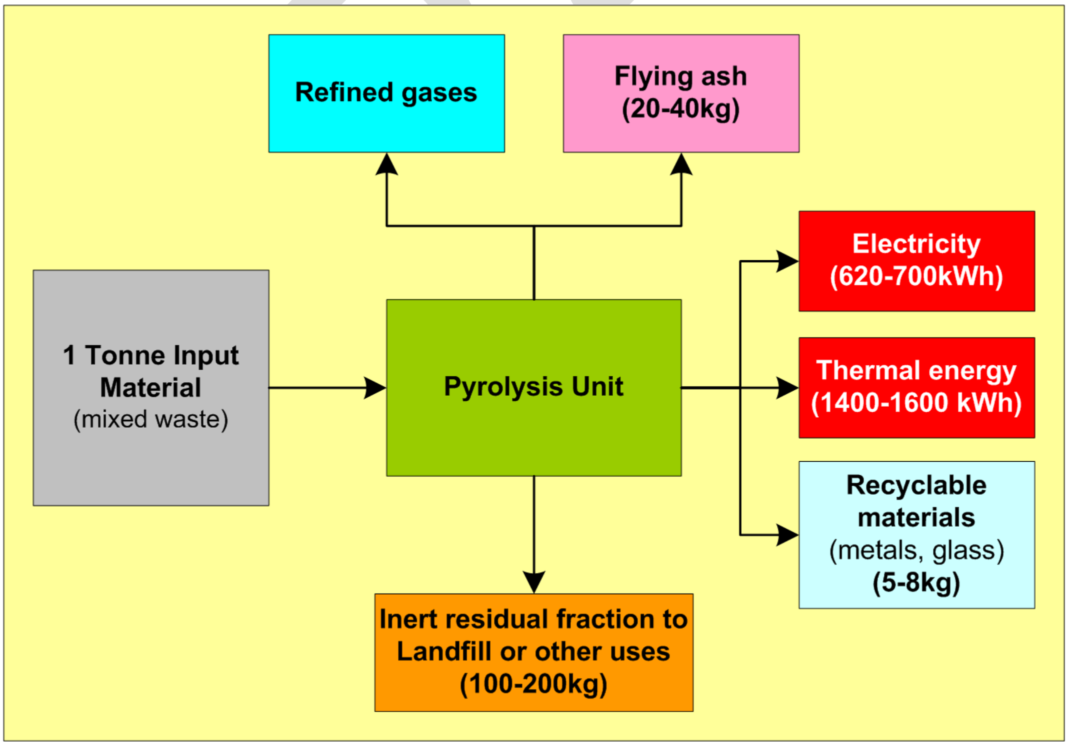


Figure 33: Indicative mass-balance of a pyrolysis unit

o Operational requirements & complexity

The operation of such a plant is complex, it requires 24-hours employment and specialised staff. Emphasis should be given to the effectiveness of the gas treatment system. It should be noted that Pyrolysis is currently not a widely commercial application and not all the available systems are suitable for processing unsorted MSW.

o Ability to co-manage other waste streams

Pyrolysis can also process a wide variety of waste however many pyrolysis technologies are designed for a specific type of waste and should be considered separately, their suitability for other types of waste.

o Flexibility for upgrade

In all thermal treatment units, the quantity of incoming material should be kept constant, so that the combustion is performed with high yield. Reducing input quantity has a direct impact on the production of electricity and hence the viability of the plant.

o emissions (contribution to the greenhouse effect, toxic air emissions)

The coefficients used to quantify greenhouse gas emissions from the application of the method are the same as those used in combustion (Due to incineration generated gaseous pollutants include abundance of inorganic and organic compounds - is required high-tech solution for obviating problems).

o recovery of materials and products

in all thermal treatment plants recycling takes zero although there is practically metal recovery system, but which cannot be estimated.

o residues to landfilling

The pyrolysis achieves greatly diversion as the total organic incinerated.

o Existing international experience of adopted practices/techniques

Regarding pyrolysis many of the units in operation are pilots and in recent years significant problems have been reported in some units that raise questions about reliability of the technology concerning the treatment of mixed municipal waste due to their heterogeneous composition.

Figure 34: Pyrolysis unit in the UK

o Advantages and disadvantages

Table 19: Pros and Cons of Pyrolysis

• Increased recycling potential • High potential of energy recovery • Reduced waste stream volume sent to landfill • Production of valuable by-products (oils, solid char, stable granulate, H2) • Flexibility of scale	• Not widely proven technology • Possible risks of failures • High requirement for pretreatment of the MSW input, leading to extra costs • High maintenance requirements and cost • Low quality carbon black production • High tar content of pyrolysis gases that may cause failures • Requirement for post-management of hazardous by-products (landfilling, trans-boundary transport, etc.)

1.2.5 Disposal

1.2.5.1 Landfilling

o Process description

The most common method of disposal of MSW at European level is the controlled disposal or landfill. This method is not and should not be taken as an alternative among other processing technologies (thermal / biological / mechanical, etc.) but a complement, since any other technology if implemented, there are residues that must be disposed of safely.

By nature landfills solution is contrary to the axiom of preserving land for future generations while are sensitive to factors that lead to pollution wider areas (spontaneous combustion cases, life of waterproofing membranes just 15-20 years, probably earthquake effects in waterproofing, etc.). The pollution potential almost eliminated by using a dual composite waterproofing and careful design of the landfill while its conversion into a sanitary landfill of residues is in addition ensure.

Disadvantages of landfilling include the following:

- Requires large land;
- Spatial difficulty in the immediate vicinity of residential areas;
- Not conducive to the recovery of materials for recycling;
- Causes air pollution and odors due to the non-collected biogas (35%) and favors the growth of pathogens;
- slight decrease in the volume of MSW is achieved (by compaction and degradation);
- Required remediation of the site in the end of life-cycle as well as subsequent aftercare;
- Requires continuously new areas and induces social reactions;
- The land value of adjacent areas usually affected negatively;
- Involves landslides risks where is not working properly;
- It involves poisoning risks of toxic gases (eg, hydrogen sulfide, methane, carbon monoxide) for workers and technical staff visiting deep wells and underground structures;
- It is the most obsolete technological method and the design of MSW management in advanced countries provides that in the near future the residue to landfill will be minimal to zero.

o Recovered products

No benefit resulting from landfill since neither materials nor energy recovered while high-calorific waste are buried.

o emissions (contribution to the greenhouse effect, toxic air emissions)

Environmental burden of the landfill are in principle the leachate generated at the beginning of deposition and during landfill life-cycle and include soluble substances found in municipal waste. The organic soluble substances are the main burden of leachate in landfills.

Biogas (mixture of organic and inorganic gases) is a key environmental outflow of waste management systems which include stages of uncontrolled anaerobic fermentation (digestion) of organic substances. Its release is of high potential to adverse impacts (air pollution, odors, explosion risk, contributing to the greenhouse effect). Landfill and generally anaerobic reactors constitute one of the major sources of production of methane (CH_4). The uncontrolled production of biogas can be a danger of explosion and fire, while methane contributes significantly to the greenhouse effect and has good calorific value (lower = 5,000 kcal / m3, upper = 9,350 kcal / m3). Removal of biogas prevents the risk of explosion.

For the collection of biogas from landfills is required an extensive collection network that is tailored to the development and operational phases. The system may be based on a horizontal or vertical elements (wells) as well as on combination.

Electricity generation from biogas recovered in landfills is achieved by generators with the help of specially modified internal combustion engines. For electricity generation a dehydrated gas supply is required, with sufficient pressure (at least 50mbar). Prior to the combustion gas cleaning by undesirable compounds is required. At a minimum is required:

- Removing water vapor to protect the equipment against corrosion and improve the calorific value of biogas.
- Removal of hydrogen sulfide (H_2S), produced by the anaerobic decomposition of sulfur compounds.

The upgrading of biogas to natural gas quality for smoothing its integration in the distribution system requires the removal of CO_2. This removal is intended primarily to improve the quality of gas and increase its calorific value so as not to affect devices configured for natural gas combustion.

1.3 Specific Descriptionof schemes selectedfor evaluation

In this section each of the19 schemes under examined in the context of the present rapid assessment is presented in particular.

1.3.1 Scheme No. 1 - Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L

The components of this scheme are the following:

- Incineration unit for mixed SW;
- Sanitary landfill for non-hazardous residues of the incineration unit; and
- Hazardous waste landfill for hazardous residues of the incineration unit.

The mixed waste is being fed into the incineration unit, where it is combusted for energy recovery and mass-reduction. Hazardous gas emissions are being held by appropriate air pollution control systems, whereas the occurring flying ash needs to be stabilized and disposed of in a hazardous waste landfill. Bottom slags from the furnace can be reused for ferrous metals recovery, as cement additive or for construction purposes (construction walls, roads, dikes, etc.) otherwise they need to be disposed of in a sanitary landfill for non-hazardous waste. Ashes and other residues (gypsum, salts, etc.) are also disposed of in a sanitary landfill for non-hazardous waste.

The indicative mass-balance diagram of the scheme is given below.

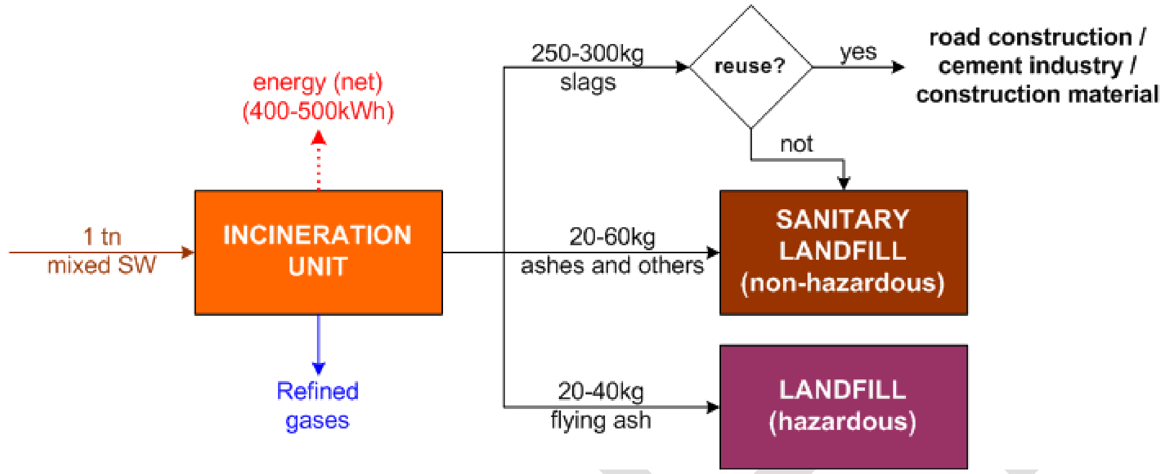


Figure 30: Indicative mass-balance diagram of scheme No. 1

According to the above mass-balance, the total mass reduction of SW ending to landfills lies around 60-96% depending on the availability of end-users for the reuse of slags. In case of slag reuse, the mass reduction may vary between 90-96%.

The net energy generation is estimated at around 400-500kWh/tn of incinerated SW.

1.3.2 Scheme No. 2 - Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L

The components of this scheme are the following:

- Pyrolysis unit for mixed SW;
- Sanitary landfill for non-hazardous residues of the Pyrolysis unit; and
- Hazardous waste landfill for hazardous residues of the Pyrolysis unit.

The mixed waste is being fed into the pyrolysis unit, where it is pyrolyzed for energy recovery. In the pyrolysis unit, metals and glass are separated (for recycling), whereas significant mass-reduction takes place. Hazardous gas emissions are being held by appropriate air pollution control systems, whereas the occurring flying ash needs to be stabilized and disposed of in a hazardous waste landfill. The residual fraction is inert and can be reused as inert material in construction works or disposed of in a non-hazardous waste sanitary landfill.

The indicative mass-balance diagram of the scheme is given below.

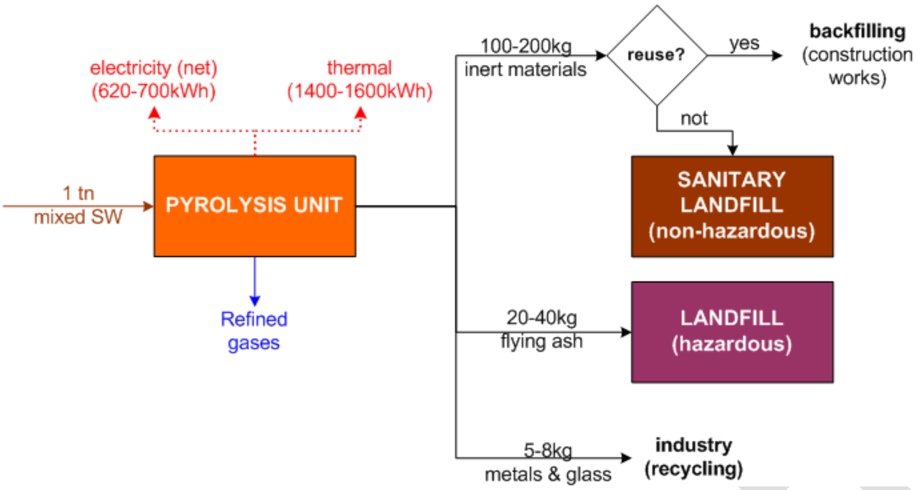


Figure 31: Indicative mass-balance diagram of scheme No. 2

According to the above mass-balance, the total mass reduction of SW ending to landfills may reach 100% in case that the inert material is reused. If not, the mass reduction rate may decrease to 80-90%. Of this, a 5-8% fraction consists of metals and glass that can be recycled.

The net electrical energy generation is estimated at around 620-700kWh/tn of incoming SW, whereas there is significant potential for thermal energy that could be directly exploited in relevant systems, varying between 1,400-1,600kWh/tn of incoming SW.

1.3.3 Scheme No. 3 - Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.

The components of this scheme are the following:

- Gasification unit for mixed SW;
- Sanitary landfill for non-hazardous residues of the Gasification unit; and
- Hazardous waste landfill for hazardous residues of the Gasification unit.

The mixed waste is being fed into the gasification unit, where it is gasified for energy recovery and mass-reduction. Metals and glass are also separated in the gasification unit and sent for recycling. Hazardous gas emissions are being held by appropriate air pollution control systems, whereas the occurring flying ash needs to be stabilized and disposed of in a hazardous waste landfill. The residual fraction, which contains bottom ash, is inert and can be reused for backfilling, in road construction or disposed of in a non-hazardous waste sanitary landfill.

The indicative mass-balance diagram of the scheme is given below.

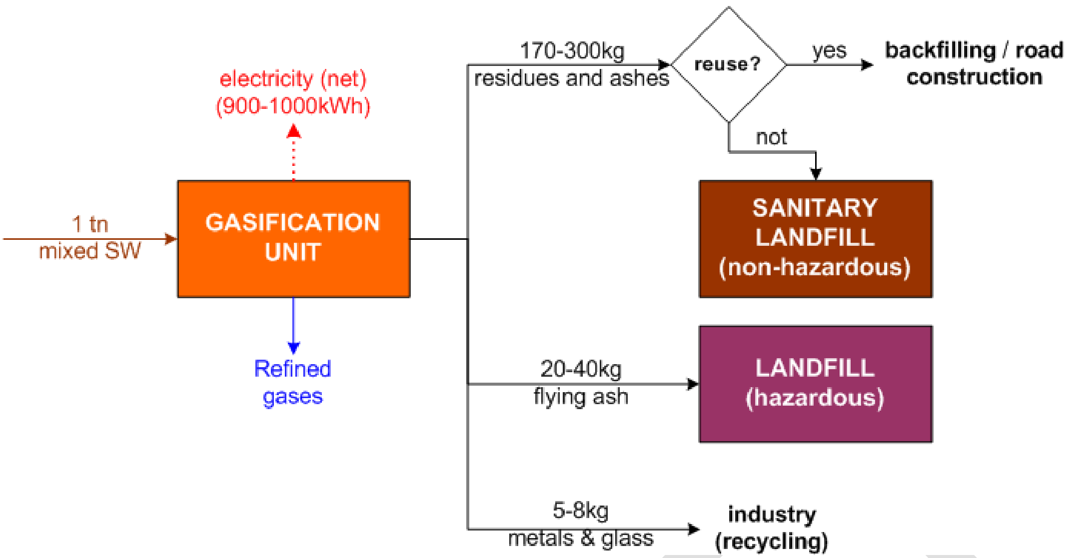


Figure 32: Indicative mass-balance diagram of scheme No. 3

According to the above mass-balance, the total mass reduction of SW ending to landfills may also reach 100% in case that the residual fraction is fully reused. If not, the mass reduction rate may decrease to 70-83%. Of this, a 5-8% fraction consists of metals and glass that can be recycled.

The net electrical energy generation is estimated at around 900-1000kWh/tn of incoming SW.

1.3.4 Scheme No. 4 (8.c1). Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L

1.3.5 Scheme No. 5 (8.c2). Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

The components of these schemes are the following:

- MBT for mixed waste, consisting of:
  - (a) “Dirty” MRF for RDF production and separation of biowaste; and
  - (b) Composting units for treatment of biowaste.
- Incineration units for the produced RDF;
- Sanitary landfill for the non-hazardous residues; and
- Hazardous waste landfill for hazardous residues of the incineration unit.

Mixed SW is being fed into “dirty” MRF. In this MRF, biowaste, metals and glass are separately sorted out and sent to the industry, whereas papers, plastics and other combustible materials (clothes, etc.) are used to produce RDF. The residual (non-recyclable) materials are sent to sanitary landfill for non-hazardous waste.

Sorted biowaste is being fed into composting unit, where it is refined and composted. The CLO can be used as a soil improver or dumpsite cover depending on its quality, whereas the residues (non-biowaste materials) of the process are sent to sanitary landfill for non-hazardous waste.

The generated RDF is combusted in an in-situ incineration unit for energy recovery. The produced flying ash is stabilized and disposed of in hazardous waste landfill. The bottom slags are disposed of in sanitary landfill for non-hazardous waste or reused as cement additive or for construction material in case of existence of the relevant market. Ashes and other residues (gypsum, salts, etc.) are also disposed of in non-hazardous waste sanitary landfil.

The indicative mass-balance diagram of the scheme is given below.

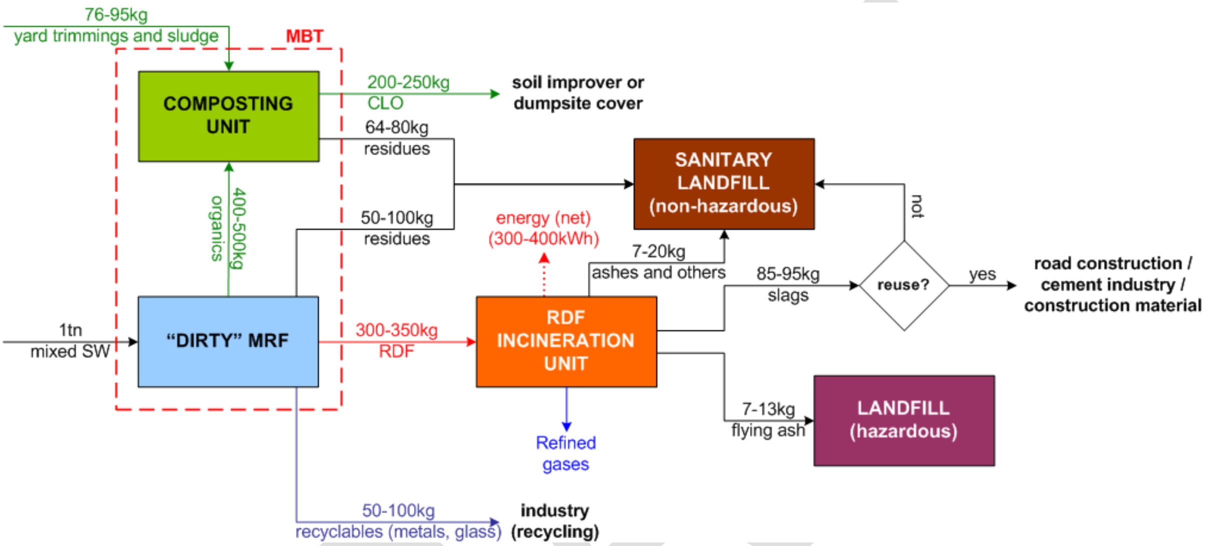


Figure 33: Indicative mass-balance diagram of scheme No. 8.c

The diversion rates of SW from landfill range between 69-87%. The final products are:

- CLO (200-250kg/tn of SW);
- recyclable materials (50-100kg/tn of SW), especially:
  - metals: ferrous, aluminum, others; and
  - glass: white glass, colored glass, etc.
- RDF (300-350kg/tn of SW able to produce 300-400kWh in an incineration unit).

1.3.6 Scheme No. 6 (8.d1). Aerobic MBT.RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.

1.3.7 Scheme No. 7 (8.d2). Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.

These schemes differ from the previous since the RDF is disposed to the industry as an alternative fuel source and is not incinerated *in-situ*.

The indicative mass-balance diagram of the scheme is given below.

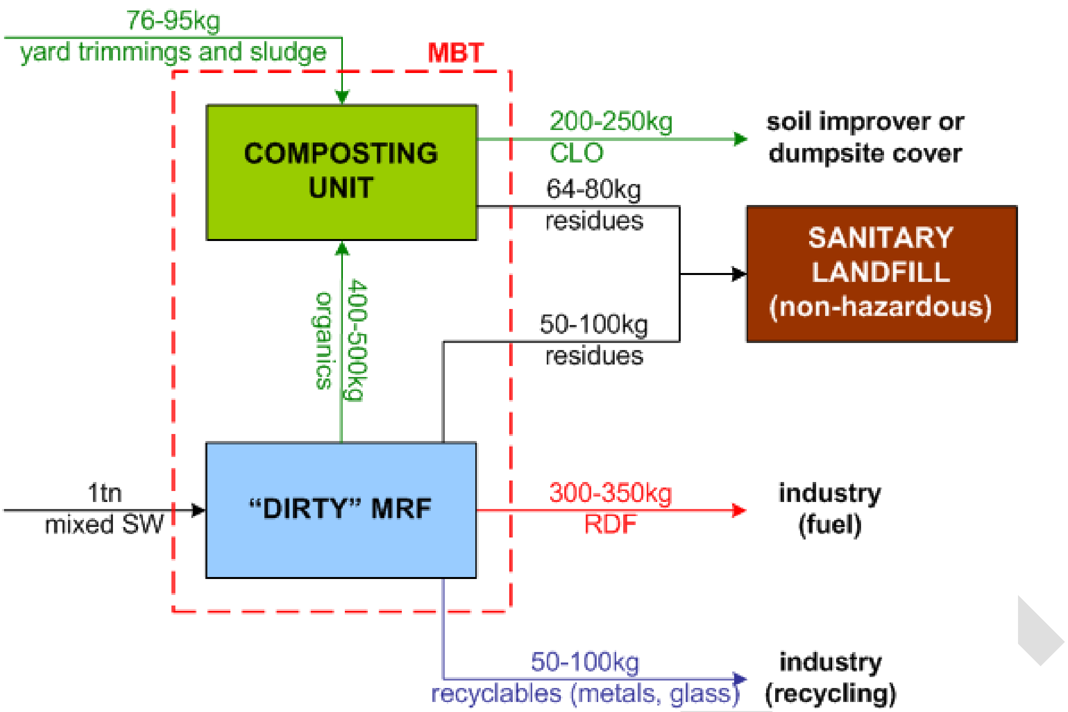


Figure 34: Indicative mass-balance diagram of scheme No. 8.d

The diversion rates of SW from landfills range between 82-89%. The final products are:

- CLO (200-250kg/tn of SW);
- recyclable materials (50-100kg/tn of SW), especially:
  - metals: ferrous, aluminum, others; and
  - glass: white glass, colored glass, etc.
- RDF (300-350kg/tn of SW).

1.3.8 Scheme No. 8 (9.c) - Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

This scheme differs from No. 8.c since the biowaste is being treated in anaerobic digestion units as a component of the MBT, and not in composting unit.

The indicative mass-balance diagram of the scheme is given below.

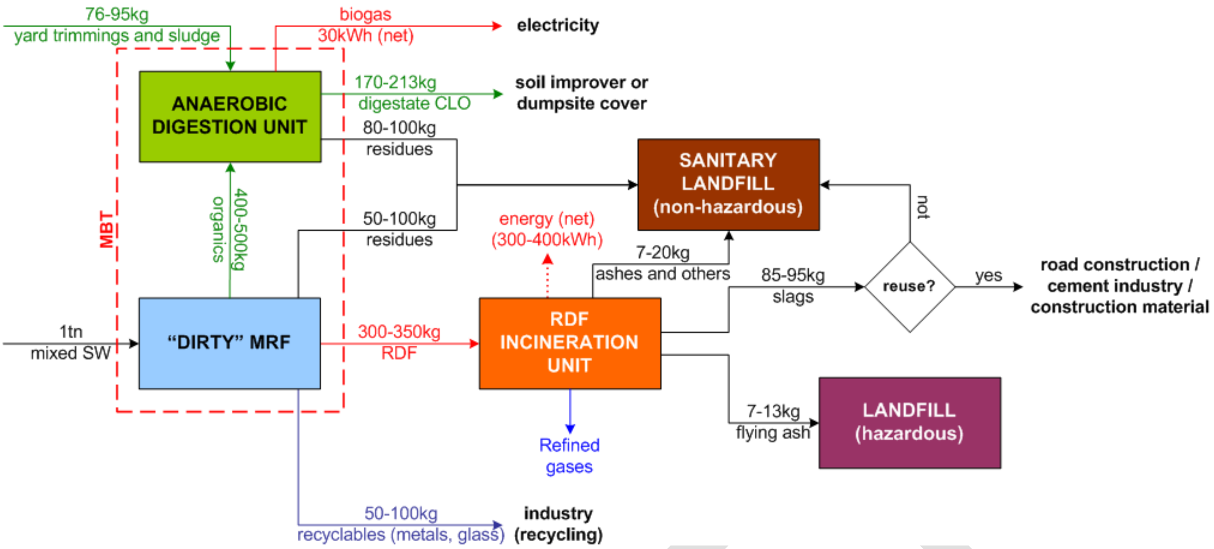


Figure 35: Indicative mass-balance diagram of scheme No. 9.c

The diversion rates of SW from landfills range between 67-85%. The final products are:

- digestate CLO (170-213kg/tn of SW);
- recyclable materials (50-100kg/tn of SW), especially:
  - metals: ferrous, aluminum, others; and
  - glass: white glass, colored glass, etc.
- RDF (300-350kg/tn of SW able to produce 300-400kWh in an incineration unit); and
- Biogas from the anaerobic digestion unit, able to produce ~30kWh/tn of SW entering the system.

1.3.9 Scheme No. 9 (9.d) - Anaerobic MBT. RDF-disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

This scheme differs from the previous one since the RDF is disposed to the industry as an alternative fuel source. Through this path, the industry undertakes the responsibility of incinerating the RDF and handling the by-products of the process.

The indicative mass-balance diagram of the scheme is given below.

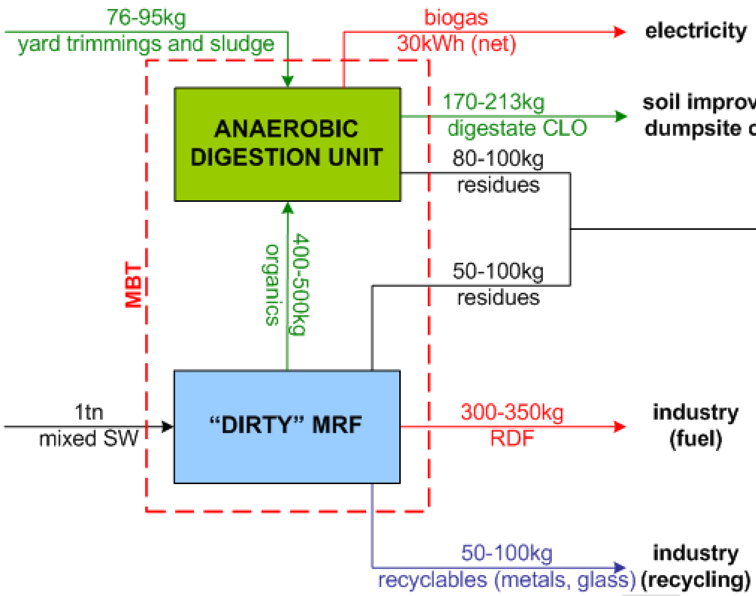


Figure 36: Indicative mass-balance diagram of scheme No. 9.d

The diversion rates of SW from landfills range between 80-87%. The final products are:

- digestate CLO (170-213kg/tn of SW);
- recyclable materials (50-100kg/tn of SW), especially:
    - metals: ferrous, aluminum, others; and
    - glass: white glass, colored glass, etc.
- RDF (300-350kg/tn of SW able to produce 300-400kWh in an incineration unit); and
- Biogas from the anaerobic digestion unit, able to produce ~30kWh/tn of SW entering the system.

1.3.10 Scheme No. 10 (8.f) - Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.

The indicative mass-balance diagram of the scheme is given below.

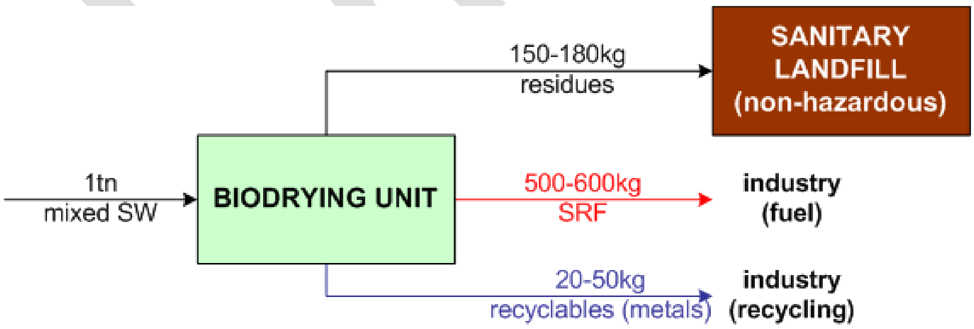


Figure 37: Indicative mass-balance diagram of scheme No. 8.f.

The diversion rates of SW from landfills range between 82-85%. The final products are:

- metals (20-50kg/tn of SW); and
- SRF (500-600kg/tn of SW able to produce 350-450kWh in an incineration unit).

1.3.11 Scheme No. 11 (8.e) - Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

The components of this scheme are the following:

- Biodrying unit for mixed waste;
- Incineration unit for the produced SRF;
- Sanitary landfill for the non-hazardous residues of all units; and
- Hazardous waste landfill for hazardous residues of the incineration units.

Mixed SW is being fed into biodrying unit. In this unit, metals are separately sorted out and sent to the industry. The rest materials are bio-stabilized and refined for subtraction of the inert content (glass, stones, etc.). This inert content (residues) is sent to sanitary landfill for non-hazardous waste, whereas the final bio-stabilized material, which consists of organics, paper, plastics and other combustible materials (clothes, etc.), forms the SRF.

The generated SRF is combusted in-situ in incineration unit for energy recovery. The produced flying ash is stabilized and disposed of in hazardous waste landfills. The bottom slags are disposed of in sanitary landfill for non-hazardous waste or reused as cement additive or construction material in case of existence of the relevant market. Ashes and other residues (gypsum, salts, etc.) are also disposed of in non-hazardous waste sanitary landfill.

The indicative mass-balance diagram of the scheme is given below.

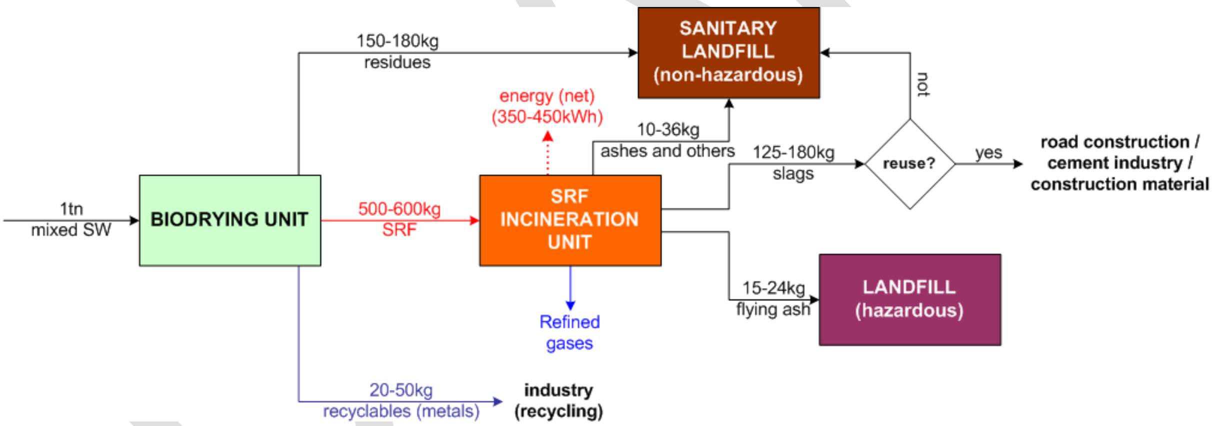


Figure 38: Indicative mass-balance diagram of scheme No. 8.e

The diversion rates of SW from landfills range between 58-82%. The final products are:

- metals (20-50kg/tn of SW); and
- SRF (500-600kg/tn of SW able to produce 350-450kWh in an incineration unit).

1.3.12 Scheme No. 13 (4) Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.

The components of this scheme are the following:

- Composting unit for pre-segregated biowaste;
- “Clean” MRF for pre-segregated recyclables; and

- Sanitary landfill for other waste and non-hazardous residues from both types of units.

Biowaste and recyclables are being collected through separate sorting-at-source collection systems. Pre-segregated biowaste is fed into composting units, whereas pre-segregated recyclables (commingled or separated) into “clean” MRFs.

In the composting units, biowaste is refined through appropriate screening and residual (non-biowaste) materials are sent to sanitary landfills, whereas the rest of biowaste is composted. Potential addition of yard trimmings and sludge from Wastewater Treatment Plants (WWTPs) during composting could be beneficial for the biological stabilization process. During stabilization, the mass of biowaste (including the yard trimmings and sludge) decreases at 50-60% rates and at the end of the cycle compost is being produced. Given that the compost is produced from pre-segregated biowaste, it is of greatest quality and can be used as a fertilizer in agriculture (not if sludge from WWTPs has been used).

In the “clean” MRFs, pre-segregated recyclables (paper/cardboard, plastics, metals and glass) are being refined and separated per specific material sub-type (indicatively: printed paper, other paper, white cardboard, brown cardboard, PET, HDPE, PP, film, ferrous metals, aluminum, other metals, white glass, colored glass, etc.). The residual (non-recyclable) materials are sent to sanitary landfill.

All non-biowaste and non-recyclable materials, including the residues of the composting units and “clean” MRFs, are disposed of in non-hazardous waste sanitary landfill; however there are several types of “other” materials that could be reused and diverted from landfills, such as inert material, furniture, wood, leather, cloth, etc.

The indicative mass-balance diagram of the scheme is given below.

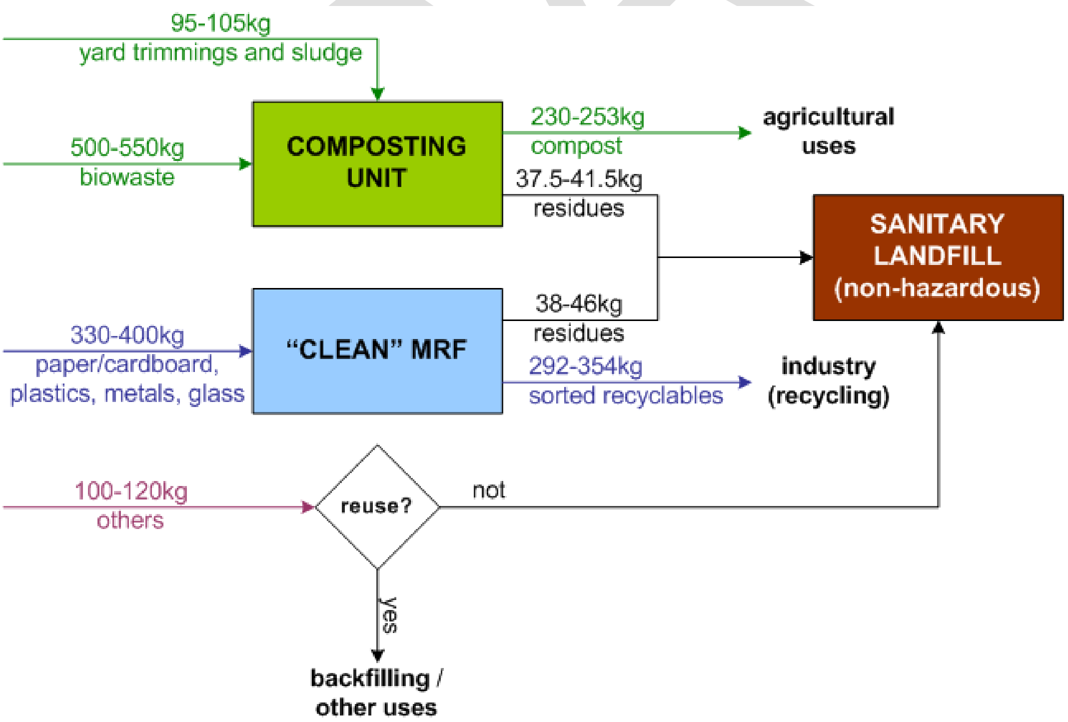


Figure 39: Indicative mass-balance diagram of scheme No. 4

According to the above mass-balance, the diversion rate of SW from landfills may vary between 79-82%. The final products are:

- compost (230-253kg/tn of SW);
- several types of recyclable materials (292-354kg/tn of SW), indicatively:
  - paper and cardboard: printed paper, other paper, white cardboard, brown cardboard, etc.;
  - plastics: PET, HDPE, PP, film, etc.;
  - metals: ferrous, aluminum, others; and
  - glass: white glass, colored glass, etc.

1.3.13 Scheme No. 14 (8.a). Mechanical – Aerobic Composting facility. RDF and in-situ incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

The components of this scheme are the following:

- Composting unit for pre-segregated biowaste;
- “Dirty” MRF for RDF production from the remaining mixed waste;
- Incineration unit for the produced RDF;
- Sanitary landfill for the non-hazardous residues of all units; and
- Hazardous waste landfill for hazardous residues of the incineration unit.

Biowaste is being collected through separate sorting-at-source collection systems and fed into composting unit. In the composting unit, biowaste is handled in the same way as previously (see Section 1.3.12). The residues (non-biowaste materials) of the process are sent to sanitary landfill for non-hazardous waste, whereas the compost is of greatest quality and can be used as a fertilizer in agriculture.

Non-biowaste waste are being collected separately from biowaste and fed into “dirty” MRFs. In these MRFs, metals and glass are separately sorted out, whereas papers, plastics and other combustible materials (clothes, etc.) are used to produce RDF. The residual (non-recyclable) materials are sent to sanitary landfill for non-hazardous waste.

The generated RDF is combusted in-situ in incineration units for energy recovery. The produced flying ash needs to be stabilized and disposed of in a hazardous waste landfill, whereas the bottom slags from the furnace can be reused for ferrous metals recovery, as cement additive or for construction purposes (construction walls, roads, dikes, etc.) otherwise they need to be disposed of in a sanitary landfill for non-hazardous waste. Ashes and other residues (gypsum, salts, etc.) are also disposed of in non-hazardous waste sanitary landfills.

The indicative mass-balance diagram of the scheme is given below.

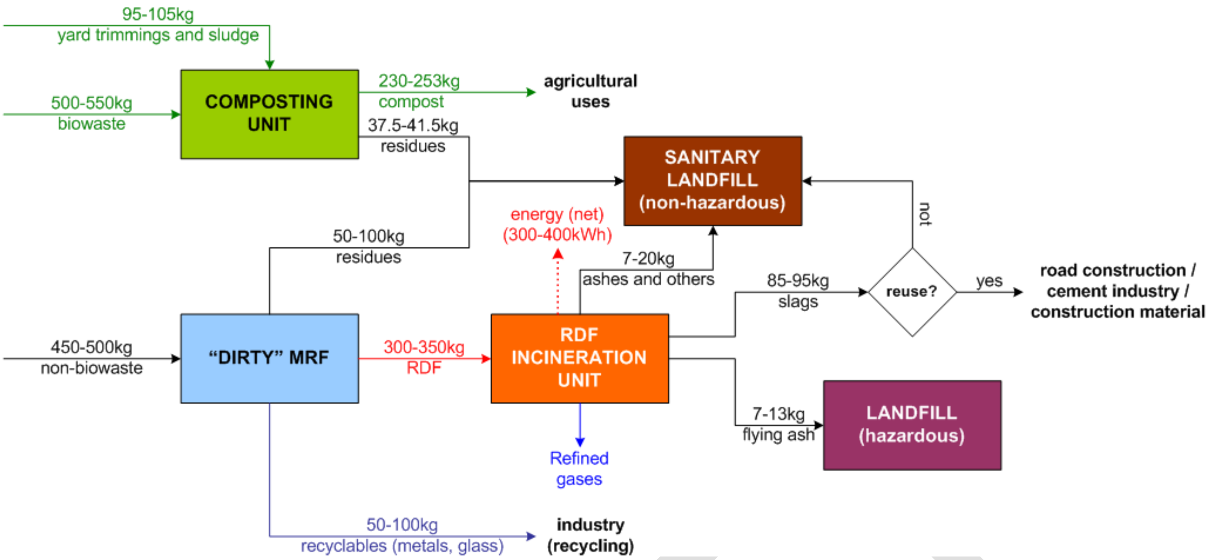


Figure 40: Indicative mass-balance diagram of scheme No. 8.a

According to the above mass-balance, the diversion rates of SW from landfills may vary between 73-81%. The final products are:

- compost (230-253kg/tn of SW);
- recyclable materials (50-100kg/tn of SW), especially:
  - metals: ferrous, aluminum, others; and
  - glass: white glass, colored glass, etc.
- RDF (300-350kg/tn of SW able to produce 300-400kWh in an incineration unit).

1.3.14 Scheme No. 15 (5)Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.

The components of this scheme are the following:

- Anaerobic digestion units for pre-segregated biowaste;
- "Clean" MRFs for pre-segregated recyclables; and
- Sanitary landfills for other waste and non-hazardous residues from both types of units.

Biowaste and recyclables are being collected through separate sorting-at-source collection systems. Pre-segregated biowaste is fed into anaerobic digestion unit, whereas pre-segregated recyclables (commingled or separated) into "clean" MRF.

In the anaerobic digestion unit, biowaste is refined and residual (non-biowaste) materials are sent to sanitary landfill, whereas the rest of biowaste is fed into the anaerobic digesters. Potential addition of yard trimmings and sludge from Wastewater Treatment Plants (WWTPs) could be beneficial for the digestion process. During stabilization, the mass of biowaste (including the yard trimmings and sludge) decreases at a ~65% rate and at the end of the cycle digestate is being produced. Given that the digestate is produced from pre-segregated biowaste, it is of greatest quality and can be used as a fertilizer in agriculture (not if sludge from WWTP has been used).

The operation of the "clean" MRF is similar as in the previous scheme. The residual (non-recyclable) materials are sent to sanitary landfill.

All non-biowaste and non-recyclable materials, including the residues of the anaerobic digestion unit and "clean" MRFs, are disposed of in non-hazardous waste sanitary landfill; however there are several types of "other" materials that could be reused and diverted from landfills, such as inert material, furniture, wood, leather, cloth, etc.

The indicative mass-balance diagram of the scheme is given below.

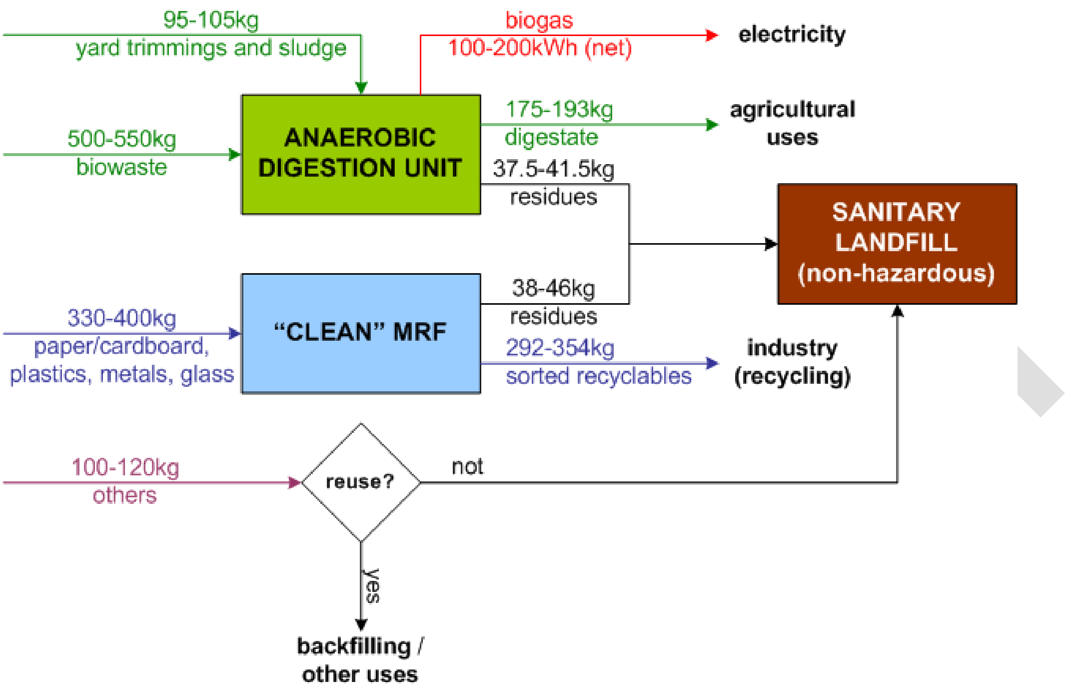


Figure 41: Indicative mass-balance diagram of scheme No. 5

According to the above mass-balance, the diversion rate of SW from landfills may vary between 79-82%. The final products are:

- digestate (175-193kg/tn of SW);
- several types of recyclable materials (292-354kg/tn of SW), indicatively:
  - paper and cardboard: printed paper, other paper, white cardboard, brown cardboard, etc.;
  - plastics: PET, HDPE, PP, film, etc.;
  - metals: ferrous, aluminum, others; and
  - glass: white glass, colored glass, etc.
- Biogas from the anaerobic digestion unit, able to produce 100-200kWh/tn of SW entering the system.

1.3.15 Scheme No. 16 (9.a) Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.

This scheme differs from No. 8.a since the pre-segregated biowaste is being treated in anaerobic digestion unit and not in composting unit.

The indicative mass-balance diagram of the scheme is given below.

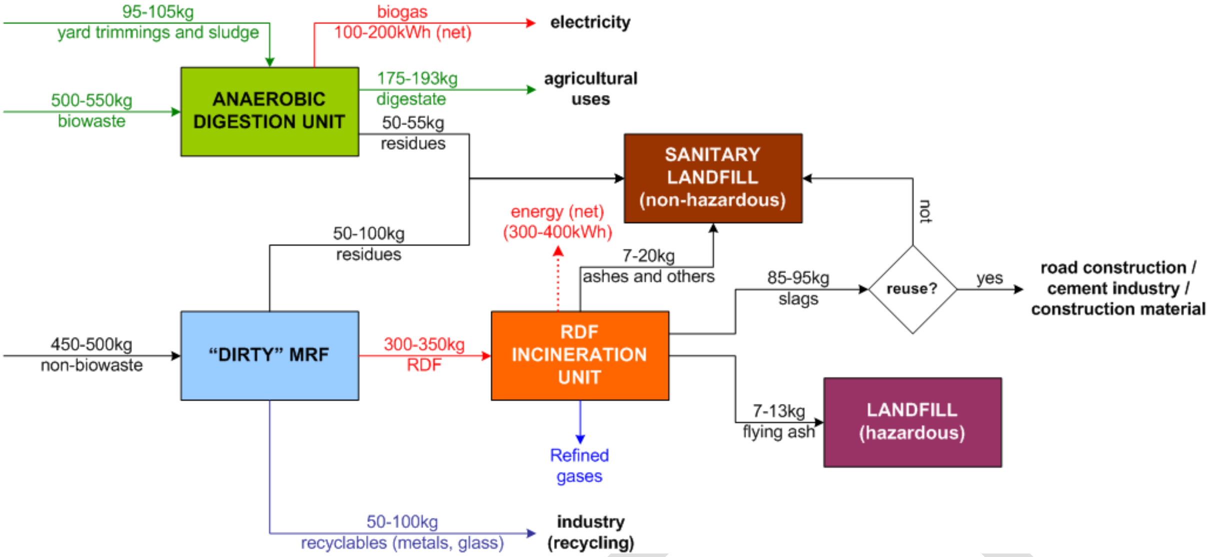


Figure 42: Indicative mass-balance diagram of scheme No. 9.a

The diversion rates of SW from landfills range between 71-88%. The final products are:

- digestate (175-193kg/tn of SW);
- recyclable materials (50-100kg/tn of SW), especially:
  - metals: ferrous, aluminum, others; and
  - glass: white glass, colored glass, etc.
- RDF (300-350kg/tn of SW able to produce 300-400kWh in an incineration unit); and
- Biogas from the anaerobic digestion unit, able to produce 100-200kWh/tn of SW entering the system.

1.3.16 Scheme No. 17. Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.

1.3.17 Scheme No. 18. Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.

1.3.18 Scheme No. 19. "Clean" MRF. Recyclables, disposal of residues in S.L.

The descriptionof theseschemeshasbeen respectively presented above.

1.4 Comparative Assessment of selected schemes

1.4.1 Method statement - Scoring system and criteria

In this sectionthe schemes presentedin the foregoinganalysis are evaluated comparatively. The evaluationis made as to criteria that are grouped in four categories:

I. Environmental
II. Financial
III. Technical and operational efficiency
IV. Social
V. Existingexperience-reliability

Each of theabove groups of criteria containsand integratesindividualsub-criteria. That is, theevaluation of each criterionarises as an evaluativesynthesisof individualsub-criteria. The individualsub-criteria used per category are given below:

I. EnvironmentalAssessment Criteria
- Preservationof abioticresources energy production
- Contributionto the greenhouse effect emissions
- Toxicityto humansand the environment
- Avoidance ofenvironmental cost due to substitutionof fossil fuels
- Recyclingandrecovery of packagingmaterials and products
- Producedresidue tolandfilling

II. Financial
- CAPEX
- OPEX
- REVENUE
- Balanced Budget Charge(CAPEX + OPEX - REVENUE)

III. Technical and operational efficiency
- Operational requirements & complexity of technology
- water consumption
- Ability to co-manage other waste streams (yard trimmings, sludge, medical, industrial, agricultural, special waste)
- Flexibility for upgrade

IV. Social
- Odors
- Aesthetic burden
- Jobs creation
- Land demand
- Social reactions / acceptance

V. Existingexperience-reliability

The evaluation as to the criteria Ικαιll and relating sub-criteria was made on monetary prices, and expressed in USD per ton of incoming waste while the evaluation as to the criteria III, IV and V and relating sub-criteria was made on the basis of rationalcorrelations.
Taking in account the different nature of elements under evaluation, normalized values were used in order to ensure uniformity in scoring. To this end all ratings given to the examined schemes as to the various sub-criteria were then normalised (converted to normalized values) according to a common scale.
To extractthe final score,eachcriterionis weighted byaweighting factoras follows:

I.	Environmental	20%
II.	Financial	15%
III.	Technical and operational efficiency	10%
IV.	Social	15%
V.	Existingexperience–reliability	40%

In the following paragraphs the evaluation as to each separate criterion and relative sub-criteria is analytically presented.

According tothe basic rationaleposed bytheintroduction of the rapid assessment, concerning the necessity for the two MSW management sub-systems(sorted-at-source waste management sub-system / mixed waste management sub-system) to be consideredseparatelyand complementarywithinan integrated system, the evaluation was conducted separately for the schemes included in sub-system (a) (**a. MIXED WASTE**

TREATMENT / DISPOSAL PLANTS) and for the schemes included in sub-system (b) (**b. PRE-SEGREGATED WASTE TREATMENT PLANTS**), andwiththisdiscretestructurepresented subsequently.

1.4.2 Environmental Assessment

The environmental assessment of the selected schemes was based on the following sub-criteria:

Criteria of Environmental Assessment	
i	Preservationof abioticresources
ii	Contributionto the greenhouse effect
iii	Toxicityto humansand the environment - Environmental cost
iv	Avoidance ofenvironmental cost due to substitutionof lignite
v	Recyclingandrecovery of packagingmaterials
vi	Producedresidue tolandfill

1.4.2.1 *Preservationof abioticresources*

Abioticresourcesare natural resources (including energy resources) such as ferricore, crude oiland other resources whichare considered 'non-living'.

The reductionof anabioticresourcedependson its ultimate reservesand the extractionrateswhichin combinationprovide an indicationof the reductionof theresource.
The term"ultimate reserves" means thequantity of resource(as achemical elementorcompound) that isfinallyavailableand is calculatedby multiplyingtheaverage naturalconcentrationof the resourcein thefirstextraction means(e.g. theearth crust) by the mass orvolumeof these means(e.g. the massof the crust)[8].

The applicationof this criterionin the evaluationof waste management is related toenergy recycling andrecovery. The resourcespreserveddue to recyclingand recoverysubstituteabioticresourceswhichotherwise would have tobe exported.The table belowgives thecomparativeassessment of the selected schemes as to the criterionof preserving of abioticresourcesby the producedenergy of eachscheme.This index was expressedto revenue fromenergy recovery,considering an indicative selling priceofelectricityat$ 0.08/kWh.

[8]Guinee J.B., Gorree M., Heijungs R., Huppes G., Kleijn R., De Koning A., Van Oers L., Wegener Sleeswijk A., Suh S., Udo de Haes H.A., De Bruijn H., Huijbregts M.A.J., Lindejer E., Roorda A.A.H., Van der Ven B.L., Weidema B.P. (2001): Handbook on Life Cycle Assessment: operational guide to the ISO standards, Kluwer Academic Publishers, Dordrecht.

Table 15: Comparativeevaluation of alternativescenarios(schemes) asthe criterionofpreservingof abioticresources

No of Alternative scheme	No of scheme in Annex	Facilitiesincluded	Power produced (kWh/tn of inc. MSW)	Revenuefromenergy recovery (USD/tn of inc. MSW)
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS				
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	450	36.00
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	650	52.00
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	950	76.00
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	238	19.04
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	238	19.04
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	0	0.00
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	0	0.00
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	366	29.28
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	72.5	5.80
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	0	0.00
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of	404	32.32

No of Alternative scheme	No of scheme in Annex	Facilitiesincluded	Power produced (kWh/tn of inc. MSW)	Revenuefromenergy recovery (USD/tn of inc. MSW)
		N/H.R. in S.L., disposal of H.R in H.W.L.		
12		Landfills with recovery and combustion of biogas -energy.	100	8.00

b. PRE-SEGREGATED WASTE TREATMENT PLANTS				
b1. Sorting-at-sourceof recyclables and biowaste				
13	4	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	**0**	**0**
14	8.a	Mechanical – Aerobic Composting facility. RDF *in-situ* energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	**238**	19.04
15	5	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	**125**	10.00
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	**388**	31.04
b2. Sorting-at-sourceof only biowaste				
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	**0**	**0**
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	**150**	**12.00**
b3. Sorting-at-source of only recyclables				
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	**0**	**0**

The above tableshows that theplasmagasificationtechnologysavesmore energy, while other technologies that do not recover energy (bio-drying with burial of stabilat, Aerobic MBT with recyclables or RDF – disposal etc.), do not make any contributionto savingof abioticresources.

1.4.2.2 *Contributionto the greenhouse effect*

Climate changeis defined as theimpact of humanemissionson the dynamicsof radiation (e.g. absorption ofthermalradiation). This canthencauseadverseeffects on the ecosystemand on human health.The enhancement ofradiativecauseswarmingon the earth'ssurface (greenhouse effect).
In addition tocarbon dioxide(CO_2),whose concentrationin the atmosphereplaysa catalytic rolefor heatabsorption andthereforeincrease in temperatureandgreat contributionto the "greenhouse effect", there are other gaseswhosemolecule hassimilarabsorptionandretentionpropertiesof infraredradiationandsignificant contributionto the phenomenon. The most importantis methane(CH_4),nitrogen compounds(N_2OandNOx),and "Freon" (Chlorinated Hydrocarbons), with much greater-asto thecarbondioxide-absorption capacityof heat.
Typicalemissionsfromwaste managementthat contributeto the greenhouse effectinclude fossilcarbon dioxidedinitrateoxideandmethane.Consequently, this indicatorincludes boththermalandbiologicalwaste treatmentprocesses.
The table belowgives thecomparativeassessment of alternative schemes as to the criterionofcontributionto the greenhouse effectbased onthe generatedequivalent CO_{2eq} in kg/tn of incoming MSW.This index is expressedbythe external(environmental) cost of emissions$CO_2$for each technologyand is considered (indicatively) to be equal to USD 35perton of CO_2.

Table 16: Contribution of examined schemesto the greenhouse effect

No of Alternative scheme	No scheme in Annex	Facilitiesincluded	CO_{2eq} (kg/tn of inc. MSW)	Environmental cost of contribution to the greenhouse effect (USD/tn of inc. MSW)
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS				
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	813	28.45
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	561	19.63
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	443	15.5
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	715	25.02
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1,065	37.27
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	525	18.38
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	931	32.58
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas - energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	691	24.18
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	501	17.53
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	1,473	51.55
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy,	866	30.31

No of Alternative scheme	No scheme in Annex	Facilitiesincluded	CO_{2eq} (kg/tn of inc. MSW)	Environmental cost of contribution to the greenhouse effect (USD/tn of inc. MSW)
		Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.		
12		Landfills with recovery and combustion of biogas -energy.	1,013	35.45
b. PRE-SEGREGATED WASTE TREATMENT PLANTS				
b1. Full sorting-at-sourceof recyclables and biowaste				
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	525	18.37
14	8.a	Mechanical – Aerobic Composting facility. RDF *in-situ* energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	715	25.02
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	501	17.53
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	691	24.18
b2. Sorting-at-sourceonly biowaste				
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	525	18.37
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	408	14.28
b3. Sorting-at-source only recyclables				
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	0	0

The above tableshows thatthe highestcontributionto the greenhouse effecthavethe Bio-drying with landfilling of SRF, Aerobic MBT within-situ incineration of RDF and landfilling of the produced biostabilised material, and Landfills. Gasification of plasma / vitrification and pyrolysis schemes have the lowestcontributionto the greenhouse effect, followed by the anaerobic schemes that produce and burn biogas.

1.4.2.3 *Toxicityto humansand the environment*

It concernsthe negativeeffectsof toxicsubstances emitted to theenvironment. Insufficiently effectivewastemanagementpractices canbe a significantthreatto humanhealth and theenvironment.Waste containstoxicsubstances whichmustbe controlledto minimizetheirdispersion in the environment. Waste containstoxicsubstances whichmustbe controlledto minimizetheirdispersion in the environment. Such substancesinclude: heavymetals(chromium, mercury and lead), nickel andcopper,bariumand antimony. Generally, thereference substancefor the quantificationindicatoris the1,4-di-chloro-benzene.

In thetable below is given the external(environmental) costs of emissionsaccording to contemporary bibliography. For the CO_2emissions a price of USD 130 /tn of CO_2 was considered as an indicativeprice of ‘pollutantsrights’ of the PowerAuthorityof the State.

Table 17: Environmental cost ofemitted pollutants

Pollutant	Cost (USD/tn)		
	Minimumprice	Maximum price	Average price
PM10	2,215.40	9,105.80	**5,660.60**
SO_2	2,175.80	8,615.20	**5,395.50**
NO_X	1,364.00	8,577.80	**4,970.90**
VOCs	832.70	1,650.00	**1,241.35**
CO_2	7.37	10.56	**8.97**
CH_4	179.63	254.43	**217.03**
N_2O	2,328.92	3,318.26	**2,823.59**
CO	2.20	9.90	**6.05**
Dioxins	2,639,688,700.00	19,393,088,000.00	**10,983,388,350.00**
Cd	22,000.00	104,500.00	**63,250**
As	178,200.00	1,284,800.00	**731,500**
Hg		0.00	**0.00**
Cr	146,300.00	1,053,800.00	**600,050**
Ni	3,300.00	22,000.00	**12,650**
Pb	5,379.00	16,137.00	**10,758**

Source: (Eunomia Research And Consulting, ZREU, LDK, HDRA Consultants and Scuola Agraria del Parco di Monza ECOTEC Research & Consulting (for ECOTEC Research & Consulting Final Report - Economic Analysis of Options for Managing Biodegradable Municipal Waste).

Based on thesevalues theemissions factorsand the respective environmental costsin USD / ton of incoming MSW for various technologies are givenin the following tables.

Table 18:. Emissionsduring the productionofbiogasenergyandenvironmental costs

Pollutant	Environmental cost (USD/tn ofemitted pollutant)	Minimum emissions (g/tn of incoming MSW) *	Maximum emissions (g/tn of incoming MSW) *	Averageemis sions (g/tn of incoming MSW)	Environmental cost (USD/tn of incoming MSW on average emissions)
SO_2	5,395.50	5.1	46.00	25.55	0.14
NO_X(as NO_2)	4,970.90	54.2	722	388.1	1.93
CO	6.05	9	722	365.5	0.00
HCL		10.8	34.3	22.55	
PCBs			0,000162	0,000162	
Dioxins	10,983,388,350	1,8E-07	5,9E-07	3,85E-07	0.0044
Furans		1,8E-07	0,000001	5,9E-07	
Total					**2.07**

* *Tsiliyannis C. (1999).*

Table 19:. Emission factorsfromcombustion of RDF andenvironmental costs.

Pollutant	Environmental cost (USD/tn ofemitted pollutant)	Emissions (g/tn of incoming MSW) *	Environmental cost (USD/tn of incoming MSW)
PM10	5,660.60	19.5	0.11
SO_2	5,395.50	97	0.52
NO_X(as NO_2)	4,970.90	388	1.93
CO	6.05	194.7	0.0012
Hg	0.00	0.1	0.00
Cd, Ti	63,250	0.1	0.01
Heavy metals	1,418,208	0.8	1.13
Total			**3.70**

* *Tsiliyannis C. (1999)*

Table 20:. Averageconcentrationof pollutants influe gases of incineration plants of mixed MSW andenvironmental costs.

Pollutant	Emissions (g/tn of incoming MSW) *	Environmental cost (USD/tn ofemitted pollutant)	Environmental cost (USD/tn of incoming MSW)
PM10	68	5,660.60	0.38
SO_2	339	5,395.50	1.83
NO_X(as NO_2)	1,360	4,970.90	6.76

Pollutant	Emissions (g/tn of incoming MSW) *	Environmental cost (USD/tn ofemitted pollutant)	Environmental cost (USD/tn of incoming MSW)
CO	677	6.05	0.,004
Hg	0.3	0.00	0.00
Cd, Ti	0.3	63,250	0.02
Heavy metals	3.4	1,418,208	4.82
Total			**13.82**

** Tsiliyannis C.A., Comparison of environmental impacts from solid waste treatment and disposal facilities, Waste Management and Research 17 (3) (1999) 231–241.*

Table 21: Concentrationsof metalsin thesolidresidue of MSW incinerationunitsandenvironmental costs.

Element	Slag (mg/kg)	Heavyash (mg/kg)	Flyash (mg/kg)	Slag average (mg/kg)	Heavyash average (mg/kg)	Flyash average (mg/kg)	Slag + Heavyash (mg/tn of inc. MSW)	Flyash (mg/tn of inc. MSW)	Pollutants in the totalsolidresidue of combustion	Cost (USD/tn of emissions)	Cost (USD/tn of inc. MSW)
Inactivated											
Chromium	100-1,000	200-800	100-1,000	550	500	550	493.5	16.5	510	600,050	0.31
Copper	250-5,000	300-1,500	50-5,000	2,625	900	2,525	1,656.8	75.8	1,732.5		
Iron	30,000-150,000	20,000-50,000	20,000-60,000	90,000	35,000	40,000	58,750	1,200	59,950		
Manganese	400-1,700	700-1,200	800-1,700	1,050	950	1,250	940	37.5	977.5		
Nickel	50-800	100-300	100-500	425	200	300	293.8	9.0	302.8	12,650	0.003
Titanium	3,500-8,000	6,500	7,000-12,000	5,750	6,500	9,500	5,757.5	285	6,042.5		
Noninactivated											
Arsenic	20-80	20-80	40-300	50	50	170	47	5.1	52.1	731,500	0.03
Cadmium	<0.5-40	50-150	200-1,000	20.25	100	600	56.5	18	74,5	63,250	0.004
Plumbum (lead)	500-5,000	2,000-10,000	2,500-19,000	2,750	6,000	10,750	4,112.5	322.5	4,435	10,758	0.04
Antimony	10-80	20-60	40-120	45	40	80	40	2.4	42.4		
Selenium	0.4-10	5-30	10-30	5.2	17.5	20	10.7	0.6	11.3		
Stannum (tin)	100-1,000	500	1,000-2,000	550	500	1,500	493.5	45	538.5		
Thallium	<0.5	<0.5	1 - 5	0.5	1	3	0.5	0.1	0.6		
Zinc	800-6,000	5,000-20,000	5,000-20,000	3,400	12,500	12,500	7,473	375	7,848		
Highlyactive											
Mercury	< 0,01-3	< 5	1 - 30	1.505	5	15.5	3.1	0.5	3.5		
Total											**0.39**

Source: Chandler et al. 1997, v.d.Sloot et al. 1997, Cossu et al. 1998; in ABF-BOKU 2001.

Assumptions forthe calculationof the emission valuesin the above table

Proportion ofcombustiblecomponentsin municipal waste 40% - 60% by weight of which 94% is transferred to theslag (includingheavyash) and 6% is transferred to flying ash.

Namelyone ton of MSW containsapproximately0.5tons of combustible ingredients, of which 0.47 tons are carriedin the slag (includingheavyash) and 0.03 tons are carriedin the flying ash.

Table 22:. Emissionsof air pollutants from gasification – plasma technology andenvironmental costs.

Pollutant	Emissions (kg/MWh)	Emissions (kg/tn of inc. MSW) (*)	Environmental cost (USD/tn of emission)	Environmental cost (USD/tn of inc. MSW)
SO_X (as SO_2)	0.5	0.5	5,395.50	2.70
NO_X (as NO_2)	0.9	0.9	4,970.90	4.47
VOCs	0	0	1,241.35	0.00
Total				**7.17**

(*) The emissionvalues perton result for energy generation equal to 1,042 kWh/tn of incoming waste.

Table 23:. Quantities of Emissions from the operation of pyrolysis plants.

Emissions	Emissions (kg/MWh)
Solid (pure carbonwhich is incorporatedintovarious inactive):	-
Gases (dust particles, CO, CO_2, CH_4, H_2)	700 m^3exhaust gas / tn of waste
Liquids (aceticacid,acetone, methanol, compositeoxygenatedhydrocarbons)	-

Table 24: Emissions from Sanitary Landfill with energy recovery and estimated environmental costs

Pollutant	Minimum emissions (g/tn of incoming MSW) *	Maximum emissions (g/tn of incoming MSW) *	Averageemis sions (g/tn of incoming MSW)	Environmental cost (USD/tn ofemissions)	Environmental cost (USD/tn of inc. MSW)
PM10	3.6	113	58.3	5,660.60	0.33
SO_2	5.1	46.00	25.55	5,395.50	0.14
NO_X(as NO_2)	54.2	722	388.1	4,970.90	1.93
CO	9	722	365.5	6.05	0.00
HCL	10.8	34.3	22.55	0.00	0.00
Total					**2.40**

** Source: Tsiliyannis C. (1999).*

Table 25: Coefficientsof gaseousemissions from Aerobic process of MSWand estimated environmental costs

Pollutant	Values (g/tn of inc. MSW)*	Average value(kg/tn of inc. MSW)	Environmental cost (USD/tn ofemissions)	Environmental cost (USD/tn of inc. MSW)
Ammonia	545-1,000	0.772		
NO_x	100	0.100	4,970.90	0.497
N_2O	11-110	0.060	2,823.59	0.169

Pollutant	Values (g/tn of inc. MSW)*	Average value(kg/tn of inc. MSW)	Environmental cost (USD/tn ofemissions)	Environmental cost (USD/tn of inc. MSW)
CO_2	98,000-553,000	325.50	8.97	2.919
CH_4	411-2,000	1.205	217.03	0.26
TOC (VOC)	0.7-500	0.25	1,241.35	0.31
Total				**4.155**

(*) EPTA Consultants, "Analysis andReview ofAvailableTechnologiesProcessingMSWfor the Regionof Epirus", Aug. 2010.

Table 26: Coefficientsof gaseousemissions from Anaerobic process of MSWand estimated environmental costs

Pollutant	Values (g/tn of inc. MSW)*	Average value(kg/tn of inc. MSW)	Environmental cost (USD/tn ofemissions)	Environmental cost (USD/tn of inc. MSW)
SO_x	2.5-30	0.016	5,395.50	0.086
NO_x	10-72.3	0.041	4,970.90	0.203
CO_2	181,000-520,000	350.0	8.97	3.139
CO	72.3	0.072	6.05	0.000
CH_4	0.0 - 411	0.205	217.03	0.044
H_2S	2.5-30	0.016		
TOC (VOC)	0.0023	$23*10^{-5}$	1,241.35	
HCL	0.011	$11*10^{-4}$		
HF	0.0021			
Cd	$9.4*10^{-7}$		63,250	
Cr	$1.1*10^{-7}$		600,050	
Hg	$5.9*10^{-7}$		0.00	
Pb	$8.5*10^{-7}$		10,758	
Zn	$1.3*10^{-7}$			
Total				**3.472**

*(*) Source: EPTAConsultants-Environmental Engineers, "Analysis andReview ofAvailable*TechnologiesProcessingMSWfor the Regionof Epirus", *Aug. 2010.*

The following two tables give the Environmental cost of bio-stabilization in the caseof incineration andin the case of landfilling of stabilat. Incalculating the costpertonof incomingwastehas beenconsideredproduction of825 kg stabilat per ton of incoming waste.

Table 27: Coefficientsof gaseousemissions frombio-stabilization andincineration of onetonestabilatand estimated environmental costs

Pollutant	Values *	Measuring units	kg/tn *stabilat*	Environmental cost (USD/tn ofemissions)	Environmental cost (USD/tn of inc. MSW)
SO_x(as SO_2)	56	g	0.056	5,395.50	0.25
NO_X (asNO_2)	156	g	0.156	4,970.90	0.64
CO_2(natural)	19.6	kg	19.6		
CO_2(unnatural)	131	kg	131	130.95	14.15
Dioxins (I-TEQ)	31	ng	3.1E-11	10,983,388,350.00	0.0003
Cd	25	mg	0.000025	63,250	0.0013
Hg	125	mg	0.000125		0,0000
Pb	125	mg	0.000125	10,758	0.0011
Ammonia	19	g	0.019		0,0000
Total					**15.04**

** Source: Consonni S. et al (2005).*

Table 28: Coefficientsof gaseousemissions frombio-stabilization andlandfilling of onetonestabilatand estimated environmental costs

Pollutant	Values *	Measuring units	kg/tn *stabilat*	Environmental cost (USD/tn ofemissions)	Environmental cost (USD/tn of inc. MSW)
PM10 (TSP)	0.622	g	0.000622	5,660.60	0.0029
SO_x(as SO_2)	2.14	g	0.00214	5,395.50	0.0096
NO_X (asNO_2)	115	g	0.115	4,970.90	0.4716
VOCs	9.9	g	0.0099	1,241.35	0.0101
CO_2(natural)	0	kg	0	8.97	
CO_2(unnatural)	71.5	kg	71.5	130.95	7.7245
CH_4	5.61	kg	5.61	217.03	1.0045
H_2	19.8	g	0.0198		0,0000
CO	439	g	0.439	6.05	0.0022
Dioxins (I-TEQ)	58	ng	5.8E-11	10,983,388,350.00	0.0005
Benzene	0.455	mg	0.000000455		0,0000
Ammonia	0.692	g	0.000692		0,0000

Pollutant	Values *	Measuring units	kg/tn *stabilat*	Environmental cost (USD/tn ofemissions)	Environmental cost (USD/tn of inc. MSW)
HCL	1.74	g	0.00174		0,0000
Total					**9.2259**

** Source: Consonni S. et al (2005).*

The following tablesummarizes theresultsof the environmentalcosts estimation for the various technologiesand schemes, not taking into account theenvironmental costsofsubstitutingof fossil fuel (lignite)which is examined following.

Table 29: Estimated environmental cost for the various technologies and schemes.

No of scheme	No of scheme in Annex	Facilitiesincluded	Environmental cost (USD/tn of inc. MSW)
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS			
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	14.22
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	7.17
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	7.17
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	3.78
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	4.98
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	0
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	1.28
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	5.77
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	2.07
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	9.23
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	15.05
12		Landfills with recovery and combustion of biogas -energy.	2.40

No of scheme	No of scheme in Annex	Facilitiesincluded	Environmental cost (USD/tn of inc. MSW)
b. PRE-SEGREGATED WASTE TREATMENT PLANTS			
b1. Separate Sorting-at-sourceof biowaste and dry streams			
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	0.0
14	8.a	Mechanical – Aerobic Composting facility. RDF *in-situ* energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	3.70
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	2.07
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	5.78
b2. Sorting-at-sourceonly biowaste			
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	0.0
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	2.07
b3. Sorting-at-source only recyclables			
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	0.0

The pricesof theabovetable shows that the scheme of Bio-drying with in-situ incineration of SRF has the higher environmental costs, followed by Incineration, whilethe MBT-Aerobic units that produce RDF for disposal and utilise the biostabilised material have the lowestenvironmental costs.

1.4.2.4 *Avoidance ofenvironmental cost* due to *substitutionof fossilfuels*

The following tablegives theestimation of the environmentalbenefits due to the substitutionof primary fuels (lignite) in energy productionbythe examinedtechnologies.

SchemesNo. 4 and 5seems to have equal environmental benefit oflignitesubstituting, sincethey are essentiallythe same technologies asthe latestdiffers only in thatthe producedcompostis not availableforcommercial usebutis buried. SchemeNo. 16 displaysenvironmental benefit ofsubstitutinglignite close to the sum oftechnologiesNo.4and No.15, since it isa combinationof the twotechnologies(includingcombustion of biogasand of RDF).

Table 30: Avoidance ofpollution due to substitution of the lignite and estimated environmental benefit in the various MSW treatment technologies and schemes

		CO_2 (as C)	NO_X	SO_2	TSP	CH_4	TOTAL
	Avoidance of emissions due to substitution of lignite (*) (g/KWh)	294	5.3	14	0.16	4.1	
	Cost of emissions (USD/tn of emissions)	130.95	4,970.9	5,395.5	5,660.6	217.03	
No of scheme	**Facilitiesincluded**	**USD per ton of incoming waste**					
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS							
1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.		12.46	35.73	0.43		48.62
2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.		27.46	78.73	0.95		107.13
3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.		27.46	78.73	0.95		107.13
4	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.		9.12	26.14	0.31		35.56
5	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.		9.12	26.14	0.31		35.56
6	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.		-	-	-		0.00
7	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.		-	-	-		0.00
8	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.		11.33	32.48	0.39		44.20

		CO_2 (as C)	NO_X	SO_2	TSP	CH_4	TOTAL
9	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas - energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.		5.06	14.50	0.18		19.73
10	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.		0.00	0.00	0.00		0.00
11	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.		10.65	30.51	0.36		41.53
12	Landfills with recovery and combustion of biogas -energy.		2.64	7.56	0.09		10.29

b. PRE-SEGREGATED WASTE TREATMENT PLANTS

b1. Separate Sorting-at-sourceof biowaste and dry streams

		CO_2 (as C)	NO_X	SO_2	TSP	CH_4	TOTAL
13	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.		-	-	-		0.00
14	Mechanical – Aerobic Composting facility. RDF *in-situ* energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.		9.12	26.14	0.31		35.56
15	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.		5.06	14.50	0.18		19.73
16	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.		11.33	32.48	0.39		44.20

b2. Sorting-at-sourceonly biowaste

		CO_2 (as C)	NO_X	SO_2	TSP	CH_4	TOTAL
17	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.		-	-	-		0.00

18	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.		5.06	14.50	0.18		19.73

b3. Sorting-at-source only recyclables

19	“Clean” MRF. Recyclables, disposal of residues in S.L.		-	-	-		0.00

** Source: Tsiliyannis C.A., Comparison of environmental impacts from solid waste treatment and disposal facilities, Waste Management and Research 17 (3) (1999) 231–241.*

1.4.2.5 *Recycling and recovery of packages materials*

The marketsof recoveredpaperandpackagingmaterialshavegreatly developedover the lastyears(particularlyin the EU toachieve the objectivesof Directives94/62and04/12).

Should be alsonotedthedynamicdevelopmentof reusablepackaging(primary, secondary and tertiarysector)due to theirkey environmentaladvantages ([9]),whichare quantifiedbythe generalizedindicatorof recycling/ reuseintroduced in 2006(Tsiliyiannis), as well as the possibility underits managementby the packagers themselves to send them for recycling at theend oftheirlife-cyclewithout requiringthe of high costs and of highuncertaintycollectivealternative managementsystem ([10]). Products thathave highindex valuedueto the reuse,easier achieve the objectives of recycling/ recovery.

The indexof recycling/ recoveryis relatedwith the general targets for recyclingand recovery of materials (plastics, glass, metals, paper). The totalquantity of materialrecoveredis the sumof these materialsat the outletof facilities. These valueshave been calculated using thetechnologies'massbalancesas presentedin section 6.1.4. The indicator isexpressed to revenues fromrecovered materials. The pricesas they resultedforthe various schemesare summarizedin the following table.

The recovery rate taken into account for the technology of plasma gasification / vitrification is equal to that of incineration technology.

The pricesof materialsvarywidelyfrom countryto country,as well as among various species(e.g. PET, HDPE of plastics, thin paper, cardboard in papers etc.). Fluctuationsin the prices ofmaterials in a local market alsoappear inany change of their internationalprices instock markets. Therefore for the calculationofrevenuethefollowing priceswere used indicatively:

- Steel: 130 USD/tn
- Aluminum:500 USD/tn
- Paper: 40.0 USD/tn
- Plastics: 70 USD/tn
- Theglasssale priceisusuallyverylowdue to the difficultyto meet theaboveconditionsin aMBT unit.

In pre-segregated waste treatment plants, the quantity of the recovered materials was considered in 50% of the respective in mixed waste MBT plants, while theselling priceof recoveredmaterials was consideredtwice thepriceof recoveredfrommixed waste MBT plants.

[9]Tsiliyannis, C.A., Dynamic Modeling of Packaging Material Flows, Waste Management & Research (Journal of ISWA), 23, 2, 155 - 166, 2005. Tsiliyannis, C.A., Parametric Analysis of Environmental Performance of Reuse/Recycle Packaging, Environmental Science and Technology (Journal of ACS), 39, 9779 - 9777, 2005. Tsiliyannis, C.A., A New Rate Index for Environmental Monitoring of Combined Reused/Recycled Packaging, Waste Management & Research, 23, 4, 304 – 313, 2005. Tsiliyannis, C.A., A Flexible Environmental Packaging Recycle/Reuse Policy Based on Economic Strength, Waste Management 27, 3 – 12, 2007.

[10]Tsiliyannis, C.A., Apportionment of Recycling to Industrial Reuser and Consumer, Environmental Modeling and Assessment 13, 195 – 208, 2008.

Table 31: Recyclingandrecovery of packaging materials in the various technologies and schemes. Packaging materials

No of scheme	No of scheme in Annex	Facilitiesincluded	Ferrous	Al	Plastics	Paper	Glass	Compost	Revenue from recovered materials (USD/tn of inc. MSW)
a. MIXED WASTE TREATMENT PLANTS									
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	35						2.28
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	35						2.28
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	35						2.28
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	33	2					4.38
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	33	2					4.38
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	33	2					4.38
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	33	2					4.38
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	31	2					4.25
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	31	2					4.25

No of scheme	No of scheme in Annex	Facilitiesincluded	Ferrous	Al	Plastics	Paper	Glass	Compost	Revenue from recovered materials (USD/tn of inc. MSW)
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	33	2					4.38
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	33	2					4.38
12		Landfills with recovery and combustion of biogas -energy.	-	-	-	-	-		0.00
b. PRE-SEGREGATED WASTE TREATMENT PLANTS									
b1. Fullsorting-at-sourceofrecyclablesandbiowaste									
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	33	2	63	129	11	250	28.59
14	8.a	Mechanical – Aerobic Composting facility. RDF *in-situ* energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	33	2				250	7.38
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	31	2	63	129	11	106	28.09
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	31	2				106	6.87
b2. Sorting-at-sourceonly biowaste									
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	-	-	-	-		400	6.00
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	-	-	-	-		350	5.25

No of scheme	No of scheme in Annex	Facilitiesincluded	Ferrous	Al	Plastics	Paper	Glass	Compost	Revenue from recovered materials (USD/tn of inc. MSW)
b3. Sorting-at-source only recyclables									
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	90	5	172	352	30		71.0

1.4.2.6 *Producedresidue tolandfill*

In the next table each scheme is evaluated with respect to the residuesproduced. The indicator used is the costsof landfilling, expressed in USDpertonof incomingwaste.

The quantitiesof residues to landfill referredforthe variousscheme in kg/tn of incoming MSW rely on the respectivemass balances presented in sec. 6.1.5.

For the estimationof the financial cost oflandfilling it has beenassumed that landfilling cost of incinerationresidues is equal to (indicatively) 100 USD/tn and that landfilling cost of inertandotherwaste is equal to (indicatively) 20 USD/tn.

Whereininthemassdiagrams the versions of either reuse or landfilling is referred for some products, the 50% of these quantities were accounted.

Table 32: Cost of residues' landfilling.

No of scheme	No of scheme in Annex	Facilitiesincluded	Residue tolandfill (kg/tn of inc. MSW)	Total environmental cost (USD/tn of inc. MSW)
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	210	21.0
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	105	10.5
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	147.5	14.75
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	205 + 10 = 215	5.10
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	430.5 + 10 = 440.5	9.61
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	147	2.94
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	372	7.44
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	225 + 10 = 235	5.50
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	165	3.30
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	815 + 20 = 835	18.30

No of scheme	No of scheme in Annex	Facilitiesincluded	Residue tolandfill (kg/tn of inc. MSW)	Total environmental cost (USD/tn of inc. MSW)
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	265 + 20 = 285	7.30
12		Landfills with recovery and combustion of biogas -energy.	1,000	20.00
PRE-SEGREGATED				
Full sorting-at-sourceof recyclables and biowaste				
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	192	3.84
14	8.a	Mechanical – Aerobic Composting facility. RDF *in-situ* energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	173 + 10 = 183	4.46
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	130	2.60
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	186 + 10 = 196	4.72
Sorting-at-source of biowaste (only)				
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	40	0.80
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	55	1.10
Sorting-at-source of recyclables (only)				
19	16.c etc.	"Clean" MRF. Recyclables, disposal of residues in S.L.	35	0.70

In the followingtable are given (indicatively) some cost prices for incineration residues management in various European countries.

Table 33: Cost of incineration residues management in various European countries

Country	Heavy ash management cost	Flying ash management cost	Total management cost
AU	69.3	399.3	468.6
DK	37.4	147.4	184.8
FR	17.05		17.05
GE	30.91	281.16	312.07
IT	82.5	141.9	224.4

Country	Heavy ash management cost	Flying ash management cost	Total management cost
LUX	17.6	8.8	26.4
Average	**42.46**	**195.71**	**205.56**

The followingtable aggregates the results of the assessmentas toall environmentalcriteria and rates the examined Schemes as to the total Environmental score.Gasification - Plasma / Vitrification, Pyrolysis, “Clean” MRF and Anaerobic MBT are the schemes with the higher (better)performance in this group of criteria, while Bio-drying with burial of stabilat and Landfills are the schemes with the lower,

Table 34: Rating of examined Schemes as to Environmental Criteria

No of Scheme	No of Scheme in Annex	Description of schemes	Preservation of abiotic resources	Contribution to the greenhouse effect	Toxicity to humans and the environment	Avoidance of environmental cost due to substitution of fossil fuels	Recycle & recovery of packaging materials	Residual to landfill	Total
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS									
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	1.89	2.60	0.25	1.82	2.08	0.00	**8.64**
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	2.74	3.60	2.10	4.00	2.08	2.30	**16.81**
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	4.00	4.00	2.10	4.00	2.08	1.40	**17.58**
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1.00	2.90	3.00	1.33	4.00	3.50	**15.73**
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1.00	1.60	2.65	1.33	4.00	2.50	**13.08**
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	0.00	3.70	4.00	0.00	4.00	4.00	**15.70**
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	0.00	2.20	3.70	0.00	4.00	3.00	**12.90**

No of Scheme	No of Scheme in Annex	Description of schemes	Preservation of abiotic resources	Contribution to the greenhouse effect	Toxicity to humans and the environment	Avoidance of environmental cost due to substitution of fossil fuels	Recycle & recovery of packaging materials	Residual to landfill	Total
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS									
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1.54	3.10	2.45	1.65	3.88	3.40	**16.02**
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.31	3.80	3.45	0.74	3.88	3.90	**16.07**
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	0.00	0.00	1.55	0.00	4.00	0.60	**6.15**
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1.70	2.40	0.00	1.55	4.00	3.05	**12.70**
12		Landfills with recovery and combustion of biogas - energy.	0.42	2.10	3.30	0.38	0.00	0.20	**6.41**

No of Scheme	**No of Scheme in Annex**	**Description of schemes**	Preservation of abiotic resources	Contribution to the greenhouse effect	Toxicity to humans and the environment	Avoidance of environmental cost due to substitution of fossil fuels	Recycle & recovery of packaging materials	Residual to landfill	**Total**
b. PRE-SEGREGATED WASTE TREATMENT PLANTS									
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	0.00	1.10	4.00	0.00	1.61	0.85	**7.56**
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	2.45	0.00	1.50	3.22	0.42	0.20	**7.79**
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	1.29	1.17	2.60	1.79	1.58	2.10	**10.53**
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	4.00	0.17	0.00	4.00	0.39	0.00	**8.56**
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	0.00	1.10	4.00	0.00	0.34	3.90	**9.34**
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	1.55	1.75	2.60	1.79	0.30	3.60	**11.58**
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	0.00	4.00	4.00	0.00	4.00	4.00	**16.00**

1.4.3 Financial Assessment

Investmentand operating costsof the facilitiesandthepotential profitthat may arisefor the projectoperator, mainlyfrom the disposal ofproducts-raw materialsandenergy-in the market, were calculated for each scheme. These figures are finally synthesizedin the index"balanced budget charge".

1.4.3.1 Investment Cost

The configuration of theinvestment costincludedthe followingcomponents:

- Landpurchase
- Shaping andpreparation ofspace andtechnicalconnection networks(access roads, water, power supply, waste watermanagement system)
- Construction works
- Technical installationsandbuildings(processesbuildings, wastestorage, wastestorage/recyclable materials)
- technical equipment
  - Transport equipment(conveyors, loaders, trucks, tractors)
  - mechanicalprocessingequipment(crushers,sieves, balers, etc.)
  - Furnace systemwith boilerandsteamsystem(on thermal treatment plants)
  - power production equipment
  - equipment for transport andtreatment of exhaust
  - Equipment for aerobic/anaerobicstabilization (on MBT)
  - Equipment for waste water treatment(pumps, tanks, pipes, etc.)
  - Othertechnical equipment(control and monitoring)

The table below as well as the graphs following that show relations of investment and operation cost for variousMSW treatment technologies and facilities applied internationally[11] were used as a basis for the purposes of the present analysis. Where necessary, properprice adjustments were made by theConsultant.

Table 35: Scalingrelations of costs and capacity in SW Treatment Plants

Type of facility	Initial investment cost (in JOD) (*)	Operation cost (in JOD/tn) (**)	Capacity (tn/y)
Incineration	$y= 5.000 * x^{0.8}$	$y= 700 * x^{-0.3}$	$20.000 \leq X \leq 600.000$
Mechanical Biological (Aerobic) Treatment	$y= 1.500 * x^{0.8}$	$y= 4.000 * x^{-0.4}$	$7.500 \leq X \leq 250.000$
Mechanical Biological	$y= 2.500 * x^{0.8}$	$y= 5.000 * x^{-0.4}$	$7.500 \leq X \leq 250.000$

[11] Panagiotakopoulos D., Sustainable Solid Waste Management (2002), Tsilemou K., Panagiotakopoulos D., Estimating Costs for Solid Waste Treatment Facilities, In: Proceedings of the ISWA World Environmental Congress and Exhibition, Rome, Italy, 17-21 October 2004.

Type of facility	Initial investment cost (in JOD) (*)	Operation cost (in JOD/tn) (**)	Capacity (tn/y)
(Anaerobic) Treatment			
Anaerobic Biological treatment	$y= 34.500 * x^{0.55}$	$y= 17.000 * x^{-0.6}$	$2.500 \leq X \leq 100.000$
Composting	$y= 2.000 * x^{0.8}$	$y= 2.000 * x^{-0.5}$	$2.000 \leq X \leq 120.000$
Sanitary Landfill (***)	$y= 6.000 * x^{0.6}$	$y= 100 * x^{-0.3}$	$500 \leq X \leq 60.000$
	$y= 3.500 * x^{0.7}$	$y= 150 * x^{-0.3}$	$60.000 \leq X \leq 1.500.000$

(*) Price level 2004.

(**) Thecost functionofincineration does not include expenditures required for the disposal of residuals of combustion.

(***) Thecost functionof Sanitary Landfill is applicable to mixed MSW. Is not valid for sanitary landfilling of residuals of other treatment plants.

1. Incineration

For the investment cost of incineration technology was used the mathematic relation[12]: $y=5.000 * x^{0.8}$ for capacities $20.000 \leq x \leq 600.000$ tn/y. The results are summarizedin the following graph and table.

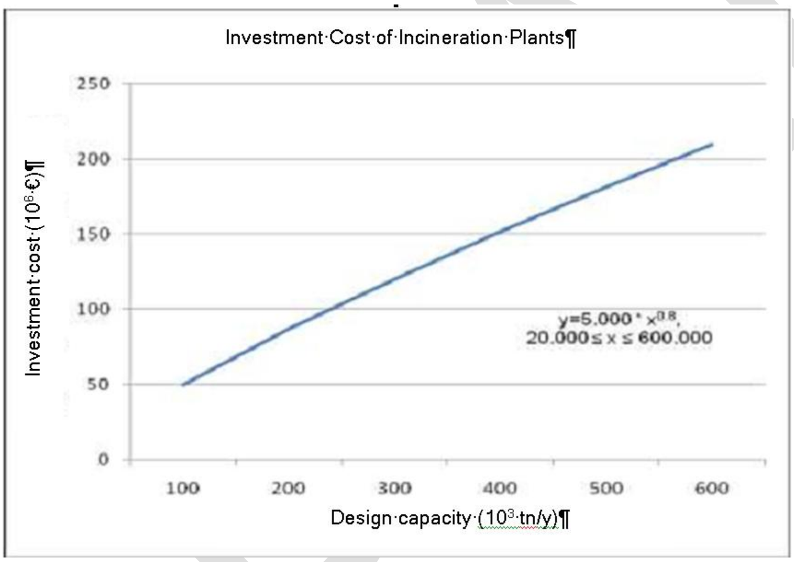


Figure 43: Investment cost of Incineration plants with capacity 20.000 – 600.000 tn/y

Investment cost (10^6 \$)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 \$ /y)	Investment cost per yearly incoming waste (\$ /tn)	Daily Capacity (tn/d)	Investment cost per daily incoming waste (\$ /tn)
24.86	37	2.38	691.18	100	252,279.95

[12] *Panagiotakopoulos D., 2002, ibid*

Investment cost ($10^{6}\ \$$)	Annual Capacity (10^{3} tn/y)	Return of capital for the 100% of investment cost ($10^{6}\ \$$ /y)	Investment cost per yearly incoming waste (\$ /tn)	Daily Capacity (tn/d)	Investment cost per daily incoming waste (\$ /tn)
61.02	110	5.74	554.84	300	202,515.61
159.33	365	15.03	436.10	1,000	159,177.89

1. **Investment cost of Pyrolysis Plants**

Investment cost ($10^{6}\ \$$)	Annual Capacity (10^{3} tn/y)	Return of capital for the 100% of investment cost ($10^{6}\ \$$ /y)	Investment cost per yearly incoming waste (\$ /tn)	Daily Capacity (10^{3} tn/d)	Investment cost per daily incoming waste (\$ /tn)
22.27	37	2.13	619.30	100	226,042.84
54.67	110	5.14	497.14	300	181,453.99
142.76	365	13.47	390.75	1,000	142,623.39

2. **Pyrolysis**

Investment cost ($10^{6}\ \$$)	Annual Capacity (10^{3} tn/y)	Return of capital for the 100% of investment cost ($10^{6}\ \$$ /y)	Investment cost per yearly incoming waste (\$ /tn)	Daily Capacity (10^{3} tn/d)	Investment cost per daily incoming waste (\$ /tn)
24.86	37	2.38	691.18	100	252,279.95
61.02	110	5.74	554.84	300	202,515.61
159.33	365	15.03	436.1	1,000	159,177.89

3. **Gasification of plasma / Vitrification Plants**

Investment cost ($10^{6}\ \$$)	Annual Capacity (10^{3} tn/y)	Return of capital for the 100% of investment cost ($10^{6}\ \$$ /y)	Investment cost per yearly incoming waste (\$ /tn)	Daily Capacity (tn/d)	Investment cost per daily incoming waste (\$ /tn)
27.12	44	2.57	619.18	120	226,000.00
56.5	110	5.29	512.04	300	186,894.94
146.9	365	13.87	402.46	1,000	146,900.00
224.32	599	21.18	374.73	1,640	136,775.10

4. **(**8.c1) **Aerobic MBT.**RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

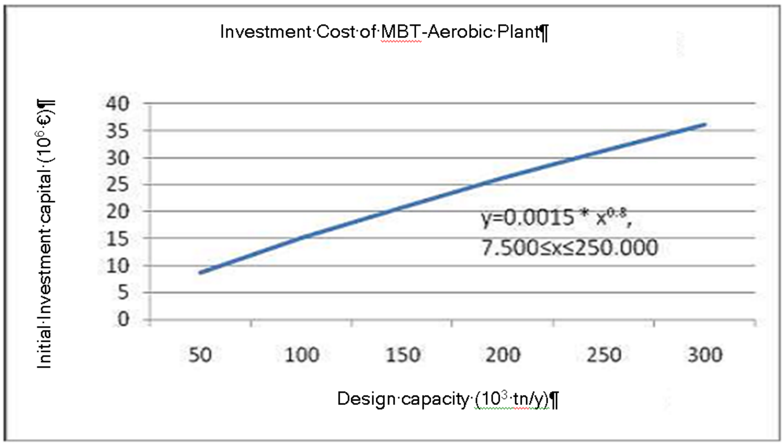


Figure 44: Investment Cost of Mechanical - Biological Treatment Plant with Aerobic stabilization of organic material, of capacity 7.500 – 250.000 tn/y.

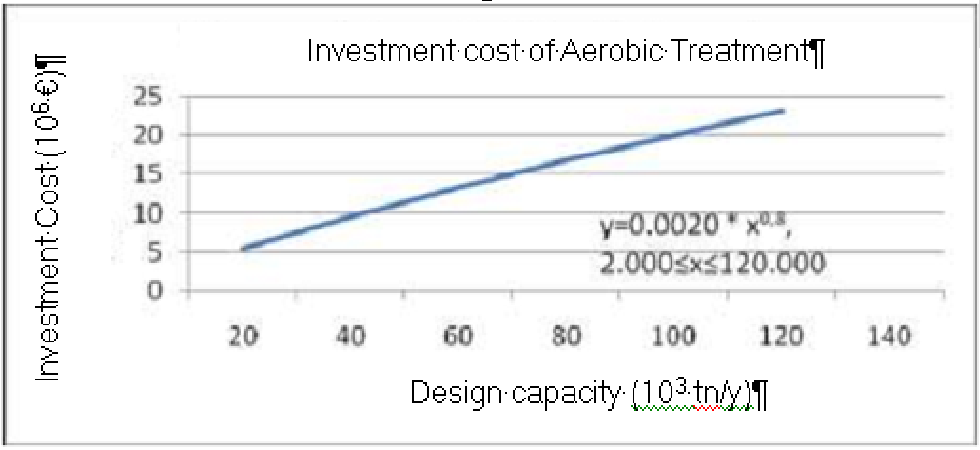


Figure 45: Investment Cost of Mechanical - Aerobic Treatment Plant with production of compost, of 2.000 – 120.000 tn/y capacity.

The investment cost prices for Mechanical Biological Treatment - Aerobic Stabilization plants taken into account were updated by the Consultant according to the current market prices and given in the table below.

Table 36: Investment Cost ofMBT - AER

Investment cost (10^6 $)	Capacity (10^3 tn/y)	Daily Capacity (tn/d)
14.24	30	100
38.65	90	300
122.04	300	1,000

For estimate the investment cost of Mechanical Biological Treatment - Aerobic (MBT-AER) with production and incineration of RDF the following curves were used[13] as basis for the

[13]Panagiotakopoulos D., 2002, ibid,

present analysis. Given that the curves reflect 2008 prices the Consultant made proper adjustments where necessary and created the table following.

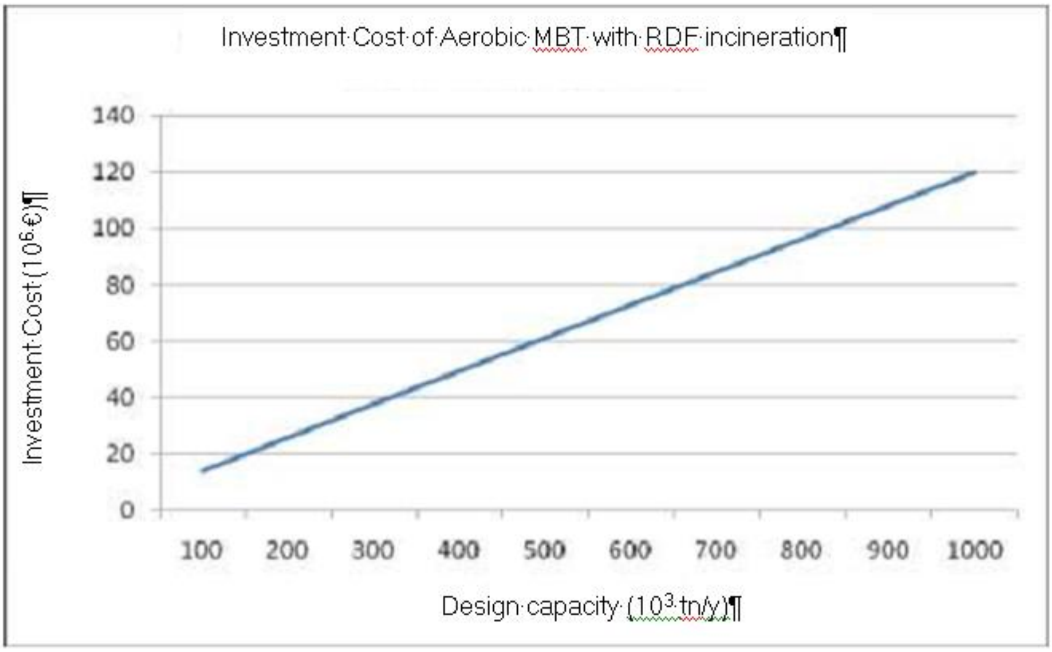


Figure 46: Investment Cost of Mechanical Biological Treatment with production and incineration of RDF, of 100.000 – 900.000 tn/y capacity.

Table 37: Investment cost of MBT with Aerobic treatment unit, production of stabilized material and RDF, burning of RDF

Investment cost (10^6 $)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 $ /y)	Investment cost per yearly incoming waste ($ /tn)	Daily Capacity (tn/d)	Investment cost per daily incoming waste ($ /tn)
5.65	9	0.53	627.78	30	188,333.34
15.82	30	1.49	527.34	100	158,200.00
42.94	90	4.06	477.11	300	143,133.34
135.60	300	12.80	452.00	1,000	135,600.00

5. **(**8.c2) **Aerobic MBT.** RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

identical to No 4 (8.c1).

6. (8.d1) **Aerobic MBT.** RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.

Kreith, F. (1994), "Handbook of Solid Waste Management", McGraw-Hill International Editions

Hogg D., "Costs for Municipal Waste Management in the EU", Eunomia Research & Consulting, Final Report to Directorate General Environment, European Commission, 2002

The investment cost is reduced by 70% as to schemes 4 and 5, due to the RDF incineration unit needed for the latest.

Investment cost (106 $)	Annual Capacity (103 tn/y)	Return of capital for the 100% of investment cost (106 $ /y)	Investment cost per yearly incoming waste ($ /tn)	Daily Capacity (tn/d)	Investment cost ($ /daily inst. tn)
1.70	9	0.16	188.33	30	56,500.00
4.75	30	0.45	158.20	100	47,460.00
12.88	90	1.22	143.13	300	42,940.00
40.68	300	3.84	135.60	1000	40,680.00

7. (8.d2) **Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.**

identical to No 6 (8.d1).

8. (9.c)**Anaerobic MBT.** RDF and in-situ incineration-energy, **utilisation of CLO**, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

The investment cost is increased by 20% as to scheme No 16, since the first treats mixed waste while the latest treats only pre-segregated. It is also increased as to No 9, since the latest makes disposal of RDF to other consumers while No 8 incinerates the RDF.

Investment cost (10^6 $)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 $ /y)	Investment cost ($ /yearly inst. tn)	Daily Capacity (tn/d)	Investment cost ($ /daily inst. tn)
10.85	10,95	1.02	977.68	30	357,079.55
31.19	36,5	2.94	854.28	100	311,880.00
80.00	109,5	7.55	730.88	300	266,680.45
216.96	365	20.48	593.93	1,000	216,960.00

9. 9.d **Anaerobic MBT.** RDF and **disposal of RDF / utilisation of CLO**, biogas and energy from combustion of biogas, disposal of non-hazardous residues in sanitary landfills

The investment cost is increased by 20% as to scheme No 15, since the first treats mixed waste while the latest treats only pre-segregated. It is also reduced as to No 8, since No 8 incinerates the RDF while No 9 disposes off RDF to other consumers.

Investment cost (10^6 $)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 $ /y)	Investment cost ($ /yearly inst. tn)	Daily Capacity (tn/d)	Investment cost ($ /daily inst. tn)
4.07	9	0.34	397.31	30	119,174.77
9.49	30	0.88	311.88	100	93,471.79
23.05	90	2.16	253.57	300	75,911.59

Investment cost (10^6 $)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 $ /y)	Investment cost ($ /yearly inst. tn)	Daily Capacity (tn/d)	Investment cost ($ /daily inst. tn)
61.02	300	5.75	203.40	1,000	60,977.96

10. (8.f) **Bio-drying**. **Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.**

Two alternative of Bio-drying production lines were examined: a) with landfilling, and b) with incinerating of the produced stabilat. The relevant investment cost rates is given in the following tables.

a) Investment cost of Biodrying Plants with landfilling of the produced stabilat

Investment cost (10^6 $)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 $ /y)	Investment cost per yearly incoming waste ($ /tn)	Daily Capacity (10^3 tn/d)	Investment cost per daily incoming waste ($ /tn)
10.74	30	1.01	356.20	100	106,860.60
22.60	90	2.14	251.11	300	75,333.34
45.54	300	4.29	151.79	1000	45,536.30

(*) Association ofWaste Management of Creta, Budget of Biodrying Unit of Heraklion.

(**) www.defra.gov.uk, Demonstrator Programme Catalogue of Applications, Waste Implementation Programme, New Technologies, 2005.

11. (8.e) **Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.**

The investment cost prices of a biodrying plant that includes also a combustion unit for the incineration of the produced stabilat were considered with reference on the budget of a biodrying unit that was recently established in Thessaloniki (data of Association ofLocal GovernmentOrganizationsof GreaterThessaloniki) with capacity 400,000 tn/y. Theinvestment costof this unitrose to 48 mil. €. Thesizeescalation of the investment costwas basedonthe respective used in combustionunits.

b) Investment cost of Biodrying Plants with incinerating of the produced stabilat

Investment cost (10^6 $)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 $ /y)	Investment cost per yearly incoming waste ($ /tn)	Daily Capacity (10^3 tn/d)	Investment cost per daily incoming waste ($ /tn)
43.34	37	4.09	1,187.42	100	433,404.89
104.38	110	9.85	953.19	300	347,912.12
212.60	365	13.29	582.45	1,000	212,594.54

12. **Landfillswithrecovery andcombustion of biogas**

The investment cost rates for Sanitary Landfills with energy recovery and 20 years operationtimehorizon, which are taken in account, have been updated and given in the followinggraph and table.

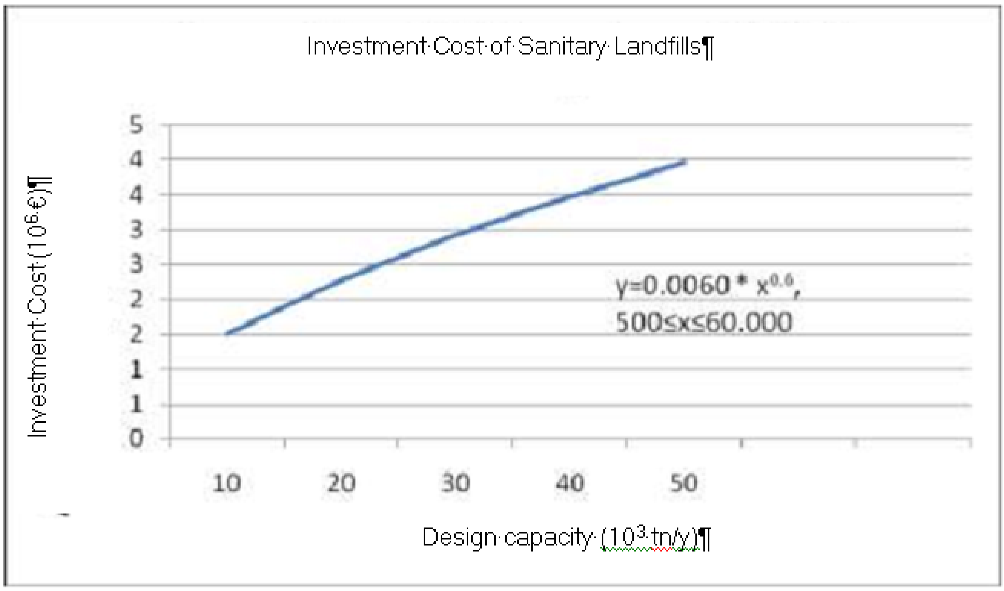


Figure 47: Investment Cost of Sanitary Landfills, capacity 500 – 60.000 tn/y.

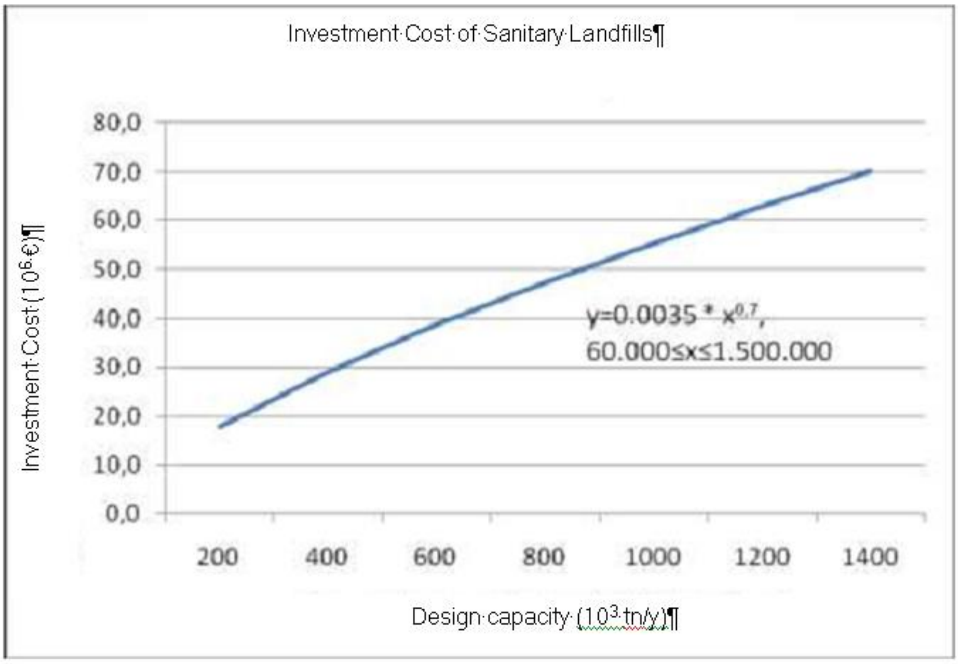


Figure 48: Investment Cost of Sanitary Landfills, of 60.000 – 1.500.000 tn/y capacity.

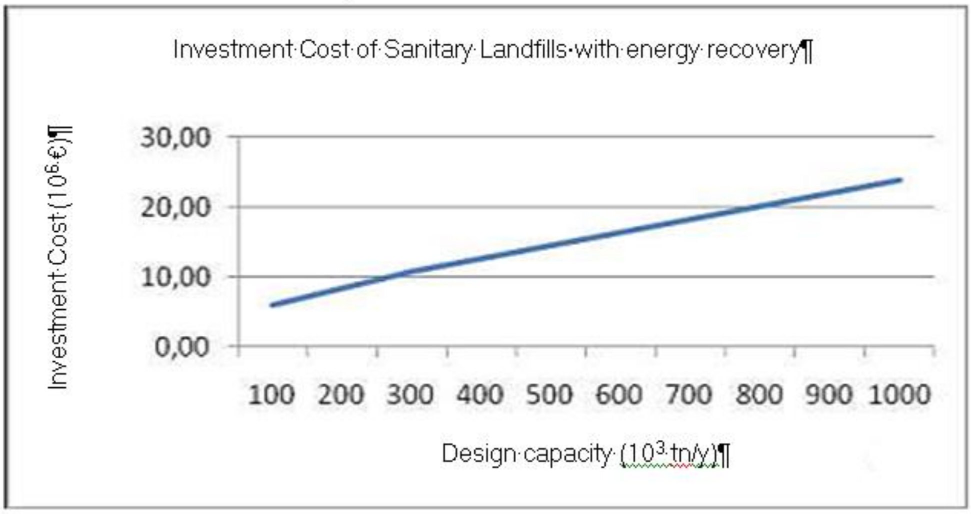


Figure 49: Investment Cost of Sanitary Landfills with energy recovery and 20 years operation time horizon.

Investment cost of Sanitary Landfills with energy recovery and 20 years operating time horizon

Investment cost (10^6 $)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 $ /y)	Investment cost ($ /yearly inst. tn)	Daily Capacity (10^3 tn/d)	Investment cost ($ /daily inst. tn)
3.05	9	0.28	339.00	30	101,700.00
6.78	30	0.64	226.00	100	67,800.00
12.20	90	1.15	135.60	300	40,680.00
27.12	300	2.57	90.40	1,000	27,120.00

b. PRE-SEGREGATED WASTE TREATMENT PLANTS

b1. Full sorting-at-sourceof recyclables and biowaste

13. (6.a)**Mechanical – Aerobic Composting facility**. Recyclables, HQ Compost, disposal of residues in S.L.

The investment cost is reduced by 20% as to scheme No 6, as the latest is an MBT.

Investment cost (10^6 $)	Annual Capacity (tn/y)	Return of capital for the 100% of investment cost (10^6 $/y)	Investment cost per yearly incoming waste ($/tn)	Daily Capacity (tn/d)	Investment cost ($ /daily inst. tn)
1.36	9	0.13	150.67	30	45,200.00
3.80	30	0.36	126.56	100	37,968.00

Investment cost (10^6 $)	Annual Capacity (tn/y)	Return of capital for the 100% of investment cost (10^6 $/y)	Investment cost per yearly incoming waste ($/tn)	Daily Capacity (tn/d)	Investment cost ($ /daily inst. tn)
10.31	90	0.97	114.51	300	34,352.00
32.54	300	3.07	108.48	1000	32,544.00

14. (8.a) **Mechanical – Aerobic Composting facility.** RDF *in-situ* incineration-energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

The investment cost is reduced by 20% as to No 4, since the latest is an MBT.

Investment cost (10^6 $)	Annual Capacity (tn/y)	Return of capital for the 100% of investment cost (10^6 $/y)	Investment cost per yearly incoming waste ($/tn)	Daily Capacity (tn/d)	Investment cost ($ /daily inst. tn)
4.52	9	0.42	502.23	30	150,666.67
12.66	30	1.19	421.87	100	126,560.00
34.35	90	3.25	381.69	300	114,506.67
108.48	300	10.24	361.60	1000	108,480.00

15. (3). **Mechanical – Anaerobic facility.** Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.

For estimate the investment cost of this schemethe following curves were used ([14]) as basis for the present analysis.

The investment cost rates for AnaerobicMBTwhich are taken in account for the calculations, have been updated and given in the followingtable.

[14]Panagiotakopoulos D., 2002, ibid

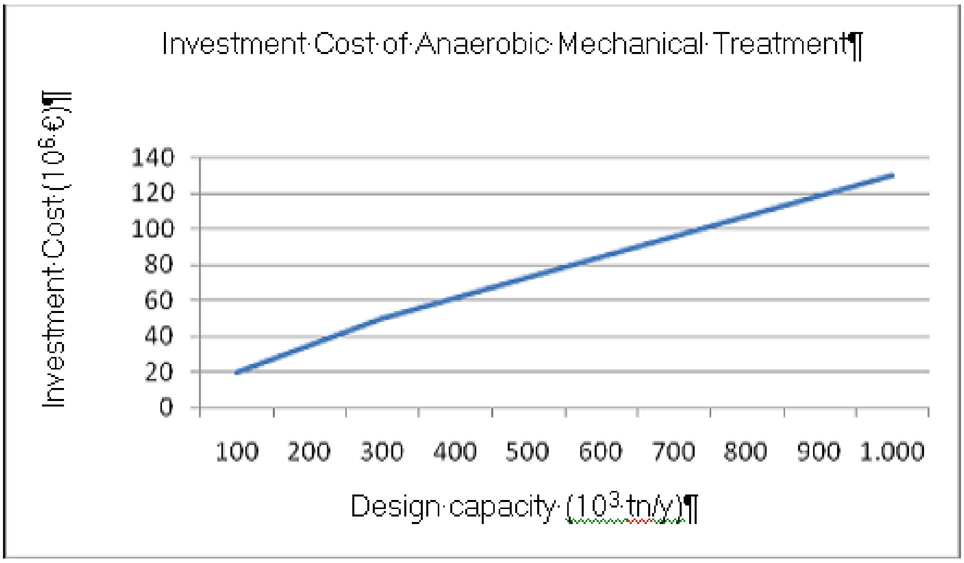


Figure 50: Investment costs of Anaerobic Mechanical Treatment Plants of 7.500 – 250.000 tn/y capacity.

Investment cost (10^6 $)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 $ /y)	Investment cost ($ /yearly inst. tn)	Daily Capacity (tn/d)	Investment cost ($ /daily inst. tn)
3.39	9	0.28	331.09	30	99,312.31
7.91	30	0.73	259.90	100	77,893.16
19.21	90	1.80	211.31	300	63,259.66
50.85	300	4.79	169.50	1,000	50,814.97

16. (9). **Mechanical – Anaerobic facility.** RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.

The investment cost structure of this scheme is equal to that of No 3increased by the cost of facility required for RDF incineration. This cost is estimated approximately in USD 102.000,00 per daily installed tone of waste.

Investment cost (10^6 $)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 $ /y)	Investment cost ($ /yearly inst. tn)	Daily Capacity (tn/d)	Investment cost ($ /daily inst. tn)
9.04	10,95	0.85	814.73	30	297,566.29
25.99	36,5	2.45	711.90	100	259,900.00
66.67	109,5	6.29	609.07	300	222,233.71
180.8	365	17.06	494.94	1,000	180,800.00

17. (10 etc.)**Mechanical – Aerobic Composting facility**. Compost / disposal of residues in S.L.

The investment cost of this scheme is reduced by 20% as to No 13, since the latest recovers recyclables.

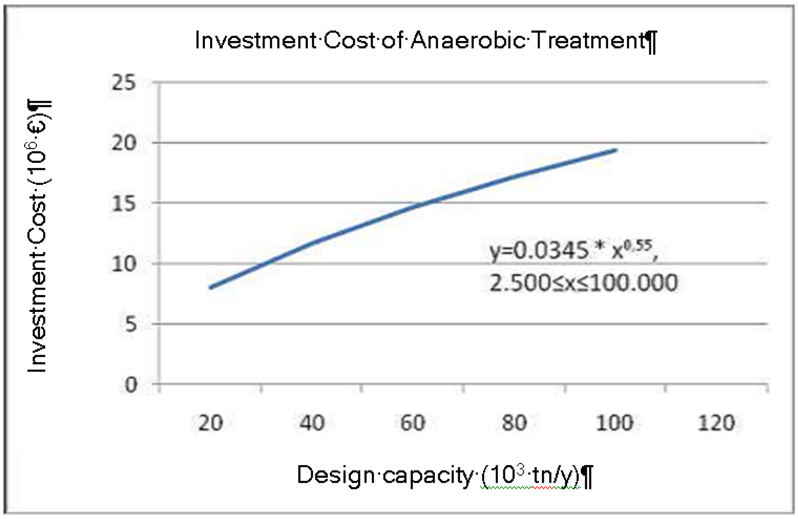


Figure 51: Investment Cost of Anaerobic Digestion, of 2.500 – 100.000 tn/y capacity.

Investment cost (10^6 $)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 $ /y)	Investment cost per yearly incoming waste ($ /tn)	Daily Capacity (tn/d)	Investment cost ($ /daily inst. tn)
1.08	9	0.10	120.53	30	36,160.00
3.04	30	0.29	101.25	100	30,374.40
8.24	90	0.78	91.60	300	27,481.60
26.04	300	2.46	86.78	1000	26,035.20

18. (13 etc.)**Mechanical – Anaerobic facility.** Compost, biogas - energy, disposal of residues in S.L.

The investment cost of this scheme is reduced by 20% as to No 15, since the latest treats recyclables and biowaste while No 18 treats only biowaste.

Investment cost (10^6 $)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 $ /y)	Investment cost per yearly incoming waste ($ /tn)	Daily Capacity (tn/d)	Investment cost ($ /daily inst. tn)
2.71	9	0.23	264.87	30	79,449.85
6.33	30	0.59	207.92	100	62,314.53
15.37	90	1.44	169.05	300	50,607.73
40.68	300	3.83	135.60	1000	40,651.98

19. (16.cetc.)**“Clean” MRF**. Recyclables, disposal of residues in S.L.

The investment cost of this scheme is reduced by 20% as to No 13, since the latest treats recyclables and biowaste while No 19 treats only recyclables.

Investment cost (10^6 $)	Annual Capacity (10^3 tn/y)	Return of capital for the 100% of investment cost (10^6 $ /y)	Investment cost per yearly incoming waste ($ /tn)	Daily Capacity (tn/d)	Investment cost ($ /daily inst. tn)
1.08	9	0.10	120.53	30	36,160.00
3.04	30	0.29	101.25	100	30,374.40
8.24	90	0.78	91.60	300	27,481.60
26.04	300	2.46	86.78	1000	26,035.20

1.4.3.2 Operation Expenses) (OPEX)

The following cost centers were taken in account for the configuration of OPEX:

- Maintenance of construction and equipment
- Security
- Management / Administration of facilities
- Staff
- Energy, water, heat
- waste water disposal
- auxiliaryfuel
- chemicals(lime, ammonia, adsorbents)

ThechartsbelowshowproposedoperationcostcurvesforvariousMSWtreatmenttechnologies ([15]).

1. Operation cost of Incineration

For estimate the operation cost of incineration plants the following curves are taken into account. The prices are shown in the table.

[15] Panagiotakopoulos D., Sustainable Solid Waste Management (2002), Tsilemou K., Panagiotakopoulos D., Estimating Costs for Solid Waste Treatment Facilities, In: Proceedings of the ISWA World Environmental Congress and Exhibition, Rome, Italy, 17-21 October 2004.

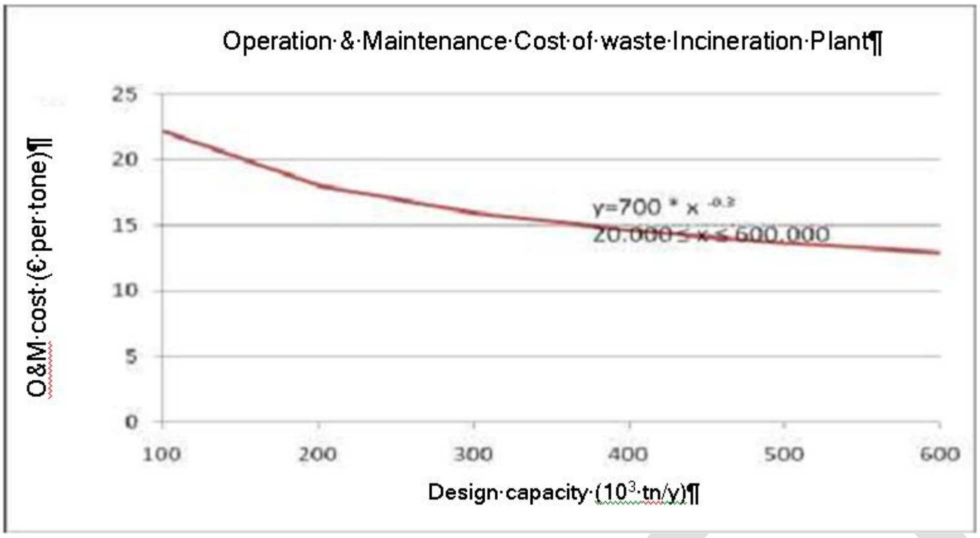


Figure 52: Operating costs of Incineration plants of capacity 20.000 – 600.000 tn/y.

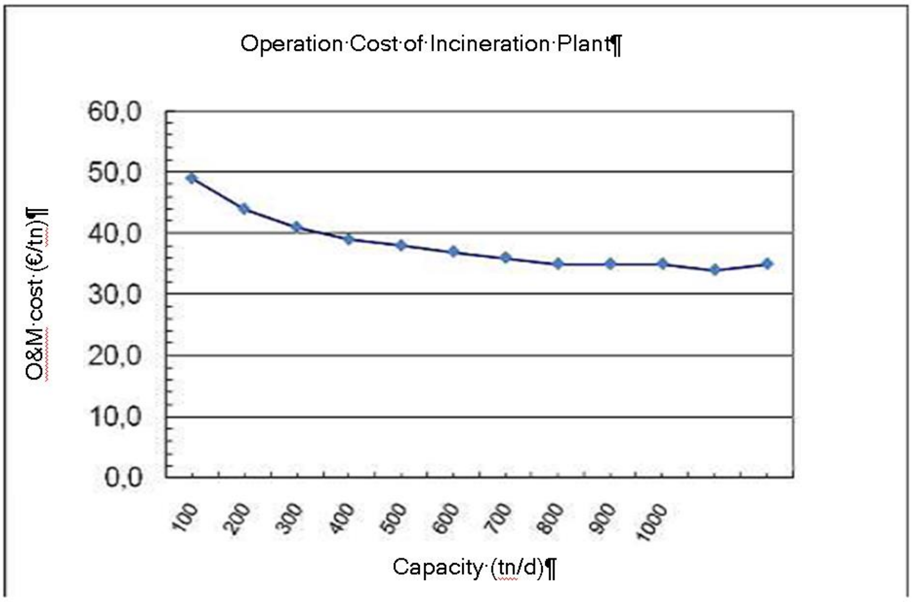


Figure 53: Operation Cost of Incineration Plants with capacity 100-1000 tn/d – Production of Energy and Steam

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
67	11	30
55	37	100
46	110	300
38	365	1,000

2. Operation cost of Pyrolysis

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
92	44	120
68	110	300
47	365	1,000
42	599	1640

3. Operation cost of Gasification of Plasma / vitrification Plants

The operation cost of this type of plants has been taken from data of providers. For a plant with capacity 1,640 tn/d the operation cost is estimated approximately at 37 €/tn (41.81 $/tn). Scale of cost was based on curves that are used in incineration plants.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
92	44	120
68	110	300
47	365	1,000
42	599	1,640

4. (8.c1) **Operation cost of Aerobic MBT.** RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

For the operation cost of MBT-AER with production of compost, recyclables and production and incineration of RDF the following curves were used. The prices were adjusted properly and given in the table below.

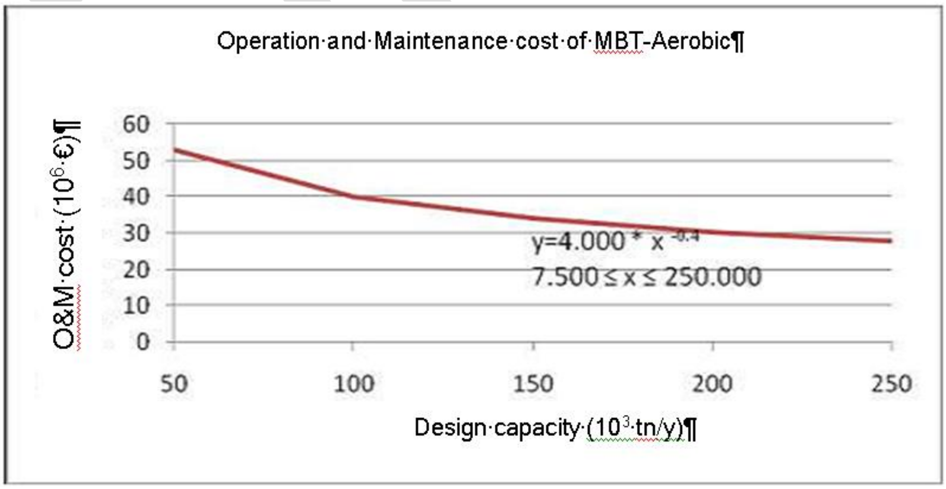


Figure 54: Operation cost of MBT – Aerobic with production of stabilized material, with capacity 7.500-250.000 tn/y

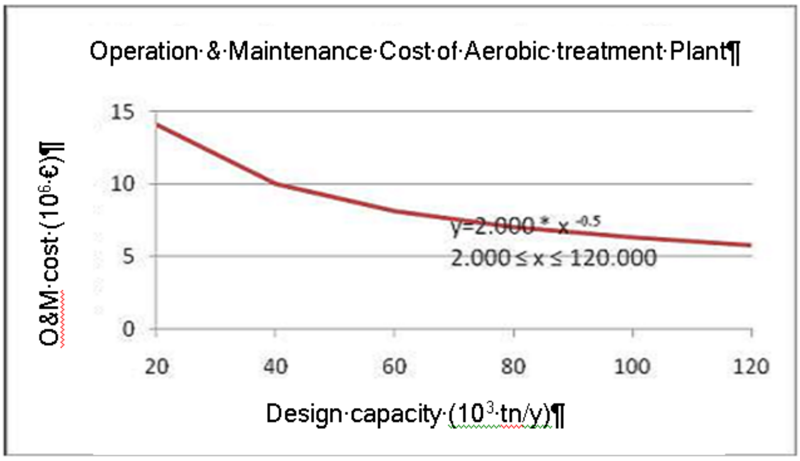


Figure 55: Operation cost of Aerobic treatment unit with capacity 2,000-120,000 tn/y.

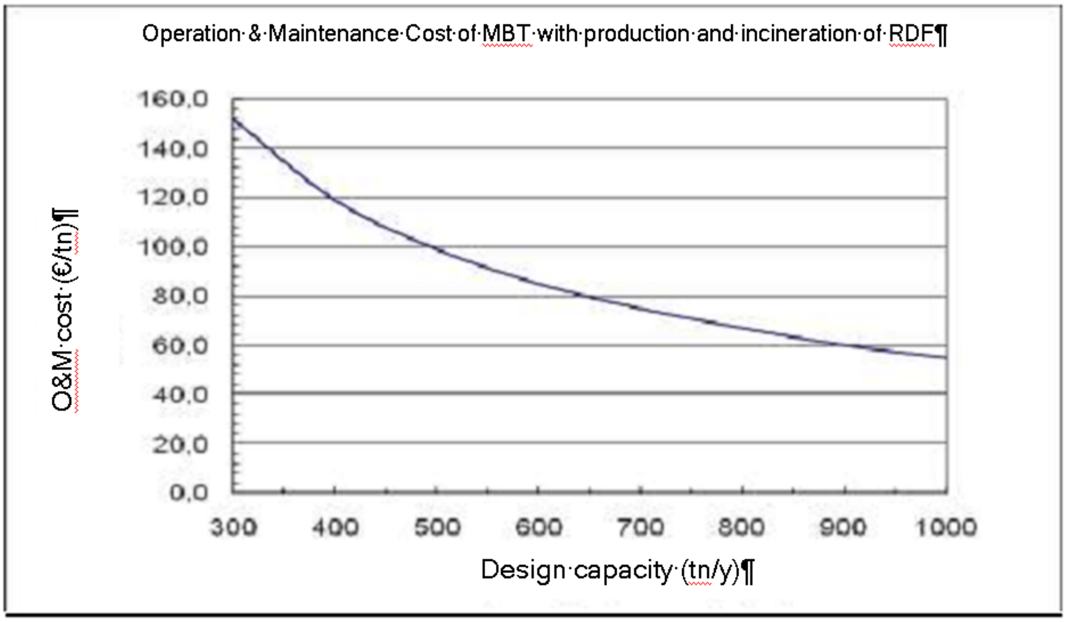


Figure 56: Operation cost of MBT with production and incineration of RDF

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
170	37	30
113	110	100
68	365	300

5. 8.c2 **Operation cost of Aerobic MBT.** RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

The operation cost structure of this type of plants is equal to that of MBT with incineration of RDF, however increased by the cost of compost landfilling.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
180	37	100
123	110	300
78	365	1,000

6. (8.d1)**Operation cost of Aerobic MBT.** RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.

The operation cost is reduced by 50% as to No 4, since the latest incinerates the RDF

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
85	11	30
57	37	100
34	110	300

7. (8.d2) **Operation cost of Aerobic MBT.** RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.

The operation cost is increased by 6%, 9% και 15% as to No 6, since the latest utilises the biostabilisedmaterial.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
89.84	37	30
61.59	110	100
38.99	365	300

8. (9.c)**Operation cost of Anaerobic MBT.** RDF and in-situ incineration-energy, **utilisation of CLO**, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

The operation cost is increased by 10% as to No 16, since No 8 is MBT.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
109.384	11	30
95.711	37	100
89.496	70	192
85.767	110	300
75.823	365	1000

9. (9.d)**Operation cost of Anaerobic MBT.** RDF- disposal, utilisation of CLO, biogas - energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

The operation cost is reduced by 50% as to No 8, since the latest incinerates in-situ the produced RDF.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
54.69	11	30
47.86	37	100
44.75	70	192
42.88	110	300
37.91	365	1000

10. (8.f) **Operation Cost of Bio-drying**. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.

For the estimation of operation cost of Biodrying plant with landfilling of stabilat were used data from the operation of a Biodrying plant recently established in Heraklion of Creta with a capacity of 200 tn/d. The cost was estimated in 25.00 €/tn (28.25 $/tn), however this should be increased by the cost of landfilling of stabilat residual.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
119	9	30
77	20	100
57	60	200
51	90	300
32	300	1,000

11. (8.e) **Operation Cost of Bio-drying**. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

The operation cost of this plant is taken equal to that of aerobic biostabilization, increased by the cost of incineration of stabilat residual as well as by the cost of heavy maintenance which is estimated at 30 €/tn (34 $/tn).

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
139	11	30
96	37	100

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
79	110	300
72	365	1000

12. Operation Cost of Sanitary Landfills with recovery and combustion of biogas

The curves given below were used for operation cost of Sanitary Landfill with 20 years life cycle and biogas recovery for energy production in 50%[16] .

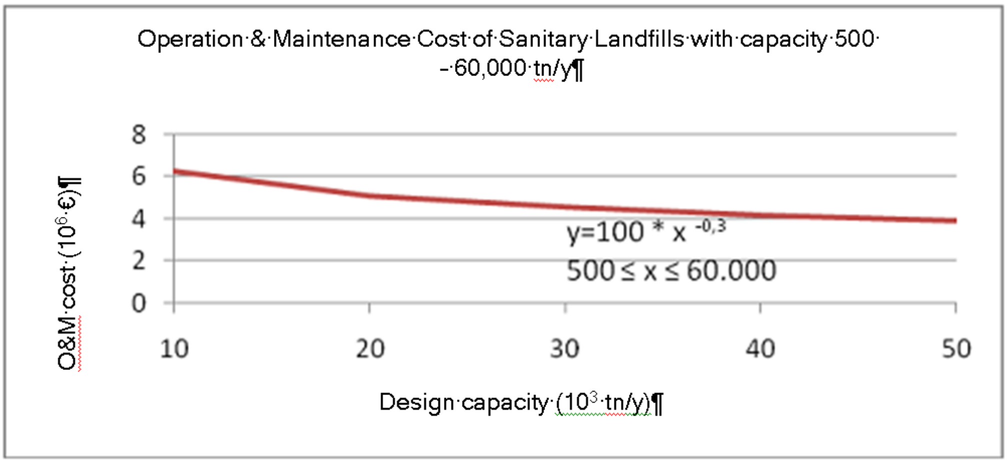


Figure 57: Cost of Operation and Maintenance of Sanitary Landfills with capacity 500-60,000 tn/y.

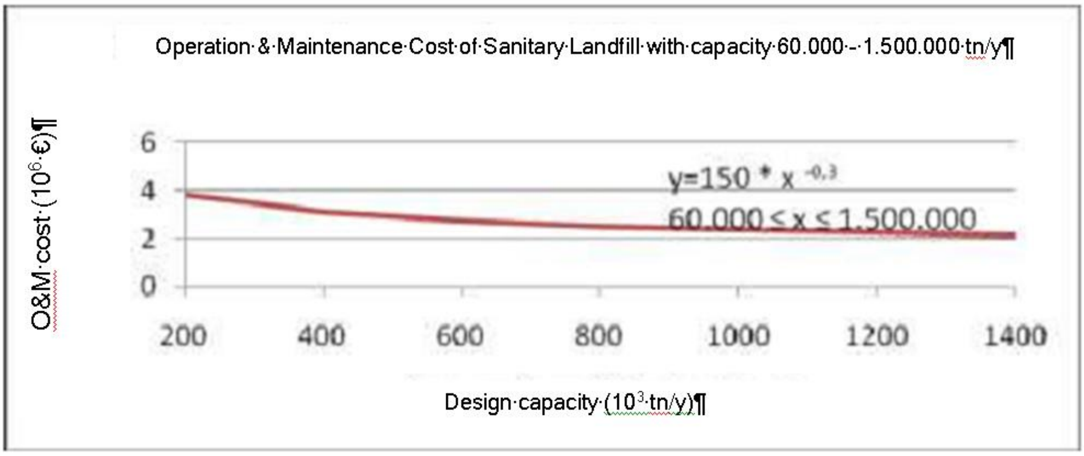


Figure 58: Cost of Operation and Maintenance of Sanitary Landfills with capacity 60,000 – 1,500,000 tn/y.

In general, the reducedannualcosts of remedyinglandfillare calculatedbythefollowingmathematic relation:

[16]Hellenic Agencyfor LocalDevelopmentand Local Government S.A., "Techno-economic Study for the establishment of Solid Waste Management Agency for Municipalities of 1st, 2nd, 3rd and 4th Management Section in the Prefecture of Etoloakarnania", October 2007.

[Reduced annual cost of remediation] = [Remediation cost in year N] x $\frac{r}{(1+r)^N - 1}$

Wherein r = discount rate (%).

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
76	9	30
45	30	100
28	90	300
11	300	1,000

b) PRE-SEGREGATED

b1. Separate Sorting-at-sourceof biowaste and dry streams

13. (4) **Operation Cost of Mechanical – Aerobic Composting facility**. Recyclables, HQ Compost, disposal of residues in S.L.

The Operation Cost ofthis scheme is reduced by10% as to scheme No 6, since the latest is MBT for mixed waste.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
80.85	37	30
55.43	110	100
35.09	365	300

14. (8.α) **Operation Cost of Mechanical – Aerobic Composting facility.** RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

The Operation Cost of **this scheme is reduced by** 10% as to scheme No 4, since the latest is MBT for mixed waste.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
161.70	37	30
110.85	110	100
70.17	365	300

15. (5) **Operation Cost of Mechanical – Anaerobic facility.** Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.

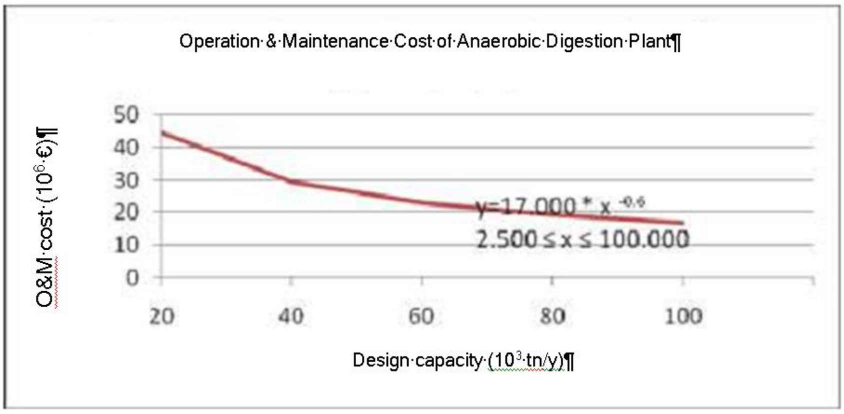


Figure 59: Operation cost of Anaerobic treatment plant with capacity 2.500-100.000 tn/y

In the table below has been estimated the annual operation cost of Anaerobic MBTs with high production and burning of biogas.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
99	11	30
87	37	100
81	70	192
78	110	300
69	365	1,000

16. (9.a) **Operation Cost of Mechanical – Anaerobic facility.** RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.

The operation cost structure of this type of plants is equal to that of MBT – Anaerobic with production and burning of biogas / production of high quality compostcompost, however increased by the cost of incineration of recovered RDF.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
124	11	30
109	37	100
96	110	300
84	365	1,000

b2. Sorting-at-sourceonly biowaste

17. **(**10 etc.) **Mechanical – Aerobic Composting facility**. Compost / disposal of residues in S.L.

The operation cost is reduced by 70% as to No 13, since the latest recovers recyclables and biowaste while No 17 only biowaste.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
24.26	37	30
16.63	110	100
10.53	365	300

18. **(**13 etc.) **Mechanical – Anaerobic facility.** Compost, biogas - energy, disposal of residues in S.L.

The operation cost is reduced by 70% as to No 15, since the latest recovers recyclables and biowaste while No 18 only biowaste.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
29.7	11	30
26.1	37	100
24.3	70	192
23.4	110	300
20.7	365	1,000

19. (16.c etc.) **“clean” MRF for pre-segregated** recyclables. **Recyclables or RDF**

The operation cost is reduced by 30% as to No 13, since the latest recovers recyclables and biowaste while No 17 only Recyclables.

Operation cost ($/tn)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)
56.60	37	30
38.80	110	100
24.56	365	300

1.4.3.3 Revenue

In the following tables is given the revenue generated from energy and materials recovery per type of production process and facility.

Table 38: Revenues from recovery of energy and materials (in €/tn of incoming waste)

No of Scheme	No of Scheme in Annex	Type of plant	Revenues from energy recovery		Revenues from recyclables and compost sales	Revenues from compost sales	Total Revenues (€/tn of inc. waste)
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS							
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	450	36.00	2.28		**-38.28**
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	650	52.00	2.28		**-54.28**
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	950	76.00	2.28		**-78.28**
4	8.c1	**Aerobic MBT.**RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	238	19.04	4.38		**-23.42**
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	238	19.04	4.38		**-23.42**
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	0	0.00	4.38		**-4.38**
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	0	0.00	4.38		**-4.38**
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	366	29.28	4.25		**-33.53**
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of	72.5	5.80	4.25		**-10.05**

No of Scheme	No of Scheme in Annex	Type of plant	Revenues from energy recovery		Revenues from recyclables and compost sales	Revenues from compost sales	Total Revenues (€/tn of inc. waste)
		H.R in H.W.L.					
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	0	0.00	4.38		**-4.38**
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	404	32.32	4.38		**-36.70**
12		Landfills with recovery and combustion of biogas - energy.	100	8.00	0.00		**-8.00**
b. PRE-SEGREGATED WASTE TREATMENT PLANTS							
b1. Separate Sorting-at-sourceof biowaste and dry streams							
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	0	0.00	28.59	8.00	**-36.59**
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	238	19.04	7.38	8.00	**-34.42**
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	125	10.00	28.09	8.00	**-46.09**
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	388	31.04	6.87	8.00	**-45.91**

No of Scheme	No of Scheme in Annex	Type of plant	Revenues from energy recovery		Revenues from recyclables and compost sales	Revenues from compost sales	Total Revenues (€/tn of inc. waste)
b2. Sorting-at-sourceonly biowaste							
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	0	0.00	6.00	8.00	**-14.00**
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	150	12.00	5.25	8.00	**-25.25**

b3. Sorting-at-source only recyclables							
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	0	0.00	71.00		**-71.00**

1.4.3.4 Balanced*BudgetCharge*

The balanced budget charge indicates the relation between the capacity and the main economic figures of an investment and is calculated with the formula:

(Revenue – Expenses) / Capacity.

The revenues are generated from sales of energy and materialsrecovered in each individual production process.

The cost of total (100%) investment capital return is shared in the annual operation cost which therefore consists of:

- the annual cost of investment capital return
- the annual cost of operation
- the annual cost of and maintenance

In the following series of tables the Balanced Budget Charge is calculated for each of the examined technologies.

1 (1) Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.							
Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
10.17	11	30	0.97	88.05	67	-38.28	116
24.86	37	100	2.37	63.99	55	-38.28	81
61.02	110	300	5.81	52.83	46	-38.28	61
159.33	365	1,000	15.17	41.57	38	-38.28	42

2 (2) Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.							
Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
24.86	37	100	2.38	64.44	91.19	-29.64	125.99
61.02	110	300	5.74	52.19	67.40	-29.64	89.95
159.33	365	1,000	15.03	41.18	46.96	-29.64	58.50

3 (3). Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
27.12	44	120	2.58	58.70	91.19	-78.28	71.62
56.50	110	300	5.38	48.92	67.40	-78.28	38.05
146.90	365	1,000	13.99	38.33	46.96	-78.28	7.02
224.32	599	1,640	21.36	35.67	41.58	-78.28	-1.03

4 (8.c1)**Aerobic MBT.** RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
5.65	9	30	0.54	59.79			59.79
15.82	30	100	1.51	50.22	169.50	-23.42	196.31
42.94	90	300	4.09	45.44	113.00	-23.42	135.02
135.60	300	1,000	12.91	43.05	67.80	-23.42	87.43

5. (8.c2) **MBT with Aerobic treatment unit,** landfilling of bio-stabilised material, production and incineration of **RDF.**

Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
6.38	9	30	0.61	67.56			67.56
17.88	30	100	1.70	56.75	179.67	-23.42	213.01
48.52	90	300	4.62	51.35	123.17	-23.42	151.10
153.23	300	1,000	14.59	48.64	77.97	-23.42	103.20

6 (8.d1) Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.

Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**

6 (8.d1) Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.

Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
1.70	9	30	0.16	17.94			17.94
4.75	30	100	0.45	15.07	84.75	-4.38	95.44
12.88	90	300	1.23	13.63	56.50	-4.38	65.76
40.68	300	1,000	3.87	12.91	33.90	-4.38	42.44

7. (8.d2). Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.

Cost of initial investment (106 $)	Annual Capacity (103 tn/y)	Daily Capacity (103 tn/d)	Capital return in 100% of investment cost (106 $/year)	Capital return in 100% of investment cost (106 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
1.70	9	30	0.16	17.94			17.94
4.75	30	100	0.45	15.07	89.84	-4.38	100.53
12.88	90	300	1.23	13.63	61.59	-4.38	70.84
40.68	300	1000	3.87	12.91	38.99	-4.38	47.52

8 (9.c) Anaerobic MBT. RDF and in-situ incineration-energy, **utilisation of CLO**, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
10.85	11	30	1.03	93.92	109.38	-33.53	169.78
31.19	37	100	2.97	80.28	95.71	-33.53	142.46
80.00	110	300	7.62	69.27	85.77	-33.53	121.51
216.96	365	1,000	20.66	56.61	75.82	-33.53	98.91

9 (9.d) Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
4.07	9	30	0.39	43.05	54.69	-10.05	87.69
9.49	30	100	0.90	30.13	47.86	-10.05	67.94
23.05	90	300	2.20	24.39	42.88	-10.05	57.23
61.02	300	1,000	5.81	19.37	37.91	-10.05	47.24

10. (8.f) **Bio-drying**. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L

Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
10.51	9	30	1.00	111.21	118.65	-4.38	225.48
10.74	30	100	1.02	34.08	76.84	-4.38	106.54
22.60	90	300	2.15	23.92	50.85	-4.38	70.39
45.54	300	1,000	4.34	14.46	31.64	-4.38	41.72

11. (8.e) **Bio-drying**. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.

Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
16.54	11	30	1.58	143.23	138.99	-36.70	245.53
43.34	37	100	4.13	111.55	108.54	-36.70	183.39
104.38	110	300	9.94	90.37	89.38	-36.70	143.06
212.60	365	1,000	20.25	55.47	81.72	-36.70	100.50

12. Landfills with recovery and combustion of biogas -energy.

Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (10^3 tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
3.05	9	30	0.29	32.29	75.71	-8.00	100.00

12. Landfills with recovery and combustion of biogas -energy.							
Cost of initial investment $(10^{6}\,\$)$	Annual Capacity (10^{3} tn/y)	Daily Capacity (10^{3} tn/d)	Capital return in 100% of investment cost $(10^{6}\,\$/\text{year})$	Capital return in 100% of investment cost $(10^{6}\,\$/\text{tone})$	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
6.78	30	100	0.65	21.52	45.20	-8.00	58.72
12.20	90	300	1.16	12.91	28.25	-8.00	33.16
27.12	300	1,000	2.58	8.61	11.30	-8.00	11.91

PRE-SEGREGATED

b1. Separate Sorting-at-sourceof biowaste and dry streams

13./4 Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.							
Cost of initial investment $(10^{6}\,\$)$	Annual Capacity (10^{3} tn/y)	Daily Capacity (tn/d)	Capital return in 100% of investment cost $(10^{6}\,\$/\text{year})$	Capital return in 100% of investment cost $(10^{6}\,\$/\text{tone})$	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
1.36	9.00	30	0.13	14.35			14.35
3.80	30.00	100	0.36	12.05	80.85	-36.59	56.31
10.31	90.00	300	0.98	10.91	55.43	-36.59	29.74
32.54	300.00	1000	3.10	10.33	35.09	-36.59	8.83

14. 8.a Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.							
Cost of initial investment $(10^{6}\,\$)$	Annual Capacity (10^{3} tn/y)	Daily Capacity (tn/d)	Capital return in 100% of investment cost $(10^{6}\,\$/\text{year})$	Capital return in 100% of investment cost $(10^{6}\,\$/\text{tone})$	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
5.65	9	30	0.54	59.79			
15.82	30	100	1.51	50.22	161.70	-34.42	177.51
42.94	90	300	4.09	45.44	110.85	-34.42	121.88
135.6	300	1000	12.91	43.05	70.17	-34.42	78.81

15 / 9.b**Mechanical – Anaerobic facility.** Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.							
Cost of initial investment $(10^{6}\,\$)$	Annual Capacity (10^{3} tn/y)	Daily Capacity (10^{3} tn/d)	Capital return in 100% of investment cost $(10^{6}\,\$/\text{year})$	Capital return in 100% of investment cost $(10^{6}\,\$/\text{tone})$	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**

15 / 9.b**Mechanical – Anaerobic facility.** Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.							
Cost of initial investment $(10^6\ \$)$	Annual Capacity $(10^3$ tn/y$)$	Daily Capacity $(10^3$ tn/d$)$	Capital return in 100% of investment cost $(10^6\ \$/\text{year})$	Capital return in 100% of investment cost $(10^6\ \$/\text{tone})$	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
3.39	9	30	0.32	35.87	112.37	-46.09	102.15
7.91	30	100	0.75	25.11	98.32	-46.09	77.35
19.21	90	300	1.83	20.33	88.11	-46.09	62.35
50.85	300	1,000	4.84	16.14	77.89	-46.09	47.95

16 / [9.a]. Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.							
Cost of initial investment $(10^6\ \$)$	Annual Capacity $(10^3$ tn/y$)$	Daily Capacity $(10^3$ tn/d$)$	Capital return in 100% of investment cost $(10^6\ \$/\text{year})$	Capital return in 100% of investment cost $(10^6\ \$/\text{tone})$	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
25.99	37	100	2.48	66.90	99.44	-45.91	120.43
66.67	110	300	6.35	57.72	87.01	-45.91	98.82
180.80	365	1,000	17.22	47.18	77.97	-45.91	79.24

b2. Sorting-at-sourceonly biowaste

17. (10 etc.) Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.							
Cost of initial investment $(10^6\ \$)$	Annual Capacity $(10^3$ tn/y$)$	Daily Capacity (tn/d)	Capital return in 100% of investment cost $(10^6\ \$/\text{year})$	Capital return in 100% of investment cost $(10^6\ \$/\text{tone})$	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
1.08	9.00	30	0.10	11.48			
3.04	30.00	100	0.29	9.64	24.26	-14.00	19.90
8.24	90.00	300	0.79	8.72	16.63	-14.00	11.35
26.04	300.00	1000	2.48	8.27	10.53	-14.00	4.79

18. (13 etc.) Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L. **Balanced Budget Charge**							
Cost of initial investment $(10^6\ \$)$	Annual Capacity $(10^3$ tn/y$)$	Daily Capacity (tn/d)	Capital return in 100% of investment cost $(10^6\ \$/\text{year})$	Capital return in 100% of investment cost $(10^6\ \$/\text{tone})$	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
2.71	9.00	30	0.26	28.70	29.70	-25.25	33.15

18. (13 etc.) Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L. **Balanced Budget Charge**							
Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
6.33	30.00	100	0.60	20.09	26.10	-25.25	20.94
15.37	90.00	300	1.46	16.26	23.40	-25.25	14.41
40.68	300.00	1000	3.87	12.91	20.70	-25.25	8.36

b3. Sorting-at-source only recyclables

19. (16.c etc.) "Clean" MRF. Recyclables, disposal of residues in S.L. **Balanced Budget Charge**							
Cost of initial investment (10^6 $)	Annual Capacity (10^3 tn/y)	Daily Capacity (tn/d)	Capital return in 100% of investment cost (10^6 $/year)	Capital return in 100% of investment cost (10^6 $/tone)	Operation Cost ($/tone)	Revenue ($/tone)	**Balanced Budget Charge ($/tone)**
1.08	9.00	30	0.10	11.48			
3.04	30.00	100	0.29	9.64	56.60	-71.00	-4.76
8.24	90.00	300	0.79	8.72	38.80	-71.00	-23.48
26.04	300.00	1000	2.48	8.27	24.56	-71.00	-38.18

The tables below rate the schemes as to the Balanced Budget Charge for two versions of capacity: 300 tn/d and 1,000 tn/d.

Table 39: Rating of examined schemes as to the Financial Criterion 'Balanced Budget Charge'. a) Capacity: 300 tn/d

No of Scheme	**No of Scheme in Annex**	**Description of schemes**	**Balanced Budget Charge**	**Normalised values**
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS				
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	60.89	**3.00**
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	65.96	**2.80**
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	38.05	**3.80**
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	135.02	**0.30**

No of Scheme	No of Scheme in Annex	Description of schemes	Balanced Budget Charge	Normalised values
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	136.93	**0.25**
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	65.76	**2.80**
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	70.84	**2.60**
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	121.51	**0.80**
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	57.23	**3.10**
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	70.39	**2.60**
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	143.06	**0.00**
12		Landfills with recovery and combustion of biogas - energy.	33.16	**4.00**

b. PRE-SEGREGATED WASTE TREATMENT PLANTS

13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	29.74	2.50
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	121.88	0.00
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	62.35	1.60
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	98.82	0.60
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	11.35	3.05
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	14.41	2.90
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	-23.48	4.00

Table 40: Rating of examined schemes as to the Financial Criterion 'Balanced Budget Charge'. b) Capacity: 1,000 tn/d

No of Scheme	No of Scheme in Annex	Description of schemes	Balanced Budget Charge	Normalised values
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS				
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	41.72	**2.60**
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	34.26	**2.80**
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	7.02	**4.00**
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	87.43	**0.65**
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	103.20	**0.00**
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	42.44	**2.50**
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	47.52	**2.30**
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	98.91	**0.20**
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	47.24	**2.30**
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	41.72	**2.60**
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	100.50	**0.10**
12		Landfills with recovery and combustion of biogas - energy.	11.91	**3.80**

b. PRE-SEGREGATED WASTE TREATMENT PLANTS

13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	8.83	**2.40**
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	78.81	**0.00**

15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	47.95	**1.10**
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	79.24	**0.00**
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	4.79	**2.55**
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	8.36	**2.42**
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	-38.18	**4.00**

1.4.4 Technical and operational efficiency Implementation time-frames

Criteriatakeninto account in estimate and assessoftheTechnical and operational efficiency of examined schemes are the following:

- *Operation requirements-complexity*
- *Water Consumption*
- *Flexibility oftechnology*
- *Ability toreceivingof otherwaste streams*

Analytically:

1.4.4.1 *Operation requirements–complexity*

This criterionseeks tobenchmarkthe degreeof difficultyin the operationof the unitsin eachScheme. The evaluationof the criterionconsists of a compositeconsiderationof several parameters such as:

- Complexityofmode of operation (degree of automation,manual work etc.);
- Monitoring and controlıngrequirementsforprocessstability;
- Ease ofmaintenance, find andreplacementof spare parts;
- Interruptiblefeedwithoutseriousimpact on the stabilityand efficiencyof the production process
- Familiarityofthe local workforce(technical, managerial)with the technology

AerobicMBT is widely applied in Europe anda large number ofunitsoperatewith this technology. It haslowoperational requirementsandcomplexity.

*AnaerobicMBE*showsan increase in recentyears. However, the method was originally developedfor the treatmentof netorganic materialsanda few of thetechnologies availablein the marketcan support thetreatmentof mixed MSW. Also, specialized staffround the clock is also required fortheoperationof such a plant, due toits complexity.

The installed capacityof *biologicaldrying*plants alsoincreases. This technologyhas relativelyincreased complexitycompared to theaerobic MBTmainlydue to the requirementsforgas treatmentby thermaloxidation. However, treatment of flue gascan be done with use of biofilterswithout however achieved thesame efficiencyinscrubbing (flue gas cleaning).

*Incineration*is aproven methodwhich is used worldwidefor severaldecades. The operationof such a plantis complex, it requires24-hoursemploymentand specialisedstaff.Emphasisshouldbegiven to theeffectiveness of thegas treatment system.

The abovealso apply tothe *pyrolysis*which -mustbeadditionallynoted that- has not currentlya largecommercial applicationastechnologyandthat not allthe availablesystems are suitablefor processingunsorted MSW.

The table below presentstherating of the examined schemes on the criterion.

The scores are normalised in the following scales:

a) In mixed waste treatment / disposal plants:30 = max 4.00 to 90 = min. 0.00
b) In pre-segregated waste treatment / disposal plants:20 = max 4.00 to 80 = min 0.00

Table 41: Operation requirements–complexity of technologies

No of scheme	No of Scheme in Annex 1	Facilitiesincluded	Operation requirements–complexity	Normalized values
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS				
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	70	1.35
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	90	0.00
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	90	0.00
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	70	1.35
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	70	1.35
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	70	1.35
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	70	1.35
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	60	2.00
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	40	3.30
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	30	4.00
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ	30	4.00

No of scheme	No of Scheme in Annex 1	Facilitiesincluded	Operation requirements– complexity	Normalized values
		incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.		
12		Landfills with recovery and combustion of biogas -energy.	30	4.00
b. PRE-SEGREGATED WASTE TREATMENT PLANTS				
b1. Separate Sorting-at-sourceof biowaste and dry streams				
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	30	3.50
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	80	0.00
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	60	1.30
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	80	0.00
b2. Sorting-at-sourceonly biowaste				
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	20	4.00
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	40	2.60
b3. Sorting-at-source only recyclables				
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	20	4.00

Thermal treatment technologies outweigh, followed by the technologies of production and combustion of biogas.

1.4.4.2 *Water Consumption*

This criterionevaluates thewater consumptiononlyduring the manufacturingprocess, as the consumptionof waterfor washingfacilitiesand staff is takencommonto all technologies.

Water consumptionis too small in *aerobicMBT*unitswherewater is only intermittentlyusedforhumidificationduringcomposting, ifnecessary.

Under*anaerobicMBE*additionalquantities of water are required duringthe anaerobic digestion.

In *bio-drying* method, where the aim is toremove moisturefrom the waste to increase thecalorificpower,notadditional water is used.

In *thermaltreatment* methods water is used inthetreatmentof waste gases.

The table below presents therating of the examined schemes on the criterion. The scores are normalised in the following scales: 0.17 (min = 0.00) to 0.00 (max = 4.00).

Table 42: Water Consumption

No of scheme	No of Scheme in Annex 1	Facilitiesincluded	Water Consumption(m^3/tn)	Normalized values
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	0.1	1.60
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	0.1	1.60
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	0.1	1.60
4	8.c1	Aerobic MBT.RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.17	0.00
5	8.c2	Aerobic MBT.RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.17	0.00
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	0.05	2.80
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	0.05	2.80
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.17	0.00
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.05	2.80
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	-	4.00
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.08	2.00
12		Landfills with recovery and combustion of biogas -energy.	-	4.00
b. PRE-SEGREGATED WASTE TREATMENT PLANTS				
b1. Separate Sorting-at-sourceof biowaste and dry streams				

No of scheme	No of Scheme in Annex 1	Facilitiesincluded	Water Consumption(m^3/tn)	Normalized values
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	0.05	2.80
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.17	0.00
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	0.05	2.80
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	0.17	0.00
b2. Sorting-at-sourceonly biowaste				
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	0.05	2.80
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	0.05	2.80
b3. Sorting-at-source only recyclables				
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	0.0	4.00

1.4.4.3 *Flexibility oftechnology*

This criterionseeks toassess theflexibilityof technology tofuture legislativetrendsshaped byinternational institutions and/or country Authorities onincreasing recyclingand organicmaterialsandfluctuations inincomingquantities whichmay be due tosocial or otherreasons.

*AerobicMBT*presentssignificant flexibility, since the functionof the mechanical treatmentcan be adjustedto incomingamounts viareductionor operationalrise time ofeach line, and finallyoperates atoneor moreshifts.The configurationofcompostingsystemsalso allowsthemtoeasily adjustquantitiesfluctuationsor futureuse forpre-segregated organic in case of future extension ofthesortingat source system.

Anaerobic Digestion systems can be modular, so they can be sized according to local needs and be upgraded over time. However, their considerable construction cost make them inappropriate for “small” units with limited capacities (<10tn/d).

Forthe mechanicalpartof the *anaerobicMBT*applytheforegoing. The anaerobicreactors ofcontinuous flowdigestion(24 hour operation) must haveasteady stream ofincomingmaterialfor their effectivefunctioning, whilebatchsystemsare not affectedat all.Thiscan be addressedeffectively withthe useof more than onereactor.

The *biologicaldrying*can respondto a lesserextentfrom aerobicMBEinquantitychangesas theround the clockbiologicaltreatment thatis the firststep intreatmenthas a specificcapacityandincreased volumesshouldbe absorbedfrom the reception areaprovided thatithas been properlysized.

In the*thermaltreatment*units, the quantity of incoming materialshould bekept constant,so that thecombustionis performedwithhigh yield.Reducinginput quantityhas a directimpact on theproduction of electricityandhencetheviabilityof the plant.

The table below presents therating of the examined schemes on the criterion. The scores are normalised in the scales: 20 (min = 0.00) to 90 (max = 4.00).

Table 43: Flexibility oftechnology

No of scheme	No of Scheme in Annex 1	Facilitiesincluded	Flexibility oftechnology	Normalized values
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	50	1.70
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	30	0.60
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	30	0.60
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	90	4.00
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	90	4.00
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	90	4.00
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	90	4.00
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	90	4.00
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	90	4.00
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	70	2.80
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	70	2.80
12		Landfills with recovery and combustion of	20	0.00

No of scheme	No of Scheme in Annex 1	Facilitiesincluded	Flexibility oftechnology	Normalized values
		biogas -energy.		
b. PRE-SEGREGATED WASTE TREATMENT PLANTS				
b1. Separate Sorting-at-sourceof biowaste and dry streams				
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	90	4.00
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	90	4.00
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	90	4.00
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	90	4.00
b2. Sorting-at-sourceonly biowaste				
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	90	4.00
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	90	4.00
b3. Sorting-at-source only recyclables				
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	90	4.00

1.4.4.4 *Ability to treat alia waste streams*

*Incineration*hasthe greatest flexibilitywith regardto theadmission of otherwastestreamssuch assewage sludge, tires.

*Pyrolysisand Gasification*canalsoprocess awide varietyof wastehowevermanytechnologiesare designedfor a specifictype of wasteandshould be consideredseparately, their suitability for othertypes of waste.

MBT technologies can additionally treat only sludge in the biological part of the installation.

The table below presents therating of the examined schemes on the criterion. The scores are normalised in the scales: 10 (min = 0.00) to 90 (max = 4.00).

Table 44: Ability to treat alia waste streams

No of scheme	No of Scheme in Annex 1	Facilitiesincluded	Ability to treat alia waste streams	Normalized values
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	90	4.00
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	40	1.50
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	40	1.50
4	8.c1	**Aerobic MBT.**RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	30	1.00
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	30	1.00
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	30	1.00
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	30	1.00
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	30	1.00
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	30	1.00
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	30	1.00
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	30	1.00
12		Landfills with recovery and combustion of biogas -energy.	90	4.00
b. PRE-SEGREGATED WASTE TREATMENT PLANTS				
b1. Separate Sorting-at-sourceof biowaste and dry streams				
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	30	1.00
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in	30	1.00

No of scheme	No of Scheme in Annex 1	Facilitiesincluded	Ability to treat alia waste streams	Normalized values
		H.W.L.		
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	30	1.00
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	30	1.00
b2. Sorting-at-sourceonly biowaste				
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	10	0.00
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	10	0.00
b3. Sorting-at-source only recyclables				
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	10	0.00

The table follows summarizes the performance of the examined schemes as to the Technical Criteria.Landfills, Bio-drying with landfilling of SRF and Anaerobic MBT with production and disposal of RDF and utilisation of CLO are the schemes that collected the higher rating.

Table 45: **Rating of examined Schemes as to Technical Criteria**

No of Scheme	No of Scheme in Annex	Description of schemes	Operation requirements - complexity	Water Consumption	Flexibility of technology	Ability to treat alia waste streams	Total
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS							
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	1.35	1.60	1.70	4.00	**8.65**
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	0.00	1.60	0.60	1.50	**3.70**
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	0.00	1.60	0.60	1.50	**3.70**
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1.35	0.00	4.00	1.00	**6.35**
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1.35	0.00	4.00	1.00	**6.35**
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	1.35	2.80	4.00	1.00	**9.15**
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	1.35	2.80	4.00	1.00	**9.15**
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	2.00	0.00	4.00	1.00	**7.00**
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in	3.30	2.80	4.00	1.00	**11.10**

No of Scheme	No of Scheme in Annex	Description of schemes	Operation requirements - complexity	Water Consumption	Flexibility of technology	Ability to treat alia waste streams	Total
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS							
		H.W.L.					
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	4.00	4.00	2.80	1.00	**11.80**
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	4.00	2.00	2.80	1.00	**9.80**
12		Landfills with recovery and combustion of biogas -energy.	4.00	4.00	0.00	4.00	**12.00**

No of Scheme	No of Scheme in Annex	Description of schemes	Operation requirements - complexity	Water Consumption	Flexibility of technology	Ability to treat alia waste streams	Total
b. PRE-SEGREGATED WASTE TREATMENT PLANTS							
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	3.50	2.80	4.00	1.00	**11.30**
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.00	0.00	4.00	1.00	**5.00**
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	1.30	2.80	4.00	1.00	**9.10**

No of Scheme	No of Scheme in Annex	Description of schemes	Operation requirements - complexity	Water Consumption	Flexibility of technology	Ability to treat alia waste streams	Total
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	0.00	0.00	4.00	1.00	**5.00**
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	4.00	2.80	4.00	0.00	**10.80**
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	2.60	2.80	4.00	0.00	**9.40**
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	4.00	4.00	4.00	0.00	**12.00**

1.4.5 Social / socioeconomic aspects

Social acceptanceandsustainabilityconstitutesyet anotherdimensionof sustainabilityin waste managementbeside theenvironmentaland economic. Thesocial sustainability is the"attitude" of the waste managementsystemtowards society.

Social criteriaandsocial indicatorstakeninto account in assessingormeasuring thesocial sustainabilityof alternativetechnologiesand systems are the following:

- Odorsfrom waste treatment
- Visual impactAestheticnuisance from waste treatment plants
- trafficburdens
- Land requirements from waste treatment plants
- Number of jobs created
- Social reactions

Analytically:

1.4.5.1 *Odors*

The term'Odors from waste treatment' describesthe possibilityofodornuisance caused byagiven wastemanagementinstallationtothe neighboring inhabitants.

The methodologyused internationallytoquantifyodornuisancefromwaste treatmentis based on theestimation of actualodor emission. Averageodoremissionrates are usedfrom characteristictreatment facilitiesper tonof waste processed.

Odor emissions are expressed in odor units: OU or OU/m^3.Theodor unit is equal to thevolume of solvent(air) that is required to diluteoneodorunit volumein order to remain below thedetection threshold. The OU/m^3 is defined as theodorconcentrationin 1 m^3 of air in theodordetection threshold ([17]).

Thefacilitieswith the highestodoremissionsare thosecontaining biologicalprocesses, ie:

- Sanitary landfilling (organic and gardenwaste)
- Aerobicandanaerobic-Mechanicalbiologicalpretreatment(mixed and household waste)

Lower odoremissionsare emitted in facilities that include temporary storageof untreatedwastesuch as:

- sortingstations(mixed, dryrecyclable)
- combustion facilities (mixed, household waste)

Facilities with low odoremissions are:

- shredding
- recycling (of paper, glass, metals, plastics)
- the incineration of RDF orSRFtocement kilnsorinother units
- the incineration

The odor emissionvaluesfor various applied technologiesare definedandgivenin the following table.

[17] *Zhang, Q., Feddes, J., Edeogu, I., Nyachoti, M., House, J., Small, D., Liu, C., Mann, D., Clark, G., 2002, Odour Production, Evaluation and Control; Project MLMMI 02-HERS- 03 Final Report submitted to Manitoba Livestock Manure Management Initiative: available at: http://www.manure.mb.ca/projects/completed/pdf/02-hers-03.pdf*

Table 46: AverageOdor Emission values

Technology	Type of waste	Gas cleaning system	AverageOdor Emission (OU/t of inc. MSW)	Commentary
Sanitary landfill	Mixedhousehold waste		1.20E+08	
	Mechanically-biologically pretreated waste		5.00E+06	
Aerobic stabilization / Composting	Organic waste + garden waste	Biofilter	5.20E+06	Averagevolume of gas17.000 m^3/tof incoming waste
	Organic waste + garden waste		1.00E+08	
Anaerobicdegradation	Organic waste + garden waste	Gasusefor power generation	3.20E+06	
Mechanical - Aerobictreatment	Mixedhousehold waste	Biofilter	3.10E+06	
	Mixedhousehold waste		6.20E+07	
Incineration	Mixedhousehold waste		54	Consideringthe loadingtime3 minutes ([18])
	Mechanically-biologically pretreated waste		9	

In the next tableare givennormalizedodorvaluesdepending on the intensityofnuisance ([19]).

Table 47: Normalization of odornuisance

Intensityof odor	Odor Emissions (OU/t of inc. MSW)	Normalized indicators
Veryto extremelystrong	≥ 1.00E+8	0
Strong	1.00E+7 - 9.99E+7	1
Sensible	1.00E+5 - 9.99E+6	2
Veryweak	1.00E+3 - 9.99E+4	3
Absence of odor	≤9.99E+2	4

The table following rates the examined schemes as to the criterion and normalizedodorvalues.

Table 48: Rating of examined schemes as to Odor nuisance

No of scheme	No of Scheme in Annex	Facilitiesincluded	AverageOdor Emission (OU/t of inc. MSW)	Normalized values
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	54	4
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	54	4

[18]Würz, W., 2000, Planung und Bau von Abfallumladestationen in: Müll Handbuch, Band 3; No 2320; MuA Lfg, 9/00; Erich Schmidt Verlag; Berlin.
[19]Zhang, Q., Feddes, J., Edeogu, I., Nyachoti, M., House, J., Small, D., Liu, C., Mann, D., Clark, G., 2002, Odour Production, Evaluation and Control; Project MLMMI 02-HERS- 03 Final Report submitted to Manitoba Livestock Manure Management Initiative. Available at: http://www.manure.mb.ca/projects/completed/pdf/02-hers-03.pdf.

No of scheme	No of Scheme in Annex	Facilitiesincluded	AverageOdor Emission (OU/t of inc. MSW)	Normalized values
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	54	4
4	8.c1	**Aerobic MBT.**RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1,30E+06	2
5	8.c2	**Aerobic MBT.**RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1,30E+06	2
6	8.d1	**Aerobic MBT.**RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	1,30E+06	2
7	8.d2	**Aerobic MBT.** RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	1.00E+7	1
8	9.c	**Anaerobic MBT.** RDF and in-situ incineration-energy, **utilisation of CLO**, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1,18E+06	2
9	9.d	**Anaerobic MBT.** RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1,18E+06	2
10	8.f	**Bio-drying**. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	9,33E+06	2
11	8.e	**Bio-drying**. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	5,20E+06	1
12		Landfills with recovery and combustion of biogas -energy.	1,20E+08	0
b. PRE-SEGREGATED WASTE TREATMENT PLANTS				
b1. Separate Sorting-at-sourceof biowaste and dry streams				
13	6.a	**Mechanical – Aerobic Composting facility**. Recyclables, HQ Compost, disposal of residues in S.L.	1,30E+06	2
14	8.a	**Mechanical – Aerobic Composting facility.** RDF and *in-situ* incineration - energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1,30E+06	2
15	9.b	**Mechanical – Anaerobic facility.** Recyclables, HQ Compost, Biogas -	1,18E+06	2

No of scheme	No of Scheme in Annex	Facilitiesincluded	AverageOdor Emission (OU/t of inc. MSW)	Normalized values
		energy, disposal of residues in S.L.		
16	9.a	**Mechanical – Anaerobic facility.** RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	1,18E+06	2
b2. Sorting-at-sourceonly biowaste				
17	10 etc.	**Mechanical – Aerobic Composting facility**. Compost / disposal of residues in S.L.	1,30E+06	2
18	13 etc.	**Mechanical – Anaerobic facility.**Compost, biogas - energy, disposal of residues in S.L.	1,18E+06	2
b3. Sorting-at-source only recyclables				
19	16.c etc.	**“Clean” MRF**. Recyclables, disposal of residues in S.L.	≤9.99E+2	4

The valuesof theabovetable show that thethermaltreatment technologieshave the minimumodor, sanitary landfillshavethe maximumand in betweenareall the othertechnologiesinthe same order ofmagnitudeof odoremissions.

1.4.5.2 *Visual impact (Aestheticnuisance) from waste treatment plants*

This indicator measuresthe visual impactofwaste treatmentfacilities taking into account the visualobstruction(solid angle) andthe heightof installation.

The visual obstruction is defined as a percentage of the visual field of an observer that is prevented by the installation. It is estimated quantitatively by measuring the solid angle (steradian) formed between the installation and the observation point. The steradian defined by the center of the sphere with unit radius andunit basisonthe spheresurfaceis takenas unit of measurement. The magnitudeof the opticalobstructiondependsdirectlyin proportion on the sizeof the facility (obstructionsurface) andinversely proportional on the distanceof the observerfrom the facility (r).

$$\textbf{opticalobstruction} = A/r^2 \ \textbf{[steradian]}$$

Fullconcealmentof the visual fieldofan object(whichmeansashemisphere)equivalents to twosteradian. The unitsteradianis rarelyusedbecause itdescribesextremelylarge values of visual impact. Instead,view of customary usage, millisteradian is used(ms: 1/1000 steradian). Noted thatthe sizesusually occurin practiceisof the order of50-600ms.

The visualobstructionis determinedin the broadercatchment areaof the highestpart of the plant, forexampleto an incineration plantthis partis thechimney. The visualobstructionis classified intofivelevels. At the lowestlevel, thefacilitycausesobvious changesin the characterof landscape and the viewsof alarge area; in theaverage level it causesmoderatechanges and in the highest levelcausesalmostimperceptiblechanges.

The scores are normalised according to the following rationale:

Visual impact	Field of vision	Normalized values

Visual impact	Field of vision	Normalized values
Insignificant	Non-visible activities	4
Moderate	Activitiesnotvisuallydiscernible	3
Medium	Activitiesvisiblebutminor	2
Considerable	Activitiesvisuallydominant	1
Significant	Activitiesvisuallydominant andout of scale	0

The*anaerobicdigestion* facilities burden thevisual environment due to theusuallyverticalreactor andtheheat treatment installation throughthe chimney, while sometypes of ADoperate withhorizontalreactor.

Annoyancefrom *biologicaldrying*unitsvariesdepending on the gas treatmentsystem(thermaloxidationorbiofilter).

In the following table is given the evaluation of alternative schemes as to the Aestheticnuisance and the normalised values.

Table 49: Impact of examined SWM schemes as to the visual affection (space aesthetic)

No of scheme	No of Scheme in Annex	Facilitiesincluded	Impact onspace aesthetic	Normalized values
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	Loweffect. Requiressmall areaandsinglebuilding infrastructure.	3
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	Loweffect. Requiressmall areaandsinglebuilding infrastructure.	3
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	Loweffect. Requiressmall area andsinglebuilding infrastructure	3
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	Particularlyincreased burden. Requiresseparatebuilding infrastructureandlandfortheestabli shmentof aerobicprocess.	0
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	Particularlyincreased burden. Requiresseparatebuilding infrastructure,landfortheestablish mentof aerobic process and more land for landfilling the biostabilised material.	1
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	Particularlyincreased burden. Requiresseparatebuilding infrastructureandlandfortheestabli shmentof aerobicprocess.	1
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	Particularlyincreased burden. Requiresseparatebuilding infrastructure,landfortheestablish mentof aerobic process and more land for landfilling the biostabilised material.	2

No of scheme	No of Scheme in Annex	Facilitiesincluded	Impact onspace aesthetic	Normalized values
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	Increasedburden. Lesslandthanaerobicprocess. Lowerheight ofchimney than RDF/SRF incineration plants.	2
9	9.d	Anaerobic MBT. RDF-disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	Increasedburden. Lesslandthanaerobicprocess. Lowerheight ofchimney than RDF/SRF incineration plants.	2
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	Particularlyincreased burden, since apartfrombuilding infrastructure it requires large landfill area forburial of stabilat.	1
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	Increasedburden. Requireslarger area thanincineration	0
12		Landfills with recovery and combustion of biogas -energy.	Particularlyincreased and significant burden. Activityvisuallydominant.	0
b. PRE-SEGREGATED WASTE TREATMENT PLANTS				
b1. Separate Sorting-at-sourceof biowaste and dry streams				
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	Particularlyincreased burden. Requiresseparatebuilding infrastructureandlandfortheestablishmentof aerobicprocess.	1
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	Particularlyincreased burden. Requiresseparatebuilding infrastructureandlandfortheestablishmentof aerobicprocess.	1
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	Increasedburden. Requireslarger area thanincineration andpossiblyvoluminousbioreactors. Lesslandthanaerobicprocess.Lowerheight ofchimney than incineration plants and RDF/SRF incineration plants.	2
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	Increasedburden. Lesslandthanaerobicprocess. Lowerheight ofchimney than RDF/SRF incineration plants.	2

No of scheme	No of Scheme in Annex	Facilitiesincluded	Impact onspace aesthetic	Normalized values
b2. Sorting-at-sourceonly biowaste				
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	Particularlyincreased burden. Requiresseparatebuilding infrastructureandlandfortheestablishmentof aerobicprocess.	1
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	Increasedburden. Lesslandthanaerobicprocess. Lowerheight ofchimney than RDF/SRF incineration plants.	2
b3. Sorting-at-source only recyclables				
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	Loweffect. Requiressmall areaandsinglebuilding infrastructure.	3

Tthe gasification of plasma / vitrification and the incineration outweigh in this criterion, followed by the technologies of production / combustion of biogas.

1.4.5.3 *Trafficburdens*

The trafficburdens generated by waste treatment processes are due to the transferof secondary materials and/or secondary waste streamsoutput fromthe premises.

To estimate this indicator is taken in consideration that thedistance traveledofsecondary products/residuesis the same forall technologies, and the index is expressed on kgs of secondary products/residues per ton of incoming MSW.

The score is normalised according to the following scale:

Trafficburdens	Normalized values
Insignificant	4
Moderate	3
Medium	2
Considerable	1
Very heavy	0

Table 50: Traffic impacts from the examined schemes

No of scheme	No of Scheme in Annex 1	Facilitiesincluded	Secondary materials, by-products, residuesto be transferred(kg/tn of inc. MSW)	Normalized values
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	345	2.75
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	187	3.25
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. /	272	2.90

No of scheme	No of Scheme in Annex 1	Facilitiesincluded	Secondary materials, by-products, residuesto be transferred(kg/tn of inc. MSW)	Normalized values
		disposal of H.R in H.W.L.		
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	560	1.70
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	560	1.70
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	772	0.90
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	772	0.90
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	545	1.85
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	545	1.85
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	750	1.00
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	395	2.50
12		Landfills with recovery and combustion of biogas -energy.	0	4.00
b. PRE-SEGREGATED WASTE TREATMENT PLANTS				
b1. Separate Sorting-at-sourceof biowaste and dry streams				
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	756	1.00
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration - energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in	545	1.85

No of scheme	No of Scheme in Annex 1	Facilitiesincluded	Secondary materials, by-products, residuesto be transferred(kg/tn of inc. MSW)	Normalized values
		H.W.L.		
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	711	1.20
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	500	2.00
b2. Sorting-at-sourceonly biowaste				
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	446	2.20
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	402	2.50
b3. Sorting-at-source only recyclables				
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	1,000	0.00

“Clean” MRF and Aerobic MBT with production and disposal of RDF and with utilisation or landfilling of bio-stabilised material are the schemes with the higher trafficburden because of thelarge amount ofmaterial carriedto the market or to disposal or to burial. SanitaryLandfill hasthe leasttrafficburden since no products /by-products are produced andthereforethere is noneed for any transfer.

1.4.5.4 *Land requirements*

The followingtable gives the land requirementsby examined scheme in m^2/tn of design capacity, consideringplantsin operationandliterature references on various technologies.

The score values are normalised according to the following scale:

Land requirements	Normalized values
Very low	4
Moderate	3
Medium	2
Considerable	1
Very high	0

Table 51: Land requirements of examined schemes

No of scheme	No of Scheme in Annex	Facilitiesincluded	Land requirements (m^2/tn)	Normalized values

No of scheme	No of Scheme in Annex	Facilitiesincluded	Land requirements (m^2/tn)	Normalized values
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	0.1	4.00
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	0.1	4.00
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	0.1	4.00
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.99	0.00
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1.88	2.00
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	0.89	2.20
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	1.78	2.60
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.7	2.80
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.6	3.40
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	0.26	3.60
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.36	0.20
12		Landfills with recovery and combustion of biogas -energy.	100 (*)	0.00

(*) Thelandfillsurfaceis calculated for20years, based on the followingassumptions:

- Production: m=1,2 kg/inhabitant/day.
- Wastedensity: ρ = 250 kg/m3
- Compaction ratio: 1:2
- Overlaymaterial:25%of the volumeof compacted waste.
- Burialin twolayers of height2,5 meach.
- Estimatedlife oflandfills: 20 years.

b. PRE-SEGREGATED WASTE TREATMENT PLANTS

b1. Separate Sorting-at-sourceof biowaste and dry streams

No of scheme	No of Scheme in Annex	Facilitiesincluded	Land requirements (m^2/tn)	Normalized values
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	0.89	2.20
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	0.99	2.00
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	0.6	2.80
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	0.7	2.60
b2. Sorting-at-sourceonly biowaste				
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	0.7	2.60
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	0.48	3.10
b3. Sorting-at-source only recyclables				
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	0.05	4.00

1.4.5.5 *Jobs creation*

The total numberof directjobs creation is examined in thiscriterion. Depending onthe type of plant the personnel include:

- The guardof the factory;
- The responsible of weighing room;
- The responsible of supply;
- The Director;
- Other administrative staff;
- Drivers of machinery – vehicles;
- Maintainers;
- Responsible persons for treatment of leachates;
- Workers in sorting section;
- Responsible of composting process;
- Responsible of combustion section;
- Responsible of gasespurification section;

The valuesof this indexdifferverystronglyfrom countryto country and fromsuppliertosupplier, so it is notpossible to draw a constant relationshipbetweenplantcapacityandjobs. Thereforemore complexrelationshipsare used accordingto the table below.

Table 52: Requiredjobsin various MSW treatment plants ([20])

Treatment plant	Relative jobs /100,000tn/y of incoming MSW
Aerobic Stabilisation	- 1.9 ln (ln Capacity) + 49.0
Biogas production	- 48 ln (ln Capacity) + 508
MBT (incl. either aerobic or anaerobic stabilisation)	16.5
Incineration	- 9.4 ln (ln Capacity) + 144.7
Sanitary Landfill	- 6.2 ln (ln Capacity) + 82.1

Based on thevaluesof the previous table,jobsfor a specificplantare calculated as follows:

Totaljobs = [Relative jobs /100,000tn/y of inc. MSW] x [tn/y of inc. MSW]

Thecreationofnewjobs is directlydependentonthe levelofautomationofaplant.

- In*thermalprocessingunits*wherethere is no directhuman interventionin processingjobs arelimited.
- The *biologicaldrying*isalsoa processwith a relatively highdegree ofautomation, wherein the onlyproducts producedarethe stabilizedresidueand recoveredmetals.
- In*MBTunits*depending on the configurationof the mechanicalsortingis possible to createnew jobsespeciallyifthere ismanualsorting. Alsothe existence ofprocessing stepssuch asrefineryand the layingofbiologically treatedorganicinsquareto their maturityensuremore jobs.

The followingtable gives therating of examined schemes as to new job creation. Score values vary between min 0.00 (0 jobs) to max 80 (max jobs), consideringplantsin operationandliterature references on various technologies. The values are then normalised proportionally on the scale 0 to 4.

Table 53: Job creation from examined schemes

No of Scheme	No of Scheme in Annex 1	Facilitiesincluded	Rating of new job creation	Normalized values
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS				
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	40	2.0
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	30	1.5
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	30	1.5
4	8.c1	Aerobic MBT. RDF and in-situ incineration- energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	80	4.0

[20]Emilia den Boer (Szpadt), Jan den Boer, Jan Berger, Prof. Johannes Jager, Julio Rodrigo, Dr. Montse Meneses, Prof. Francesc Castells, Umur Natus –Yildiz, Gernod Dilewski, Orhan Boran, The Use of Life Cycle Assessment Tool for the Development of Integrated Waste Management Strategies for Cities and Regions with Rapid Growing Economies, Deliverable Report on D5.1 and D5.2: Social Sustainability Criteria and Indicators for waste management (Work package 5), LCA-IWM, Darmstadt, 31.08.2005

No of Scheme	No of Scheme in Annex 1	Facilitiesincluded	Rating of new job creation	Normalized values
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	80	4.0
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	50	2.5
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	50	2.5
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	70	3.5
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	50	2.5
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	40	2.0
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	50	2.5
12		Landfills with recovery and combustion of biogas -energy.	20	1.0
b. PRE-SEGREGATED WASTE TREATMENT PLANTS				
b1. Separate Sorting-at-sourceof biowaste and dry streams				
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	70	3.5
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	80	4.0
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	70	3.5
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	80	4.0
b2. Sorting-at-sourceonly biowaste				

No of Scheme	No of Scheme in Annex 1	Facilitiesincluded	Rating of new job creation	Normalized values
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	60	3.0
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	60	3.0
b3. Sorting-at-source only recyclables				
19	16.c etc.	"Clean" MRF. Recyclables, disposal of residues in S.L.	50	2.5

1.4.5.6 *Social acceptance*

Thesolid wastemanagement projectsusuallyhave difficulty inlocation due toreactionsfrom the local community.

Based oninternational experience, the constructionof *thermalprocessing* unitsis connectedwith increasedreactions when compared to*MBEmethods*due tothe potential risks associatedwithair emissions.

The followingtable rates the examined schemes as to the social acceptance level. Scoring varies between 0.00 (no social acceptance) and 80 (max social acceptance) consideringvarious technologies andliterature references from international experience. The values are then normalised proportionally on the scale 0 to 4.

Table 54: Rating of examined schemes as to the Social acceptance level.

No of scheme	No of scheme in Annex	Facilitiesincluded	Socialreactions	Ratingof socialacceptance	Normalized values
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS					
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	Verystrongsocial reactions	20	1
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	Verystrongsocial reactions	20	1
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	Moderatesocial reactions (burnsgas instead of fossil fuels, and does not produce liquids, flyandheavy ash)	30	1.5
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	Strongsocial reactions (although producinglowresidue) due to odors releasesandburning of RDF	40	2
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	Strongsocial reactions (although producinglowresidue) due to odors releasesandburning of RDF	40	2
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	Moderate social reactions due to odors releases	60	3
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	Moderate social reactions due to odors releases	60	3
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	Moderate to Strongsocial reactions due to burning of RDF	80	4
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas - energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	No significant social reactions due to low releases to the environment (closed process, burning gas, compost produced in closed bioreactors without aerobic process)	80	4

No of scheme	No of scheme in Annex	Facilitiesincluded	Socialreactions	Ratingof socialacceptance	Normalized values
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	Highsocialreactionsdue toodorsreleasesfromthe process andthelandfill(burial of the partiallystabilizedresidue)	60	3
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	Strong socialreactions due toodors releasefromthe process and the combustionofstabilat	40	2
12		Landfills with recovery and combustion of biogas -energy.	Verystrongsocial reactions due to odors releases, dust and aesthetic degradation	20	1
b. PRE-SEGREGATED WASTE TREATMENT PLANTS					
b1. Separate Sorting-at-sourceof biowaste and dry streams					
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	Moderate social reactions due to odors releases	60	3
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	Strongsocial reactions (although producinglowresidue) due to odors releasesandburning of RDF	40	2
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	No significant social reactions due to low releases to the environment (closed process, burning gas, compost produced in closed bioreactors without aerobic process)	80	4
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	In general acceptable method. Low social reactions may occur	60	3
b2. Sorting-at-sourceonly biowaste					
17	10 etc.	Mechanical – Aerobic Composting facility. Compost /	Moderate social reactions due to odors releases	60	3

No of scheme	No of scheme in Annex	Facilitiesincluded	Socialreactions	Ratingof socialacceptance	Normalized values
		disposal of residues in S.L.			
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	In general acceptable method.	80	4
b3. Sorting-at-source only recyclables					
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	In general acceptable method.	80	4

"Clean" MRF, Anaerobic digestion plants for pre-segregated organic and Anaerobic MBT are the schemes with higher scores in the criterion, while landfill and thermal treatment technologies meet strong social reactions.

The table following summarizes the performance of the examined schemes as to the social criteria.

Table 55: Rating of examined schemes as to the Social criteria.

No of Scheme	No of Scheme in Annex	Description of schemes	Odors	Traffic burdens	Aesthetic nuisance	Land requirements	Job creation	Social reactions	Total
a. MIXED WASTE TREATMENT / DISPOSAL PLANTS									
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	4.00	2.75	3.00	4.00	2.00	1	**16.75**
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	4.00	3.25	3.00	4.00	1.50	1	**16.75**
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	4.00	2.90	3.00	4.00	1.50	1.5	**16.90**
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	2.00	1.70	0.00	0.00	4.00	2	**9.70**
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	2.00	1.70	1.00	2.00	4.00	2	**12.70**
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	2.00	0.90	1.00	2.20	2.50	3	**11.60**
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	1.00	0.90	2.00	2.60	2.50	3	**12.00**
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in	2.00	1.85	2.00	2.80	3.50	4	**15.15**

No of Scheme	No of Scheme in Annex	Description of schemes	Odors	Traffic burdens	Aesthetic nuisance	Land requirements	Job creation	Social reactions	Total
		H.W.L.							
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	2.00	1.85	2.00	3.40	2.50	2	**14.75**
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	2.00	1.00	1.00	3.60	2.00	3	**12.60**
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	1.00	2.50	0.00	0.20	2.50	2	**8.20**
12		Landfills with recovery and combustion of biogas -energy.	0.00	4.00	0.00	0.00	1.00	1	**6.00**

No of Scheme	No of Scheme in Annex	Description of schemes	Odors	Traffic burdens	Aesthetic nuisance	Land requirements	Job creation	Social reactions	Total
b. PRE-SEGREGATED WASTE TREATMENT PLANTS									
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	2.00	1.00	1.00	2.20	3.50	3	**12.70**
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in	2.00	1.85	1.00	2.00	4.00	2	**12.85**

No of Scheme	No of Scheme in Annex	Description of schemes	Odors	Traffic burdens	Aesthetic nuisance	Land requirements	Job creation	Social reactions	Total
		H.W.L.							
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	2.00	1.20	2.00	2.80	3.50	4	**15.50**
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	2.00	2.00	2.00	2.60	4.00	3	**15.60**
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	2.00	2.20	1.00	2.60	3.00	3	**13.80**
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	2.00	2.50	2.00	3.10	3.00	4	**16.60**
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	4.00	0.00	3.00	4.00	2.5	4	**17.50**

1.4.6 Existingexperience-reliability

It is commonly agreedthat increasedcommerciallyinstalled capacityof a technologyis a signofreliability. However, reducedinstalled capacitydoes notnecessarily meanlow reliabilityas sometechnologieshave been developedonly in recentyearsand not alloperatingparametershave beenfullyclarified,a fact thatis also reflectedin the availableliterature.

*AerobicMBT*is acombination of mechanicalandaerobicbiological treatment, twoproventechniqueswith a highdegree of reliability.

Anaerobic Digestion hascomparativelylowerreliability, as itismore appropriatefor cleanorganic wastewhilethe mechanically separatedorganicof mixed waste (*MBT – Anaerobic*) haveincreased percentagecontaminants.

The *biologicaldrying*is a variantof aerobicMBEandwhat has been aforementioned is applied.

Regarding the*heat treatmentmethods*, the experience andknowledge gainedover theyears, as well asthe emergenceof majorenvironmental problems(e.g, soilandgroundwaterpollution, air pollution, reducingfossil fuel reserves, increasingenergy needs, etc.),whichnecessitatedthe impositionof strict standardsandlimitationsin managingall typesof wasteand in human activitiesin general, significantlychanged thecharacterof so-called Thermal treatment of MSW.

*Incineration*is usedfor decades and the existing experienceandknow howisverylarge,makingthis technologysufficiently reliableandefficient.

Regarding*pyrolysis*many of theunitsin operationarepilotsand in recent yearssignificant problemshave been reported insomeunitsthat raisequestions about reliabilityof the technology ([21])concerning the treatment ofmixed municipal wastedue to theirheterogeneouscomposition.

The followingtable rates the examined schemes as to the international existingexperience and the reliability of relevant technologies. The scoring varies from min 0.00 (no or very poor experience-reliability) to 90 (max experience–reliability), consideringliterature references from international applications. The values are then normalised proportionally on the scale 0 to 4.

[21] Juniper – Pyrolysis and Gasification Factsheet 2008.

Table 56: Rating of examined schemes as to the international existing experience and reliability of relevant technologies

No of scheme	No of Scheme in Annex 1	Facilitiesincluded	Rating of existing experience - reliability	Normalized values
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	90	4.00
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	30	0.00
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	30	0.00
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	90	4.00
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	90	4.00
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	90	4.00
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	90	4.00
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	60	2.00
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	60	2.00
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	70	2.70
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	70	2.70
12		Landfills with recovery and combustion of biogas -energy.	90	4.00

b. PRE-SEGREGATED WASTE TREATMENT PLANTS
b1. Separate Sorting-at-sourceof biowaste and dry streams

13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	90	4.00
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	90	4.00
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	60	2.00
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	60	2.00
b2. Sorting-at-sourceonly biowaste				
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	90	4.00
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	60	2.00
b3. Sorting-at-source only recyclables				
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	90	4.00

1.4.7 Inclusive Evaluation

In the fourfollowing tablesthe aggregatedresultsof the evaluationof the examined schemes are given on allcriteria, weighted byweighting factorspercriterions as definedearlier, separately formixed wasteandfor pre-segregated waste treatment plants.

The first two tables present the results concerning plants of capacityto 300tn/daywhereasnext two of capacityto 1,000tn/day. The resultsinoneandin the other casedifferonly with respectto thecriterion of financialevaluation, becauseof the variabilityof financial figures in relation to thecapacity (investment cost, capital return and OPEX, revenues, balanced budget charge).

The evaluatedschemesare presented inrankingin descending orderof finalscore.

a) plants of capacityto 300tn/day

As regardsto mixed waste treatment, the schemeswiththe highest totalscore are the Aerobic MBT that produces RDF for disposal to other consumers (cement industry, power plants etc.) and biostabilised material for utilisation (scheme No 6) and the Anaerobic MBT that produces CLO for utilisation and energy from biogas (scheme No 9).

Schemes No 7 (Aerobic MBT that produces RDF for disposal to other consumers and biostabilised material led to burial) and No 1 (Incineration with energy recovery) follow by short distance.

Respectively as regards to pre-segregated waste treatment, the schemewiththe highest totalscore is the “Clean” MRF for recyclables (scheme No 19), followed by the Mechanical – Aerobic Composting facility (scheme No 17) and the Mechanical – Anaerobic facility (scheme No 18).

b) *plants of capacityto 1,000tn/day*

Despite the fact thatfinancial indicatorsare differentiatedin the caseofincreased capacitythe final ranking of the schemes is maintainedthe sameas in the previouscase, for both the mixed and the pre-segregated waste.

Table 57: Final rating of examined Schemes

62.a. MIXED WASTE TREATMENT / DISPOSAL PLANTS (Case i: Plants of Capacity 300 tn/day).

No of Scheme	No of Scheme in Annex	Description of schemes	Environmental	20%	Financial (300 tn/day)	15%	Technical	10%	Social	15%	Existing experience - reliability	40%	Total
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	15.70	**3.14**	2.80	**0.42**	9.15	**0.92**	11.60	**1.74**	4.00	**1.60**	**7.81**
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	16.07	**3.21**	3.10	**0.47**	11.10	**1.11**	14.75	**2.21**	2.00	**0.80**	**7.80**
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	12.90	**2.58**	2.60	**0.39**	9.15	**0.92**	12.00	**1.80**	4.00	**1.60**	**7.28**
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	8.64	**1.73**	3.00	**0.45**	8.65	**0.87**	16.75	**2.51**	4.00	**1.60**	**7.16**
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	16.02	**3.20**	0.80	**0.12**	7.00	**0.70**	15.15	**2.27**	2.00	**0.80**	**7.10**
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	17.58	**3.52**	3.80	**0.57**	3.70	**0.37**	16.90	**2.54**	0.00	**0.00**	**6.99**
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	15.73	**3.15**	0.30	**0.05**	6.35	**0.64**	9.70	**1.46**	4.00	**1.60**	**6.88**

No of Scheme	No of Scheme in Annex	Description of schemes	Environmental	20%	Financial (300 tn/day)	15%	Technical	10%	Social	15%	Existing experience - reliability	40%	Total
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	13.08	**2.62**	0.25	**0.04**	6.35	**0.64**	12.70	**1.91**	4.00	**1.60**	**6.79**
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	16.81	**3.36**	2.80	**0.42**	4.70	**0.47**	16.75	**2.51**	0.00	**0.00**	**6.77**
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	12.70	**2.54**	0.00	**0.00**	9.80	**0.98**	8.20	**1.23**	2.70	**1.08**	**5.83**
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	6.15	**1.23**	2.60	**0.39**	11.80	**1.18**	12.60	**1.89**	2.70	**1.08**	**5.77**
12		Landfills with recovery and combustion of biogas -energy.	6.41	**1.28**	4.00	**0.60**	12.00	**1.20**	6.00	**0.90**	4.00	**1.60**	**5.58**

62.b. PRE-SEGREGATED WASTE TREATMENT PLANTS (Case i: Plants of Capacity 300 tn/day).

No of Scheme	No of Scheme in Annex	Description of schemes	Environmental	20%	Financial (300 tn/day)	15%	Technical	10%	Social	15%	Existing experience - reliability	40%	Total
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	16.00	**3.20**	4.00	**0.60**	12.00	**1.20**	17.50	**2.63**	4.00	**1.60**	**9.23**
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	9.34	**1.87**	3.05	**0.46**	10.80	**1.08**	13.80	**2.07**	4.00	**1.60**	**7.08**
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	11.58	**2.32**	2.90	**0.44**	9.40	**0.94**	16.60	**2.49**	2.00	**0.80**	**6.98**
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	7.56	**1.51**	2.50	**0.38**	11.30	**1.13**	12.70	**1.91**	4.00	**1.60**	**6.52**
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	10.53	**2.11**	1.60	**0.24**	9.10	**0.91**	15.50	**2.33**	2.00	**0.80**	**6.38**
14	8.a	Mechanical – Aerobic Composting facility. RDF and *in-situ* incineration -energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	7.79	**1.56**	0.00	**0.00**	5.00	**0.50**	12.85	**1.93**	4.00	**1.60**	**5.58**
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	8.56	**1.71**	0.60	**0.09**	5.00	**0.50**	15.60	**2.34**	2.00	**0.80**	**5.44**

Table 58: Final rating of examined Schemes

63.a. MIXED WASTE TREATMENT / DISPOSAL PLANTS (Case ii: Plants of Capacity 1,000 tn/day).

No of Scheme	No of Scheme in Annex	Description of schemes	Environmental	20%	Financial (300 tn/day)	15%	Technical	10%	Social	15%	Existing experience - reliability	40%	Total
6	8.d1	Aerobic MBT. RDF - disposal, utilisation of biostabilised material, Disposal of N/H.R. in S.L.	15.70	3.14	2.50	0.50	9.15	0.92	11.60	1.74	4.00	1.60	**7.89**
9	9.d	Anaerobic MBT. RDF- disposal, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	16.07	3.21	2.30	0.46	11.10	1.11	14.75	2.21	2.00	0.80	**7.80**
7	8.d2	Aerobic MBT. RDF-disposal, landfilling of bio-stabilised material. Disposal of N/H.R. in S.L.	12.90	2.58	2.30	0.46	9.15	0.92	12.00	1.80	4.00	1.60	**7.35**
1	1	Incineration– energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	8.64	1.73	2.60	0.52	8.65	0.87	16.75	2.51	4.00	1.60	**7.23**
3	3	Gasification - Plasma / Vitrification – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	17.58	3.52	4.00	0.80	3.70	0.37	16.90	2.54	0.00	0.00	**7.22**
8	9.c	Anaerobic MBT. RDF and in-situ incineration-energy, utilisation of CLO, biogas -energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	16.02	3.20	0.20	0.04	7.00	0.70	15.15	2.27	2.00	0.80	**7.02**
4	8.c1	Aerobic MBT. RDF and in-situ incineration-energy, utilisation of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	15.73	3.15	0.65	0.13	6.35	0.64	9.70	1.46	4.00	1.60	**6.97**
2	2	Pyrolysis – energy. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	16.81	3.36	2.80	0.56	4.70	0.47	16.75	2.51	0.00	0.00	**6.91**

No of Scheme	No of Scheme in Annex	Description of schemes	Environmental	20%	Financial (300 tn/day)	15%	Technical	10%	Social	15%	Existing experience - reliability	40%	Total
5	8.c2	Aerobic MBT. RDF and in-situ incineration-energy, landfilling of biostabilised material, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	13.08	2.62	0.00	0.00	6.35	0.64	12.70	1.91	4.00	1.60	**6.76**
10	8.f	Bio-drying. Metals /stabilat (SRF) – landfilling of SRF, Disposal of N/H.R. in S.L.	6.15	1.23	2.60	0.52	11.80	1.18	12.60	1.89	2.70	1.08	**5.90**
11	8.e	Bio-drying. Metals, stabilat (SRF) and in-situ incineration of SRF-energy, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	12.70	2.54	0.10	0.02	9.80	0.98	8.20	1.23	2.70	1.08	**5.85**
12		Landfills with recovery and combustion of biogas -energy.	6.41	1.28	3.80	0.76	12.00	1.20	6.00	0.90	4.00	1.60	**5.74**

63.b. PRE-SEGREGATED WASTE TREATMENT PLANTS (Case ii: Plants of Capacity 1,000 tn/day).

No of Scheme	No of Scheme in Annex	Description of schemes	Environmental	20%	Financial (300 tn/day)	15%	Technical	10%	Social	15%	Existing experience - reliability	40%	Total
19	16.c etc.	“Clean” MRF. Recyclables, disposal of residues in S.L.	16.00	3.20	4.00	0.80	12.00	1.20	17.50	2.63	4.00	1.60	**9.43**
17	10 etc.	Mechanical – Aerobic Composting facility. Compost / disposal of residues in S.L.	9.34	1.87	2.55	0.51	10.80	1.08	13.80	2.07	4.00	1.60	**7.13**
18	13 etc.	Mechanical – Anaerobic facility. Compost, biogas - energy, disposal of residues in S.L.	11.58	2.32	2.42	0.48	9.40	0.94	16.60	2.49	2.00	0.80	**7.03**
13	6.a	Mechanical – Aerobic Composting facility. Recyclables, HQ Compost, disposal of residues in S.L.	7.56	1.51	2.40	0.48	11.30	1.13	12.70	1.91	4.00	1.60	**6.63**
15	9.b	Mechanical – Anaerobic facility. Recyclables, HQ Compost, Biogas - energy, disposal of residues in S.L.	10.53	2.11	1.10	0.22	9.10	0.91	15.50	2.33	2.00	0.80	**6.36**
14	8.a	Mechanical – Aerobic Composting facility. RDF and in-situ incineration - energy, HQ Compost, Disposal of N/H.R. in S.L., disposal of H.R in H.W.L.	7.79	1.56	0.00	0.00	5.00	0.50	12.85	1.93	4.00	1.60	**5.58**
16	9.a	Mechanical – Anaerobic facility. RDF and in-situ incineration-energy, HQ Compost, Biogas - energy, disposal of residues in S.L. Disposal of N/H.R. in S.L. / disposal of H.R in H.W.L.	8.56	1.71	0.00	0.00	5.00	0.50	15.60	2.34	2.00	0.80	**5.35**

1.5 Commentsandobservations

The selectionof solidwastemanagement technologiesis a complexprocess thatdependsonseveralparametersandvariables, as it became clearfrom the analysisandthe evaluation criteria setforthin theprecedingsections.

During thedecision-making processregardingthe management of solidwastein Lebanon, inapplying therelevantbasicguidingdecision, the competentauthoritiesfor decisionsand stakeholderswill be askedto deal withanumber of issues, concerns andquestions. The optionson themcanbe judgedlargelyby the adoptionof the evaluation results, as given in paragraph 5.1.5.7. But theproblemisthat most timesthe same evaluationcriteriaare ratedwithdifferent weight, not only fromthe variousstakeholdersbutevenby executivesandrepresentativesof the same entity. This is a longstandingrealitywhen dealingwithmulti-parametric questions and especiallywith questions relatingto the selection of wastemethodsandmanagement technologies.

Consideringthe above, the commentsandobservations that are listedin this sectionintend toassistthe competentauthoritiesin forma validandinformed view on the*applicabilityof availablemethodsin Lebanon*, taking into accountall the criticalparameters for eachavailable technologyin conjunction with the particularconditions of the country. This willbeattemptedthrough coding ofcritical issuesandhighlight the mainconditions thatshouldbe taken into account beforemaking a final decision.

Criticalissues/concerns andquestionsare codedas follows:

- **MSW management model:**
  - Management of mixed or of pre-segregated at source waste?

- **Purposeof productionoftreatmentplants:**
  - Energyrecoveryorrecyclables recovery?
  - High quality Compost or bio-stabilised material;

- **Competitivetechnologieswiththe sameproductionpurpose:**
  - MBT units with production of energy or Thermal Process units with production of energy?
  - If Thermal Process units, Incineration, Pyrolysis or Gasification?
  - If MBT, MBT-Aerobic or MBT-Anaerobic?
  - If Aerobic, what type?
  - If Anaerobic, what type?

These critical issues are discussed below.

1.5.1 MSWmanagementmodel: Managementofmixedorofpre-segregatedatsource waste;

The Decisionno.1/2015of COMstatedthe mainmanagement objectiveand thedeadlinefor achieving it:

“Recuperating 60% of the waste through separation, recycling and composting as well as energy regeneration in the first three years of the contract and 75% in the following years until we reach the stage of thermal disintegration (including RDF, or incineration or other) based on what will be decided later”.

The fraction offermentablewasteinLebanonconstitutesmore than 50% of the totalquantity produced. Thisimplies that a prerequisiteforachieving the objectiveof the firstthree years(Recuperating 60% of the waste),is thediversion of averylarge proportionof the fractionoffermentable. Themanagement modelthat can supportsuch an extentdiversionis that ofmixed waste,becausethis modelcan workdirectly (i.e. immediately uponcompletion of constructionand placing into serviceof mixed waste treatment plants).

In contrast, thegoalofdiverting60% cannotbeachievedbyamanagementmodelthatwouldbebasedonasortingatsource system(orsystems). And thisbecause itthismanagement modelcan yieldonlyaftera considerable periodof timenecessaryfor design of thepre-sortingsystem(s) design, for preparingand implementing proper awareness campaigns for households andbusinesses to supportthepre-sortingsystems, familiarization of households andenterprises inapplicationof the systems.

Since the objective ofthe first three years, as set out in the relevantdecisiondoes not explicitlyindicatewhether theseparation, recycling and compostingconcerns on sorted–at-source ormixedwaste,whatwe recommend as an answerto the question:"*management model based on mixedorsorted-at-sourcewaste*?” consists of two parts:

- ✓ Directimplementationof mixedwastetreatment plants.These plants fall into twolargefamiliesof methods / technologies: the Mechanical– Biological Treatment (MBT) and the Thermal Treatment.
    - o The basicutility of *thermal process plants* isto drastically reduce thevolume of waste, which reachesup to90% of the initial volume. Therefore **space scarcity** andsignificant energy needs"facilitate" theoperation of thermal process plants.
    - o The*Mechanical Biological Treatment* can also playan importantrole inachieving the short-term objectivesofthe Decisionon the landfill, since it does not demandthe development of sorting-at-source programs,has a relativelylow cost anddoes not require largeeconomiesof scale,thereforemade suitablefor smallerpopulation concentrations. Furthermore, it is characterized bysufficient flexibilityas it canoperatewith a lowerfeedingthan design capacity and canbe easily converted intocomposting plantfor sorted-at-source waste.Thus thedevelopmentof MBTplantsnot bindthe optionsof a region,by limitingpotential for developmentrecyclingprogramsforalong timein the future.
- ✓ Initiate actionsby the Stateforthe establishment andoperation of sorting-at-sourcesystem or systems (e.g. for recyclables, for bio-waste etc.),including: systems design, planningandimplementing information programs and awareness campaigns addressed to households andenterprises, pilotschemes testing, phasingextending the system(s).

Thefirst partof theaboveproposalensuresconditionsforachieving the objectiveof the Decision 1/2015 that is set forthe first three years, whilethe second partensuresthe rationalpreparation neededforthe successful implementation ofmanagement modelsbasedonpre-segregation, free fromthe pressureoftime limitssetby law.

1.5.2 Purposeof productionoftreatmentplants

1.5.2.1 *Energyrecoveryvsrecyclables recovery*

Both therecoveryof recyclablematerialsandenergy fromwastefall within thespiritand wordingof the DecisionNo.1/2015of COM:

“Recuperating 60% of the waste through separation, recycling and composting as well as energy regeneration …”.

Plantswhich support thepower generationdirectionare:

- Thethermal treatmentunits designedfor combustion/pyrolysis/gasification ofmunicipal wastetoproduce energy;
- The MBT plants ([22]) designed for recovery /production of productswhich areraw materialsfor energy production (RDF or SRF or/and biogas), i.e.:
  - MBT - Aerobic plants, configured for production of RDF and accompanied byin-situincinerationunits for RDF;
  - MBT - Anaerobic plants, configured for production of RDF and accompanied byin-situincinerationunits for RDF, and for production and combustion of biogas;
  - Biodrying units configured for production of SRF and accompanied byin-situincinerationunits for SRF.

Accordingly, plants which support therecoveryof recyclabledirection are:

- MBT - Aerobic and MBT - Anaerobic plants, configured for recovery of recyclables;
- Plants for treatment of pre-segregated waste, i.e.:
  - Mechanical Separation – Aerobic or Mechanical Separation – Anaerobic units for pre-segregated packaging materials and pre-segregated bio-waste,
  - Aerobic Composting or Anaerobic Composting units for solely pre-segregated bio-waste,
  - MaterialsRecoveryFacilities (MRF) for solely pre-segregated packaging recyclables.

The main issuesto be addressedon the selectionof mixedwaste treatmentplants with in-situproduction of energyfor supply to thegrid,are:

- The existence of designatedarrangements, institutionalizedby the competentstate authorityfor purchaseelectricityproduced fromWtE plants (standards and specifications for RDF, SRF,biogas, pricing regime etc.). Identify andassessdurationof implementation of any complementaryactions and measures required to completethe institutionalizationof the purchase of electricityproduced from WtE plants;
- The sufficiencyinpower gridto receiveadditionalelectric chargewhichwill result fromtheenergy producedfrom WtE plants (limits on the maximumallocationof additional chargeperareaetc.). Identify andassessdurationof implementation of any complementaryactions and measures required to completegrid issues.

As regards the MBT facilities to recoverrecyclables, whereas in theory could be expected to produce outputs that canbe sold andgenerate revenue, reality is different. While some of the recyclables (ferrous metals, aluminium, paper, glass)

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[22]TheMBTplantsmaybesodesignedfor: a) recoveryof recyclablematerials(ferrous, aluminum, plastic, paper, glass) orb) production ofRDF/SRF, in conjunction with the production of:a)solelybio-stabilisedmaterial(MBT-Aerobic) orb) bio-stabilisedmaterial andbiogas(MBT-Anaerobic).

often can generate revenues, the main MBT output streams (bio-stabilised material and RDF) often need to be handled or disposed at a cost. The recyclables recovered in mechanical process of mixed MSW arenotcleanandcontainvariousimpuritiesmainlyoforganicmaterial. Consequently, comparedwithmaterial derivedfrom sorted-at-source segregation they are harderabsorbedandat lower prices by themarketfor secondary products.

The availability of markets for different outputs, and related costs or revenues for handling these, should therefore be considered carefully before deciding on the MBT – recyclables option and a specific process layout.

- *Disposal ofRDF*

The selection of MBT for extraction and preparation of RDF destined fordisposalto other recipients (whereupon should be in the formdry RDF-dRDF),insteadofin-situcombustionforpower generation, should basically depend on the presence of off-takers for such a product and related handling costs in comparison to landfilling this part of the treated waste.

It should be pointed out that the market and demand for RDF is dynamic, and it is therefore not possible to draw a general conclusion without studying the actual regional market conditions at a specific time.

The costs that have to be paid to off-takers of RDF vary depending on the quality and demand. During recent years the supply has exceeded the demand forcing MBT operators to pay relatively high gate fees. However, with an increasing demand following increasing interest from cement kilns and power plants to replace fossil fuels, and new investments in RDF fired WtE facilities, treatment costs are decreasing. In addition to gate fees, the costs of transports to off-takers need to be factored in when assessing the viability of a RDF proposal.

Since the cost of handling/treatment of RDF can have a significant impact on the overall financial viability of a MBT facility, it is important to properly assess the total treatment costs. A long-term off-take agreement can reduce risks in this regard.

In this direction,the question that should beinvestigatedandresolved-beforedeciding toimplementsuch aunit-is whetherthere has beenproper preparationamongpotentialstakeholders(cement industry, steel industry, power plants etc.) andadequatematurityof an agreementbetween themtohave securedin advancetheabsorptionof theproduct. Elements whichwill be requiredfor such apreparation/ agreementare:

- product standards and specs;
- economic relationshipofdelivery-receiptof the product.

1.5.2.2 Production of high-quality compost vs production of bio-stabilised material (CLO);

High qualitycompostfor useas a fertilizer canbe produced onlyover pre-segregated biowaste (Aerobic Composting or Anaerobic Digestion treatment plants).

Mixed waste treatment plants can only produce a lower quality *bio-stabilised material* forwhich the competentauthorities shouldreflect onhow to disposeof.

- *Disposal ofCompost-like output (CLO)*

High heavy metal contents in compost-like output (CLO) often results in difficulties getting the product approved for use as compost by authorities and accepted by the market, and thereby often limit CLO use to e.g. landfill covers, remediation and landscaping applications. Efforts to separately collect household hazardous waste like batteries would contribute to reducing the heavy metal content of the CLO, but not to an extent that the output from mixed waste streams could be used for compost applications.

A related issue to consider is whether it is necessary to landfill all stabilised bio-waste, or whether there are options to use this MBT output as a material for landfill covers, or as an input to artificial soils for non-agricultural purposes. To minimise the landfilled amounts and related costs, efforts should be made to find alternative uses for the stabilised residual waste, to the extent allowed under national legislation.

1.5.3 Competitive technologies with the same production purpose

1.5.3.1 Thermal Process units vs MBTunits with production of energy

Thermal treatment plants producemore energy thanenergy-designed MBTs ([23]). Significantenergy needs,combinedwithdifficulties inpower supply,"facilitate" theoperation of thermal process plants.

Importantrole in the economicefficiencyofthermaltreatment plantsplaysthe possibility of utilizingofsteamaftertheturbine, eitherby passingto neighboringplantsortouse fortele-heating of urbancenters, where localconditionsare favorable. If it is notpossible toexploitthe latentheatofsteam, then itmustbe liquefied, so that the water canbe recycled to thesteam boiler. In this case theheat ofliquefactionis not utilized, but ends upin the environment.

As regards MBT configured for the production of RDF and in-situ incineration in a unit designed on purpose:thispracticeisverycommonmainlybecauseitoffersindependencefromthetrends ofthemarketforsolidfuels. On the otherhand, the implementationof such a solutionrequireshigh investment costsand operationof such a plantmay competeinwastereduction orrecycling programs.

Beforetakingthe selection decisionfor any treatment plant with energy production (except of energy production from biogas), the competent authoritiesshould takeseriously into accountthe following conditions:

- That the quantity of incoming materialshould bekept constant,so that thecombustionis performedwithhigh yield.Reducinginput quantityhas a directimpact on theproduction of electricityandhencetheviabilityof the plant. In general, the sustainabilityof combustion plantswith a capacity ofless than300,000tons per yearis considereduncertain. To ensuresustainability should beincreasing gate-fee.

- That the waste to be fed in the incinerator should have aminimumcalorific value of 6 MJ/kgin all seasonsof the yearand an averageannual minimum calorific value at least7 MJ/kg.

[23]Forwastewith a lowercalorific valueof about8 MJ/kgthe totalelectricity production in anincineration plantis estimated at520 kWh/ton and the excesselectricity thatcan bedisposed of to others, at around450 kWh/ton. In a typicalinstallation ofanaerobic treatment, the availability ofexcesselectricityto third partiesis65 kWhper tonne of MSW.

- That allmeasures required for controlling, limiting and purification of airemissions as well as forthe safe managementof flyash,in accordancewith international standards, willprovidein a binding wayand implemented.

1.5.3.2 If Thermal Process units, Incineration, Pyrolysis or Gasification?

When a decisionhasbeen taken tousethermalprocessing technology, the most important criterionthat shouldbeconsidered in orderto make the"internal"optionamong the availablethermaltechnologiesis the internationalexperience that proves theapplicabilityand performance oftechnologies intreatment of municipalwaste. In this regard:

- *Combustion*isanoldandwell-proventechnologywhichhasbeenwidelyappliedforthetreatmentofmunicipalwaste.

- *PyrolysisandGasification*arenewertechnologies in progress, promoted as environmentallyfriendlier ones but not yetapplied on a largecommercial scale. Theinternational examplesoftheir application intreatment of municipalwasteconcern, in theirvastmajority, totest, pilot andsmall-scale applications, while highyieldsare recordednot in thetreatmentof mixed wastebut in RDF process. This factinvolves a highriskforthe performance of theseplants in treatment of mixed municipalwaste.

- the techniques of*gasification* and*pyrolysis*are appliedmore successfullyinmorehomogeneousfuels such asRDF,despiteinmixed MSW.

Regarding the environmental performance of thermal treatment methods:

- *Pyrolysisandgasification* producesmaller amounts ofwaste gas, due the useof zeroorevenminute amounts ofoxygen in air. Thebase gasgenerated inthese processes is rich inhydrogen, carbon monoxide and carbon dioxide, hydrocarbons, etc. (depending on the initial composition of the waste), andfurtherusedas fuel. Alsoimportantis the factthat intheseprocessesa large number ofpollutants (e.g., sulfur, heavymetals, etc.) remainsintheashwithout being transferredinthegasphaseandaggravatethequalityoftheatmosphere. This fact, coupled with thattheproduced gasis further usedas fuel, oftenreduces the numberand type ofrequiredantipollutiontechnologies.

- As regards *pyrolysis*many of theunitsin operationarepilotsand in recent yearshave beenreportedsignificant problemsin someunitsthat raisequestions about thereliabilityof the technologyin terms ofprocessingof mixed municipalwastedue to theirheterogeneouscomposition. Environmental effects of a pyrolysis unitareexpected, as gas,liquid and solidpollutants will be emitted during operationinto the environment, which of coursearеclearly of lower scale in relation to thecombustion.

- The*gasification* displays the higherenergy performance among allwastetreatment plants (about twiceof combustion units). It is moreapplied, in relation to thepyrolysis,primarilybecause ofnon-formedmarket for the liquidproducts of the latest.

1.5.3.3 If Incineration plant, “mass-fired” or “RDF-fired”?

There are two typesof conventionalincinerationplants: units that requireminimalpretreatment ofwaste(“mass-fired”)and unitsoperatingwith treatedRDF as fuel. The “mass-fired”typeunits arethe majorityof installedplants. Their grandadvantage isthat the waste enters in the combustionunit without anypretreatment.

It is obvious that fluctuations of the energy content of waste are enormous in mass-fired units and depend on the climate, the relevant period, the composition of the waste etc. Consequently, mass-fired units are integrated with relative difficulty in a power recovery system.

The RDF-fired units present certain important advantages, compared with the mass-fired plants:

- are integrated more easily in energy recovery and distribution grid because the RDF has a higher calorific value compared to untreated waste and much smaller fluctuations in the energy content.
- Controlling an RDF-fired unit is clearly easier.
- The space required is much less, than a mass-fired unit.
- Finally, the pretreatment of the waste to produce RDF allows removal of a number of waste types, such as PVC, metals, etc. contributing to the creation of dangerous pollutants carried by the gases of the incineration plant.

1.5.3.4 If Incineration plant, what type of incinerator?

The most common types of incinerators are:

- *moving grate*,
- *rotating furnace*,
- *fluidised bed*.

The *moving grate* technology is the oldest and traditionally the most widely applied method of thermal treatment of all kinds of waste.

The main advantages of a *fluidised bed* incinerator are:

- avoid the occurrence of local temperature differences and therefore reduce pollutant gaseous emissions, which are a result of incomplete combustion due to temperature differences,
- possibility of energy utilization of difficult fuels, with a high moisture and ash content,
- increasing the degree of conversion of the fuel and more efficient utilization of the combustion air, which leads to a smaller excess air requirements (in this case about 55% compared to conventional 100%).

A *rotary kiln* incinerator processes successfully many types of waste and pollutants that other technologies cannot cope.

The main advantages of a *fluidized bed* incinerator include:

- ✓ avoid the occurrence of local temperature differences and therefore reduce emissions of air pollutants, which is a result of incomplete combustion due to temperature differences,
- ✓ possibility of energy exploitation of difficult fuels with high moisture content and ash,
- ✓ increase the fuel conversion degree and more efficient use of combustion air, which leads to a smaller excess air requirements (in this case about 55% compared to conventional 100%).

In any case, the competent authorities should take all necessary measures for purification of waste gases to contribute to the reduction of hazardous pollutants found in the gases produced by the combustion (CO, CO_2, H_2O, NO_x, SO_2 and a series of other harmful substances, which depends on the composition of waste, mainly HCl, HF, heavy metals and polycyclic hydrocarbons – i.e. dioxins, furans), as well as measures for fly ash collection and safe management.

1.5.3.5 If *Gasification*, what type?

- Thegasificationprocesswhichhas the greatestdevelopmentin recentyears is the*gasificationinfluidizedbed*which perform emissionslower than thetechnologyof combustion.
- *Gasification – Plasma / Vitrification* is smaller, sinceusedabout 8times lessair than in theincineration,resulting4 timessmaller amount ofgasfor cleaning,and thusmuch smaller amount ofgasemissioninto the environment. An importantdrawbackof the methodis that it hasimplemented to datemainlyinspecialwaste streams (radioactivewaste, solid wasteincinerationplants, etc.), butits application in MSW (whichhaveextremelyheterogeneouscomposition) is verylimited andfewdata is available.

- The *combinedcoal and wastegasification* that can be performedin parallelor directgasificationis indemonstrativestage in units usingcoal as abasefuelwhichis substitutedup to 30% from biomassandmunicipal waste.

1.5.3.6 If Biological treatment, Aerobic, Anaerobic or Biodrying?

- *AerobicMBT* is widely applied in Europe anda large number ofunitsoperatewith this technology. It haslowoperational requirementsandcomplexity.

- *AnaerobicMBT,* also widely applied and proved technology is more appropriatefor pre-segregatedorganic waste.

- The installed capacityof *biologicaldrying*plants alsoincreases.This technologyhas relativelyincreased complexitycompared to theaerobicMBEmainlybecause of the requirementsfortreatmentof waste gasesby thermaloxidation. Thegas treatmentcan also be reachedthroughthe biofilterwithout however achieving thesame efficiencyinflue gas cleaning.

1.5.3.7 If Aerobic unit, what type?

- *Extended aerated pile or static windrow composting*

  The *extended aerated pile/windrow* is a forced-air version of a “continuous culture”. It is an advantageous approach when large amounts of material are involved.

  Aerated static piles/windrows can produce excellent compost, provided that two basic operating conditions are met:

  - the initial material has adequate porosity, and
  - the air flow system works properly and provides adequate air flow uniformly during the active compost period to all areas of the pile/windrow.

- *Passive static pile or static windrow composting*

  Passive systems require minimal operational effort and costs, but they do not allow for quick composting, since composting requires around six months to two years to be finalised, as well as additional long periods to stabilise. So, such systems are not widely applied in MSWM and are not recommended.

- *Turned windrow composting*

  Windrow composting efficiency and product quality are dependent primarily upon two major factors: the initial compost mix, and the management practices.

- *In-Vessel composting*

In-vessel composters are generally more automated than windrow or static pile systems, and can produce a top quality finished product on a consistent basis.

Common reasons for choosing in-vessel composting over other methods include:

- shortening of the mesophyllic and thermophilic stages of decomposition of organic waste;
- achievement of higher process efficiency, which minimises space requirements;
- decrease of number of pathogens in the end product;
- easier control of odours and emissions;
- easier control of contact of animals (birds, rodents, etc.) with the decomposing material.
- process and materials handling control;
- better public acceptance due to the aesthetics/appearance of the composting site;
- more consistent product quality.

Disadvantages of the enclosed vessel method include:

- high capital and operational costs due to the use of computerized equipment and skilled labour.
- less manpower requirements (where anincrease employmentpolicyisa priority)

1.5.3.8 If Anaerobic unit, what type?

The existingfacilitiesfor anaerobicdigestionof solidwastemay be distinguished onthree broadcategories, depending on the materialsprocessed:

1. *units for digestion of sorted-at-sourcebiowaste*, ie. of a relativelypureorganic wastestream (kitchen waste andsmall sizegardenwaste -grass, leaves)
2. *units for digestion of organic fraction of mixed waste*, as department of a mechanical-biological treatment process, aiming at the productionof biogasand of alow valuecompostorcover materialin Sanitary Landfills.
3. *centraldigestion units*, wherein the organic fractionofsorting-at-source MSW is processed incombination withother wastes(mainlyagricultural wasteas well asslurry of Waste Water Treatment Plants).

Twomain technologies ofanaerobicdigestionoperateinternationally: “Wet” (where thefeed liquorcontainstotal solids3 to 8%) and “Dry” (where thefeed liquorcontainsat least 25% solids).To achievesuchhigh dilution in *“Wet” anaerobic*digestion large quantities of wateris required to be added and heated,which mustbe removedafter thedigestion.

If wetanaerobicprocessis selected,twoseriallyreactors should be used(one forthe hydrolysis anddecompositionof the organicacidand oneformethanogenesis) because single stagemesophilicdigestionreactorpresentsserious operationalproblems.

In *“Dry” anaerobic* units the digestion takes place in single stage mesophilic or thermophilic reactors of continuousorperiodicfunction.