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Biodegradable municipal waste management in Europe

Part 3: Technology and market issues

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1.1. Introduction

This chapter presents an overview of the principal technologies available for diverting biodegradable municipal waste (BMW) from landfill. The focus in this report is on the food and garden waste. For each technology, the following aspects are addressed:

- brief description of the technology or technology type
- advantages and disadvantages
- typical costs
- suitability for treating BMW.

The final selection of applicable treatment methods to divert biodegradable waste away from landfills would normally depend on infrastructural, economic and environmental conditions in a particular planning area. Such an evaluation would quickly reduce the number of treatment methods relevant to the particular plan area.

Issues to be addressed in selecting treatment options include:

- quantity, type and accessibility of biodegradable material;
- proven demands for fertilisers, soil conditioners and/or energy (electricity or district heating);
- characteristics of the particular plan area (e.g. distance to farming land, construction activities including landscaping);
- availability of district heating distribution system;
- current energy price level which, based on waste fuels, will make energy production feasible;
- available sites for the establishment of treatment facilities including adequate sanitary zones.

1.1.1. Overview of treatment methods

BMW can be recycled or recovered in order to reuse cellulose fibre or to recover nutrients and energy contained in the waste. Recovery may be conducted according to two overall principles, which are biological and thermal treatment respectively.

By biological treatment methods is meant the aerobe process defined as composting and the anaerobic digestion process.

The **composting process** is feasible as a stabilising and bulk reduction method provided that a market for production of compost is established. Purification of the waste fraction by source separation is very important.

The **anaerobic digestion** method — in terms of co-digestion, wet method — is feasible as a bulk waste reduction method provided farm slurry in sufficient quantity can be supplied and local farmers use the resulting fertiliser residue. A market for gas must be established. Purification of the waste fraction by source separation is very important. The separate digestion method is technically feasible provided a market for gas and fertiliser is established. It should, however, be noted that the track record for this method is less than 10 years.

In general, biological treatment plants should be located at a suitable distance from residential areas taking into account national requirements regarding odour and noise emissions. Home-composting is suitable for suburban or dense housing areas. The composting unit should, ideally, be located more than five meters from doors and windows.

'Thermal treatment methods' in this report means incineration, gasification and pyrolysis.

Incineration ([1]) is feasible as a basic bulk reduction method. If there is energy production a market for surplus heat and/or electricity has to be established. Purification of the waste fraction is not important. Solid residuals must be reused or disposed.

Gasification and pyrolysis are emerging methods as bulk waste reduction methods but only few track records of full-scale operations at large capacities have yet been proved (e.g. the German pyrolyse plant at Burgau has been in operation since 1984).

Though environmental data from waste treatment has continuously improved in recent years, the different purposes for the technologies and the strategies on the waste have led to different data being measured using different methods. The measuring methods limit the range of data available, as some figures are hard to obtain due to technical obstacles. This can make a comparative and schematic presentation difficult.

Regional conditions will greatly influence which methods are to be chosen for the treatment of biodegradable waste in a specific area. The market for products such as compost, distribution of heat and energy, transport distances of waste, the possibility of separate collection and many other issues are central to waste planning. Consequently, Table 1 is developed to give waste planners an overview of the state of technology.

Table 1 **Overview of technologies for the treatment of BMW**

Overview of technologies for biodegradable waste	Biological method		Thermal method		
	Compost	Anaerobic digestion	Incineration	Pyrolysis	Gasification
Proven technology, track record	Yes; Very common	Yes; common	Yes; very common	Partly; few	Partly; few
Basic principle	Degradation by aerobic micro-organisms	Degradation by anaerobic micro-organisms	Combustion	Anaerobic thermo-chemical conversion	Thermo- chemical conversion
Cost of treatment	Low to high	Medium to high	Medium to high	Medium to high	High to very high
Suitability	Good	Good	Good	Medium	Depending on technology
Waste acceptance	Source separated waste only since matter and nutrients is to be recovered as pure as possible	Source separated wet waste only since matter and nutrients is to be recovered as pure as possible	All waste since air cleaning technology is good and residual solids are minimised by volume reduction	In particular suitable for contaminated, well defined dry waste fractions	Source separated dry waste only unless combined with better cleaning technology
Acceptance of wet household Waste	Yes	Yes	Yes	Possible but normally no	Possible but normally no
Acceptance of dry household Waste	Yes	Yes	Yes	Yes	Possible
Acceptance of garden and park waste	Yes	No	Yes	Yes	Possible
Acceptance of waste from hotels and restaurants	Yes	Yes	Yes	Yes	Possible but normally no
Acceptance of paper and board	Small amounts of paper possible	No	Yes	Yes	Possible
Excluded waste fractions	Metal, plastic, glass, (plants without high degree of sanitary treatment: no waste of animal origin)	Metal, plastic glass, garden waste, (plants without high degree of sanitary treatment: no waste of animal origin)	None	Wet household waste	Wet household waste
Availability of environmental data					
Solids	High	Medium — high	Medium — high	Medium	Medium

(1) See also 'economic valuation of environmental externalities from landfill disposal and incineration of waste', European Commission 2000.

Overview of technologies for the treatment of BMW, cont. Table 1

Overview of technologies for biodegradable waste	Biological method		Thermal method		
	Compost	**Anaerobic digestion**	**Incineration**	**Pyrolysis**	**Gasification**
Air	Low	Medium	Medium — high	Medium	Medium
Water	Medium — high	High	High	Medium — high	Medium — high
Control of odour	Bad — good	Bad — good	good	Medium — good	Good
Working environment	Bad — good	Medium — good	good	Good	Good
Energy recovery	No	Yes; 3 200 MJ/ tonne waste	Yes; 2 700 MJ/tonnes waste	Yes; approx. 70 % of incineration + energ y contained in the by-product char	Yes; as incineration
Carbon cycle (% of weight)	50 % in compost 50 % to air	75 % in fibres/ liquids 25 % as biogas	1 % in solids 99 % to air	20–30 % in solids 70–80 % to air	2 % in solids 98 % to air
Nutrient recovery (kg nutrient/tonne waste input)	Yes; 2.5–10 kg N 0.5–1 kg P 1–2 kg K	Yes; 4.0–4.5 kg N 0.5–1 kg P 2.5–3 kg K	No	No	No
Products for recycling or recovery,(weight- % of waste input)	40-50 % compost	30 % fibres, 50–65 % fluids	15–25 % bottom ash (incl. clinker grit, glass), 3 % metal	30–50 % char (incl. bottom ash, clinker, grit, glass), 3 % metal	15–25 % vitrified bottom ash (incl. clinker grit, glass). 3 % metal
Residuals for other waste treatment or for land filling (weight- % of waste input)	2–20 % overflow sieving (plastic, metal, glass, stones)	2–20 % overflow sieving (plastic, metal, glass, stones)	3 % fly ash (incl. flue gas residues)	2–3 % flue gas residues	2 % gas cleaning residues

1.2. Centralised composting

1.2.1. Brief description of technology

Biodegradable waste is composted with the objective of returning the waste to the plant production cycle as fertiliser and soil improver. The variety of composting technologies is extensive as composting can be carried out in private gardens as well as in advanced, highly technological centralised plants. The control of compost processing is based on the homogenisation and mixing of the waste followed by aeration and often irrigation. This leads to a stabilised dark media, rich in humic substances and nutrients. Central solutions are exemplified by low cost composting without forced aeration and technologically more advanced systems with forced aeration and temperature feedback. Central composting plants are capable of handling more than 100 000 tonnes of biodegradable waste per year, but typically the plant size is about 10 000 to 30 000 tonnes per year. Biodegradable wastes must be separated prior to composting: only pure food waste, garden waste, wood chips and, to some extent paper, are suitable for producing good quality compost.

The composting plants consist of some or all of the following technical units: bag openers, magnetic and/or ballistic separators, screeners (sieves), shredders, mixing and homogenisation equipment, turning equipment, irrigation systems, aeration systems, draining systems, bio-filters, scrubbers, control- and steering systems.

The composting process occurs when biodegradable waste is piled together with a structure allowing oxygen-diffusion and with a dry matter content suiting microbial growth. The temperature of the biomass increases due to the microbial activity and the insulation properties of the piled material. The temperature often reaches 65–75°C within a few days and then declines slowly. This high temperature furthers the elimination of pathogens and weed seeds.

Depending upon the composition of the waste material and the applied method of composting, the compost will be ready after three to 18 months. The products of central composting are solids in the form of compost and residuals; fluids in the form of leachate; gas in the form of carbon dioxide, evaporating water and ammonia. Odorous compounds other than ammonia may be generated especially when oxygen supply is inadequate.

The stabilised compost is screened before being used for plant growing purposes. The screen overflow (residuals) is recycled as structural material for the composting process or land filled if the content of visible impurities is high. The leachate is used for watering the composting mass or is discharged. Composting systems operating with an exhaust air system may heat-exchange the incoming air, while ammonia etc. can be treated in scrubbers and bio-filters.

In general, composting methods can be divided into two main groups: composting *without* forced aeration and *with* forced aeration. A lot of confusion exists regarding naming of the different compost treatment options. The following terminology is recommended. Composting with forced aeration is subdivided into batch-wise/static composting or continuously/agitated composting in relation to the principles of feeding and turning regimes (Stentiford, 1993; Finstein and Hogan, 1993). Static piles are turned only weekly or monthly, whereas agitated piles are moved continuously giving room for continuous feeding. If all materials are set up at the same time its called batch-wise. See Table 2.

Table 2 **Categorisation of composting method**

Method	Principles for feeding and turning	Demands on structure-stability *	Type of facility
Without forced aeration	Batch-wise and static	Very high High	Mattress/bed (1) Windrow (1)
With forced aeration	Batch-wise and static	High High High	Aerated-windrow (2) Semi-permeable cover (3) Container/box/tunnel-static (4)
	Continuously and agitated	Medium Medium Medium Medium Low	Indoor-mattress/agitated-bed (4) Channel/agitated-bay (4) Tunnel-agitated (4) Tower multi-floor (4) Drum (4)

*): on final mixture of input material.

Footnotes 1-4: Indicates increasing degree of odour control possibilities (often of costs as well). Odour problems often stem from pre-treatment. Footnotes 3 and 4 are in-vessel type of facilities.
Reference: UK Compost Association, 1999; Stentiford, 1993; Finstein and Hogan, 1993).

1.2.2. Advantages and disadvantages

Advantages

- Possible simple, durable and cheap technology (except some in-vessel facilities);
- approximately 40–50 % of mass (weight) is recovered for plant growth;
- maximum recovery of the nutrients required for low-input farming systems (i.e., P, K, Mg and micronutrients). Liming effect of compost;
- production of humic substances, beneficial micro-organisms, and slow-release nitrogen required for landscape gardening and horticulture;
- eliminates weeds and pathogens in the waste material;
- possible good opportunities of process control (except at most facilities without forced aeration);
- good working environment can be achieved (e.g. pressurised operating cabins with filters).

Disadvantages

- Requires source separation of BMW, including continuous information to waste generators;
- a market for the compost products must be developed and maintained;
- periodical emission of odorous compounds, especially when treating BMW;
- loss of 20–40 % of nitrogen as ammonia, loss of 40–60 % of carbon as carbon dioxide;
- potential vector-problems (seagulls, rats, flies) when treating BMW;
- skilled staff needed when treating BMW.

1.2.3. Typical costs

Composting without forced aeration

Plants typically consist of a few buildings, mobile machinery, and the composting area covered by a roof or uncovered, and with some kind of pavement. Usually it is cheaper to build a plant for pure garden waste. This is not taken into account in Table 3.

Composting without forced aeration Table 3

Economic information		
Capacity (tonnes per annum)	**Typical capital costs Note 1 (EUR)**	**Typical operating costs Note 2 (EUR)**
2 000	300 000	130 000
5 000	600 000	240 000
10 000	900 000	400 000
20 000	1 300 000	730 000
50 000	2 200 000	1 3500 000
100 000	4 500 000	2 600 000

Note 1: Capital costs including site costs, planning costs and construction/plant development costs.
Note 2: Operating costs excluding the costs of residue disposal, staff costs, income from sales of residue/by products.
Reference: Morten Brøgger, pers. comm.

Composting with forced aeration

Capital costs obviously vary depending on the chosen type of facility. This in turn is dependent on the demands for air cleaning, water treatment, waste fractions etc. Operating costs have been calculated from knowledge gained from existing plants. It is very difficult to compare operating costs, as these depend heavily on account principles and local conditions. The figures in Table 4 are reliable for general planning purposes.

Composting with forced aeration Table 4

Economic information		
Capacity (tonnes per annum)	**Typical capital costs Note 1 (EUR)**	**Typical operating costs Note 2 (EUR)**
2 000	550 000–800 000	270 000
5 000	950 000–1 500 000	550 000
10 000	1 600 000–2 700 000	950 000
20 000	2 700 000–4 700 000	1 600 000
50 000	5 400 000–9 400 000	2 700 000
100 000	9 400 000–16 100 000	5 400 000

Note 1: Capital costs including site costs, planning costs and construction/plant development costs.
Note 2: Operating costs excluding the costs of residue disposal, staff costs, income from sales of residue/by-products.
Reference: Wannholt, 1999b; UK Compost Association, 1999; Morten Brøgger, pers. comm.

1.2.4. Suitability for diverting BMW away from landfill

Composting is highly suitable as an option for diverting BMW away from landfill. The principal advantages are that a useful and potentially valuable product is being manufactured from waste and that the negative consequences associated with land filling such as the production of landfill gas and leachate with high BOD are avoided.

The main obstacle to successful composting of BMW is contamination of the waste stream. There is little point in investing public or private money in the construction of composting facilities if, at the end of the day, the compost produced cannot be put to beneficial use due to inadequate quality. A key strategic issue, therefore, is ensuring that as 'clean' as possible a waste stream is collected for composting. This means investing resources in separate collection and public education.

Another key issue is ensuring that adequate and reliable markets are available for compost produced from BMW.

1.3. Home and community composting

An overview of different types of home and community composting facilities is presented in Table 5. Simple home composting technology is normally not suitable for treating BMW of animal origin, because operating temperatures rarely exceed 55 °C and, through inadequate mixing, not all the waste material is exposed to a suitably high temperature. Where an (isolated or placed inside) automatic turning drum with a batch feeding system is used or similar batch systems, BMW of animal origin as well as of vegetable origin can, generally, be composted without any particular health risks. However, care and caution are required when composting wastes of animal origin to ensure that the waste is adequately treated and does not pose a health risk. This would include ongoing monitoring of both the process and the compost produced.

The composting process in home composting facilities treating BMW must be furthered by the addition of fairly dry, carbonaceous structural material to lower the loss of nitrogen during the composting and to lower the risk for anaerobic conditions. The need for a proper amount of carbonaceous material is often not fulfilled. The municipality could provide a shredding service to the home composters shredding their woody garden waste a few times yearly and possible supplement with extra wood chips if needed.

Local, environmentally sound home composting schemes in city blocks and dense low suburban housing depend on the availability of sufficiently large green spaces such as garden lots, shrubbery, lawns etc. on which to use the compost. A minimum of 1 m^2 green area per 10 % of the 'BMW potential per participating person' being home composted, is needed to avoid over-fertilisation with N and P (2). Typically, 50 % of the 'municipal biodegradable waste potential' will be collected and composted, and the area needed is then 5 m^2 per participating person (Reeh, 1996; U. Reeh, pers. comm.). However, phosphorous must be also removed from the area (i.e. by harvesting crops) to avoid over-fertilisation.Participation of 60-80 % of all households in a home composting scheme is common, though some of these households do not actively use their composting container (Domela, 2000; Skaarer & Vidnes, 1995; Reeh, 1992).

Garden waste from private gardens or parks may be shredded on-site and used for mulching of the grounds below bushes etc. as a way to prevent the establishment of annual weeds. This effect lasts 1–2 years for shredded mixed garden waste (no or low content of green leaves) and longer for shredded branches. It must be noted, that plant pathogens can easily be spread with the chips if any of the plant material is infected. Infected plant material should be taken to incineration. Especially when shredding garden waste for private garden owners, the resulting chips should be used in the same garden. Landscape gardeners working with the maintenance of parks will normally be able to recognise infected plant material and remove it. There are a large number of shredders and smaller chippers on the market.

1.3.1. Suitability for diverting BMW away from landfill

Home or community composting is suitable for treating BMW and can contribute to a reduction in the quantities of BMW put out for collection. A key advantage of community composting is that it is a local solution to a waste management problem and directly involves the community in dealing with its own waste. Generally, individuals or communities that engage in home or community composting are likely to have a higher awareness about waste issues which should have a knock-on effect on the reuse or recovery of other waste streams.

However, it is unlikely that home and community composting alone will deliver the levels of BMW diversion from landfill required to meet the targets set by the landfill directive and it would therefore be unwise to rely solely on small-scale composting initiatives to deliver the diversion rates required by the directive. Ideally, a mixture of central composting, particularly

(2) This calculation is based upon the collection of 43 kg BMW of vegetable origin per participant per year, 70 % of the households participating and a resulting compost containing 1.4 % N-total and 0.3 % P-total in the dry matter.

for large urban and suburban areas and community/home composting for small urban and rural areas should be encouraged, to maximise participation in composting schemes.

Overview of four types of home and community composting facilities Table 5

	Simple pile	Small container	Medium sized containers or composting area	Automatically rotating insulated drum
Acceptable waste	BMW of vegetable origin only. Garden waste without branches. Chopped garden waste.	BMW of vegetable origin only. Soft green garden waste. Small amount of chopped garden waste.	BMW of vegetable origin only. Soft green garden waste. Small amount of chopped garden waste.	BMW of vegetable and animal origin. Soft green garden waste. Small amounts of chopped garden waste.
No of households	1	1–4	50–250	40–120
Price of installation (EUR)	0	50-500	3 000–25 000 *	14 000–25 000 *
Estimated work (hr./month/ installation)	0–2	1–4	5–25	5–10
Needed level for information and control	Low	Low	High (avoiding visible impurities)	High (avoiding visible impurities)
Composting time (months)	12–36	9–18	2–9	2–9
Use of compost worms	Possible Unusual	Possible Common	Often possible Unusual	Not possible
Quality of product	Low (weeds, plant pathogens)	Low-medium (weeds, plant pathogens)	Low-medium (weeds, plant pathogens)	Low-high

Examples:
Small container: Example of a static plastic drum 'Humus' (1–2 households, EUR 75 /installation). Example of a static, insulated double box 'Rotate 550' (1-2 households, EUR 160 /installation; Swedish manufactured). Examples of a manually rotated, insulated drum 'CorroKomp 230' and 'Joraform JK 270' (2-4 households, EUR 500 /installation; Swedish manufactured).
Composting area: Example 'Nonneparken' in Herfølge, Denmark (155 households, EUR 21 000 for installation, 10 hr/month; from Reeh, 1992).
Automatically rotating insulated drum: Example 'CorroKomp 2000' (40–60 households, EUR 14 000 /installation with two drums; Swedish manufactured) and 'Joraform JK 2700' (60–120 households, EUR 21 500 /installation with two drums; Swedish manufactured).
* The more expensive solutions are normally chosen for a lower number of selected (low-density) residential areas and are not seen as the solutions for an entire town.
References: Knud Rose Petersen, pers. comm.; Karin Persson, pers. comm., Ulrik Reeh, pers. comm.

1.4. Anaerobic digestion

1.4.1. Brief description of technology

Anaerobic digestion is a biological treatment method that can be used to recover both nutrients and energy contained in biodegradable municipal waste. In addition, the solid residues generated during the process are stabilised. The process generates gases with a high content of methane (55–70 %), a liquid fraction with a high nutrient content (not in all cases) and a fibre fraction.

Waste can be separated into liquid and fibre fractions prior to digestion, with the liquid fraction directed to an anaerobic filter with shorter retention time than that required for treating raw waste. Separation can also be conducted following digestion of the raw waste so that the fibre fraction can be recovered for use, for example as a soil conditioner. The fibre fraction tends to be small in volume but rich in phosphorus, which is a valuable and scarce resource at global level.

Anaerobic digestion technologies chosen for treating BMW have generally consisted of separate digestion in a 'dry' process (e.g. Valorga, Kompogas, Dranco) because most of the plants digesting household waste tend to be established in large cities where implementation of integrated solutions (i.e. co-digestion with other waste products) is difficult due to relative unavailability of liquid manure.

The three main methods available, separate digestion (dry method), separate digestion (wet method) and co-digestion (wet method) are described below.

Separate digestion, dry method
With separate digestion, dry method, the organic waste is first tipped into a shredder to reduce the particle size. The waste is sieved and mixed with water before entering the digester tanks (35 % dry matter content). The digestion process is carried out at temperatures of 25–55 °C resulting in the production of biogas and a biomass. The gas is purified and used in a gas engine. The biomass is de-watered and hereby separated into 40 % water and 60 % fibre and reject (having 60 % dry matter). The reject fraction which is disposed at, for example, a landfill. The wastewater produced is recycled to the mixing tank ahead of the digester.

Separate digestion, wet method
With separate digestion, wet method, the organic waste is tipped into a tank, where it is transformed into a pulp (12 % dry matter). The pulp is first exposed to a hygienic process (70 °C, pH 10) before being de-watered. The de-watered pulp is then hydrolysed at 40 °C before being de-watered once again.

The liquid from the second de-watering step is directed to a bio-filter where the digestion is carried out resulting in biogas and wastewater. This water is reused in the pulp or, for example, may be used as a liquid fertiliser. The fibre fraction from the second de-watering is separated into compost and reject fractions to be disposed of at, for instance, landfill. The compost usually requires further processing prior to sale. The biogas is purified and utilised in a gas engine resulting in the production of electricity, heat and flue gas. Some of the heat can be used to ensure stable temperatures during the hydrolysis and the bio-filter processes.

In this process, one tonne of household waste will generate 160 kg biogas (150 Nm^3), 340 kg liquid, 300 kg compost fraction and 200 kg residuals (including 100 kg inert waste). According to analyses it is found that 10–30 % of the nutrient content (tot-N, tot-P and tot-K) remains in the compost fraction.

Co-digestion, wet method
With co-digestion, wet method, organic waste is shredded and screened before further treatment. The shredded waste is then mixed with either sewage sludge or manure from farms, at a ratio of 1:3–4. The mixed biomass is first exposed to a hygienic process (70°C) before being fed to the digestion phase, which is conducted at temperatures of 35-55 °C. The process generates biogas and a liquid biomass, which is stored before being used as a liquid soil fertiliser. The biogas is purified and utilised in a gas engine resulting in the production of electricity, heat and flue gas. Some of the heat can be used to ensure stable temperatures during the hygienic and the digestion phases.

One tonne of household waste will generate 160 kg biogas (150 Nm^3), 640 kg liquid fertiliser, 0 kg compost fraction and 200 kg residuals (including 100 kg inert waste). According to analyses it is found that 70–90 % of the nutrient content (tot-N, tot-P and tot-K) remains in the liquid fertiliser fraction. Thus it is possible to achieve very high recovery and utilisation of the nutrients. However it should be emphasised that liquid fertilisers, produced from sewage sludge, are much more difficult to sell than liquid fertilisers produced from manure.

1.4.2. Advantages and disadvantages
The mentioned advantages and disadvantages are accountable for all three anaerobic treatment methods.

Advantages
- Almost 100 % recovery of nutrients from the organic matter (nitrogen, phosphorus and potassium) if the digested material is ploughed down immediately after spreading on the fields

- production of a hygienic fertiliser product, without risk of spreading plant and animal diseases. The nitrogen is more accessible for the plants after digestion
- reduction of odour, when spreading on the fields compared with spreading of non-digested material
- CO_2 neutral energy production in the form of electricity and heat
- substitution of commercial fertiliser.

Disadvantages
- Requirements for source separation of waste
- the fibres require additional composting if intended for use in horticulture or gardening
- a market for the liquid fertiliser must be developed before establishment of the treatment method, unless the liquid has a very low nutrient content and thereby can be discharged to the public sewer
- methane emissions from the plant and non-combusted methane in the flue gasses (1–4 %) will contribute negatively to the global warming index.

1.4.3. Typical costs

Separate digestion, dry method Table 6a

Economic information		
Capacity Note 1 (tonnes per annum)	**Typical capital costs Note 2 (EUR)**	**Typical operating costs Note 3 (EUR)**
5 000	2.9–3.1 million	120 000 p.a.
10 000	5.3–5.6 million	220 000 p.a.
20 000	9.5–10.0 million	400 000 p.a.

Note 1: The BMW proportion amounts to approximately 100 % of the annual input.
Note 2: Plant cost excluding energy conversion gas engine, tax, planning and design fee. (Hjellnes Cowi AS and Cowi AS, 1993).
Note 3: Operating costs excluding the costs of transport, residue disposal, staff costs, income from sales of residue/by products and incomes from net sales of energy. Operating costs includes yearly maintenance costs estimated to 4 % of the initial capital cost. (Hjellnes Cowi AS and Cowi AS, 1997).

Co-digestion, wet method Table 6b

Economic information		
Capacity Note 1 (tonnes per annum)	**Typical capital costs Note 2 (EUR)**	**Typical operating costs Note 3 (EUR)**
20 000	3.7–4.5 million	130 000 p.a.
50 000	4.6–5.5 million	150 000 p.a.
100 000	10.5–12.5 million	350 000 p.a.

Note 1: The BMW proportion amounts to approx. 20 % of the annual input.

Note 2: Plant cost excluding energy conversion gas engine, tax, planning and design fee. (Danish Energy Agency, 1995).

Note 3: Operating costs excluding the costs of transport, residue disposal, staff costs, income from sales of residue/by products and incomes from net sales of energy. Operating costs includes yearly maintenance costs estimated to 3 % of the initial capital cost. (Danish Energy Agency, 1995; Claus D. Thomsen, pers. comm., Reto M. Hummelshøj, pers. comm.).

Staff costs may vary from plant to plant i.e. 5–15 persons for 100 000 tonnes per annum per plant. Total operating costs excluding transport may reach EUR 6 per tonne (Linboe et al., 1995). Electric consumption at a plant is typically about 0.2 kWh/m^3 biogas, and process heat consumption about 3 MJ/m^3 biogas.

1.4.4. Suitability for diverting BMW away from landfill

Anaerobic digestion is fully suitable for treatment of the food fraction of BMW presuming that the waste is pre-sorted. Anaerobic digestion is not suitable for treating newspaper, textile and wooden park waste. Anaerobic digestion produces biogas that can be used for heating or combined heat and power production, provided that there is a market — or the gas can be used to power public transport vehicles such as town buses or waste collecting lorries. The liquid fertiliser, slurry or fibre fraction from anaerobic digestion is optimally used in cooperation with agriculture.

1.5. Incineration

1.5.1. Brief description of technology

Incineration reduces the amount of organic waste in municipal waste to about 5 % of its original volume and sterilises the hazardous components, while at the same time generating thermal energy that can be recovered as heat (hot water/steam) or electric power or combinations of these. The incineration process also results in residual products, as well as products from cleaning of the flue gas, which have to be deposited at a controlled disposal site such as a landfill or a mine. Sometimes wastewater is produced. Nutrients and organic matter are not recovered. The principal technologies available on the market are described below.

Grate incineration

Waste is tipped into a silo, where a crane mixes the incoming material. Often bulky material is shredded and returned to the silo. The mixed waste is then fed into the incinerator's charging chute by means of the crane system. From the charging chute, the waste is fed into the furnace. It is dried and ignited on the first grate parts, by the time it reaches the latter grate parts it is burnt out and leaves the furnace in the form of clinker. The incineration temperature is at a minimum of 950 °C and the retention time in the after-burner should be a minimum of 2 seconds at a minimum of 850 °C.

At larger incinerators, the grate system is supplemented with a rotary kiln ensuring efficient burnout of all combustibles. The hot flue gases produced during the incineration process are led to a boiler plant specifically designed for flue gases from incineration of waste. In this boiler the energy is utilised for steam or hot water production.

Fluidised bed incineration

A few fluidised-bed incinerators are in operation in Europe. The main difference between the fluidised bed technology and the grate systems is that the grate is substituted with a fluidised sand bed to transport the waste during the incineration process. The fluidising process is obtained by blowing air from underneath the sand bed in an upward direction. Depending on the air velocity the fluidised bed system may either be bubbling or circulating, where the airborne volatile fines are returned to the incineration zone after passage of a cyclone. Fluidisation may also be achieved by rotating beds.

Compared to the grate combustion process described above there are some major differences such as:

- the fluid bed is more sensitive to bulky waste but less sensitive to fluctuations in the calorific value;
- the fluid bed incineration process produces a low amount of NO_x, which is comparable with grate systems with flue gas re-circulation and optimised process control;
- the fluid bed process has a lower thermal flue gas loss but a higher parasitic power demand — some 50 % higher than the grate based system;
- the clinker from the fluid bed system is very inert and the amount of non-combusted material is very low in the clinker, but the fly ash production is considerably higher than at the grate systems;
- the fluid bed has been shown to involve a slightly higher capital investment.

Flue gas cleaning

Before leaving the boiler the flue gases are cleaned in a flue gas purification plant in which particles, heavy metals, acid gases like hydrochloric acid, HF, SO_2, NO_x and dioxins are removed before the flue gas, through a fan, is fed to a chimney. There are three principle systems used for the cleaning of flue gases:

- the dry system, with dry lime injection, activated carbon injection and bag-house filter;

- the semi-dry system, with injection of lime slurry, activated carbon injection and bag-house filter;
- the wet system, with an electrostatic precipitator in front of a wet, two-stage scrubber for acid gases followed by activated carbon injection and bag-house filter.

There are different ways of designing the flue gas cleaning system. These differences are usually due to the variations in national legislation within the European countries. Some countries, for example, do not allow the production of wastewater, which results in a combination of the different processes.

1.5.2. Advantages and disadvantages

Advantages

- Well-known process installed worldwide, with high availability and stable running conditions (this bullet counts for grate incineration only)
- Energy recovery with high efficiency of up to 85 % can be achieved, if generating combined heat and power or heat only
- All municipal solid waste as well as some industrial wastes can be disposed of unsorted via this process
- The volume of the waste is reduced to 5–10 %, which primarily consists of clinker that can be recycled as a gravel material for road building if sorted and washed;
- The clinker and other residues are sterile
- CO_2 neutral energy production, substituting combustion of fossil fuels.

Disadvantages

- Extensive investments
- Extensive flue gas cleaning system
- Generation of fly ash and flue gas cleaning products, which have to be deposited at a controlled landfill (amounts to approximately 2–5 % by weight of the incoming waste)
- Generation of NO_x and other gases as well as particles.

1.5.3. Typical costs

Grate incineration Table 7

Economic information		
Capacity (tonnes per annum) Note 1	**Typical capital costs Note 2 (EUR)**	**Typical operating costs Note 3 (EUR)**
50 000	25 million	950 000 p.a.
100 000	45 million	1 750 000 p.a.
200 000	90 million	4 000 000 p.a.
500 000	160 million	6 800 000 p.a.

Note 1: The BMW proportion amounts typically to 50–70 % of the annual input.

Note 2: Plant cost excluding tax, planning and design fee and land based on Danish conditions. In central Europe the cost of plants is approximately a factor 1.5–2 higher, especially in Germany. (Reto M. Hummelshøj, pers. comm., Stig Gregersen, pers. comm.).

Note 3: Operating costs excluding the costs of transport, residue disposal, staff costs, income from sales of residue/by products and incomes from net sales of energy. Operation costs includes yearly maintenance cost estimated to 3 % of the initial capital costs. (MCOS/Cowi, 1999).

A plant with extensive flue gas cleaning and combined heat and power production, in order to operate continuously, will require between 20 and 40 people, depending on plant size, but also on the number of administrative staff situated at the incineration plant and degree of outsourcing of maintenance work. A simple biomass boiler plant for wooden park waste will have a capital cost of about EUR 0.5 million per MJ/s capacity and total operating cost of EUR 25 000–40 000 p.a. per MJ/s capacity.

1.5.4. Suitability for diverting BMW away from landfill

Incineration can be considered technically and economically feasible provided the market for the energy products of heat and power is available and stable. Thermal treatment, with waste to energy (WTE), is environmentally sound with lower greenhouse gas emissions compared with landfills, anaerobic digestion and composting.

Dioxin-type compounds in emissions to the atmosphere may be a public issue when decision-makers are going to choose a waste treatment system but there are strict EU standard limits on emissions of dioxin etc. from incineration plants.

It should be noted that addition of relatively non-polluting waste, such as certain fractions of BMW, may increase the total emission doze of pollutants as the flue gas quantity is increased. The main disadvantage of incineration is the high cost and that nutrients such as phosphorus and potassium and humus, present in the raw waste, are lost.

1.6. Pyrolysis and gasification

1.6.1. Brief description of technologies

Pyrolysis and gasification represent refined thermal treatment methods as alternatives to incineration. The methods are characterised by the transformation of the waste into product gas as energy carrier for later combustion in, for example, a boiler or a gas engine. Flue gas volumes are reduced in comparison to incineration, so that the demand for voluminous flue gas cleaning equipment is reduced.

The purpose of pyrolysis and gasification of waste is to minimise emissions and to maximise the gain and quality of recyclable products as well as to minimise the amount of organic waste and sterilise the hazardous components. Surplus heat is generated and can be recovered as heat (hot water/steam) or electric power or combinations of these with a high power-to-heat ratio. The processes produce residual products, as well as products from cleaning of the gases, which has to be deposited at a controlled landfill/mine. Wastewater is also normally produced and treated before it is discharged to the sewage system or evaporated in cooling towers. Nutrients and organic matter are not recovered.

Pyrolysis

Pyrolysis is a thermal pre-treatment method, which can be applied in order to transform organic waste to a medium calorific gas, liquid and a char fraction aimed at separating or binding chemical compounds in order to reduce emissions and leaching to the environment. Pyrolysis can be a self-standing treatment, but is mostly followed by a combustion step and, in some cases, extraction of pyrolytic oil (liquefaction).

Waste is tipped into a silo where a crane mixes the incoming material and moves the material to a shredder and from here to another silo. The mixed waste is then fed into a gas tight hopper arrangement, screw- or piston feeder. The coarsely shredded waste now enters a reactor normally an external heated rotary drum operated under atmospheric pressure. In the absence of oxygen the waste is dried and hereafter transformed at 500–700 °C by thermo-chemical conversion i.e., destructive distillation, thermo-cracking and condensation into hydrocarbons (gas and oils/tar) and solid residue (char/pyrolysis coke) containing carbon, ash, glass and non-oxidised metals.

If the process temperature is 500 °C or below, the process is sometimes called thermolysis. The retention time of the waste in the reactor is typically 0.5-1 hour. The >300 °C hot product gas is normally led to a boiler plant, where the energy content is utilised for steam or hot water production. The raw product gas is **not** suitable for operation of an internal combustion engine due to the high content of tar in the gas phase, which will condense when the gas is cooled before entering the gas engine. Thermo-cracking of the tars in the gas followed by gas cleaning may solve the cleaning need.

Gasification

Gasification is a thermal treatment method, which can be applied to transform organic waste to a low calorific gas, recyclable products and residues. Gasification is normally followed by combustion of the produced gasses in a furnace and in internal combustion engines or in single gas turbines after comprehensive cleaning of the product gas. Coarsely-shredded, sometimes pyrolysed waste enters a gasifier, where the carbonaceous material reacts with a gasifying agent, which may be air, O_2, H_2O in the form of steam, or CO_2. The process takes place typically at 800–1 100 °C (oxygen blown entrained flow gasification may reach 1 400–2000 °C) depending on the calorific value and includes a number of chemical reactions to form combustible gas with traces of tar. Ash is often vitrified and separated as solid residue.

The main difference between the pyrolysis and gasification is that by gasification the fixed carbon is also gasified. Gasification plants may be designed as 1- or 2-step processes. The gasifier itself may be either up flow, down flow and entrained flow fixed bed type or for big plants also bubbling or circulating fluid bed types, atmospheric or pressurised when combined with gas-turbines. Sometimes the first step is a drying unit, in other cases a pyrolysis unit. Both pyrolysis and gasification units may be installed in front of coal fired boilers of power plants, which enables co-firing with a very high power-to-heat ratio.

1.6.2. Advantages and disadvantages

Advantages of pyrolysis

- Better retention of heavy metals in the char than in ash from combustion. (at 600°C process temperature the retention is as follows: 100 % chromium, 95 % copper, 92 % lead, 89 % zinc, 87 % nickel and 70 % cadmium)
- Low leaching of heavy metals from deposition of the solid fraction chromium and reduced to 20 % for cadmium and nickel
- Production of gas with a LCV (low calorific value) of 8 MJ/kg (10–12 $MJ/Nm^{3)}$, which can be combusted in a compact combustion chamber with short retention time and very low emissions
- CO_2 neutral energy production substituting combustion of fossil fuels
- Less quantity of flue gas than from conventional incineration
- Hydrochloric acid can be retained in or distilled from the solid residue
- No formation of dioxins and furans
- The process is well suited to difficult waste fractions
- Production of sterile clinker and other residues.

Disadvantages of pyrolysis

- Waste must be shredded or sorted before entering the pyrolysis unit to prevent blockage of the feed and transport systems
- Pyrolytic oils/tars contain toxic and carcinogenic compounds, which normally will be decomposed through the process
- The solid residue contains about 20–30 % of the calorific value of the primary fuel (MSW), which however can be utilised in a following combustion zone (incineration/gasification plant)
- Relative high cost
- Back-up fuel supply is required at least during start-up.

Advantages of gasification

- High degree of recovery and good use of the waste as an energy resource (energy recovery with high efficiency of up to 85 % can be achieved, if generating combined heat and power or heat only, electricity gain of 25–35 % is possible)
- CO_2 neutral energy production, substituting combustion of fossil fuels
- Better retention of heavy metals in the ash compared to other combustion processes especially for chromium, copper and nickel
- Low leaching of heavy metals from deposits of the (vitrified) solid fraction particularly for chromium and also reduced for cadmium and
- nickel,
- Production of sterile clinker and other residues
- Production of gas with a LCV (low calorific value) of 5 MJ/Nm^3 (airblown) or 10 MJ/Nm^3 (oxygen-blown) which can be combusted in a compact combustion chamber with a short retention time resulting in very low emissions (alternatively it can be cleaned for tar particles and used in a lean-burn internal combustion engine);
- Less quantity of flue gas than that from conventional incineration
- Gas cleaning systems can remove dust, PAH, hydrochloric acid, HF, SO_2 etc., from the produced gas resulting in low emissions

- The process is well suited to contaminated wood.

Disadvantages of gasification
- Waste must be shredded or sorted before entering the gasifier unit to prevent blockage of the feed and transport systems;
- The gas contains traces of tars containing toxic and carcinogenic compounds which may contaminate the quench water resulting in the need to re-circulate washing water or treat as chemical waste;
- Complicated gas clean-up for motor use;
- The combustion of product gas generates NO_x;
- The solid residue may contain some unprocessed carbon in the ash;
- High cost;
- Only very few non prototype-like plants are available on the market.

1.6.3. Typical costs

A plant normally consists of two or more lines. The costs shown in Table 8 are stated for a highly sophisticated integrated pyrolyse-gasification plant.

Table 8 **Costs relating to an integrated pyrolyse-gasification plant**

Economic information		
Capacity (tonnes per annum)	Typical capital costs Note 1 (EUR)	Typical operating costs Note 2 (EUR)
20 000	(8)–15 million	(0.8) million p.a.
50 000	35 million	1.2 million p.a.
100 000	60 million	2.1 million p.a.
200 000	90–100 million	3.3 million p.a.

Note 1: Plant cost excluding tax, planning and design fee and land based on Danish conditions. In central Europe the cost of plants is approximately a factor 1.5–2 higher, especially in Germany (MCOS/Cowi, 1999).
Note 2: Operating costs excluding the costs of transport, residue disposal, staff costs, income from sales of residue/by products and incomes from sales of energy. Operating cost includes chemical cost e.g. for oxygen, natural gas, nitrogen and limestone and yearly maintenance cost of 3 % of initial capital cost (MCOS/Cowi, 1999).

The number of staff required is 25–40, depending on process, site, size and number of administrative staff situated at the plant. The cost for a simple biomass gasification plant for wood waste is about EUR 1 million per MJ/s waste based on 45 % moisture on weight basis.

1.6.4. Suitability for diverting BMW away from landfill

Pyrolysis and gasification of the organic wet fraction of biodegradable waste alone is unusual, as this would need expensive pre-drying of the waste. The processes are more suitable for the dry fraction of the biodegradable waste but would still have to meet the strict emissions regulations set for incineration plants treating municipal solid waste.

Gasification of chipped park waste (wood chips), can be carried out in relatively simple gasification plants designed for biomass, with low emissions. Gasification of other waste fractions and mixtures will increase the complexity and cost of the plant considerably. Gasification can be considered as a treatment method, provided that a stable market for the produced energy and recyclable products is available.

Gasification of selected waste fractions is environmentally sound with low greenhouse gas emissions compared with, for example, composting and conventional incineration, where gasification can be considered as a refined incineration process. Pyrolysis can be considered as a treatment method for contaminated waste fractions such as car shredder waste, plastics and pressure impregnated wood. It is expected that pyrolysis and gasification plants will have a wider application field in the future due to environmental reasons and the flexibility of the systems which can be combined with other new or existing combined heat and power plants.

2. Quality and market issues

2.1. Introduction

Adequate and reliable markets for good quality compost, energy and other products from waste treatment are essential to prevent biodegradable waste from going to landfills. Market potential must be thoroughly investigated before decisions are made about waste management systems, but market research unfortunately has the obvious disadvantage of being time dependent and rapid changes in preconditions might change a market radically. However, a basic knowledge about markets will often prevent the effects of changes from being fatal. Energy markets have so far been unlimited.

The following chapter assumes that all products can be considered marketable, though some might have a negative price. All products have to meet quality standards to be both acceptable to the environment and to the consumer. This chapter focuses mainly on products destined for plant growth because of the growing attention that such matters are receiving at European level, in particular:

- the plans for an EU compost directive (working document on biological treatment of biowaste);
- the revision of the EU sewage sludge directive;
- the development of CEN-standards for soil improvers and growth media (including compost), resulting in standards for pH, EC, OM, DM and density (CEN 1999a,b,c,d);
- the EU eco-label for soil improvers and growing media (European Commission, 2001).

2.2. Compost and solids from anaerobic digestion

2.2.1. Compost quality

Compost of high quality can be produced by simple technology whereas good process management eliminates problems with malodour, handling properties, weeds or pathogens. A consistently good source separation of BMW and the use of paper bags, and/or buckets eliminate problems with visible impurities, heavy metals or organic pollutants (e.g., the plastic softener DEHP).

Choice of composting plant type is mainly governed by the need to avoid potential odour and vector problems, the limitations in the size of the available area, and the desire to treat an expanding range of waste types in the future. The most efficient/quickest elimination of pathogens is normally achieved with forced aeration treatment.

Compost has to be used in the right amount at the right time of year depending upon the type of compost and application area. Characteristics such as degree of stability and electrical conductivity are very important in determining possible areas of application.

Future estimates of waste quantities and the area needed for compost storage are very often underestimated. Good process management is very difficult under these conditions and most often result in low quality compost and loss of market share. A single batch of bad compost can have a long-lasting devastating effect on the reputation of a plant and should be disposed of.

2.2.2. Compost marketing

The vast majority of composting plants are not actively marketing their products compared with, for example, companies marketing phosphorous fertilisers or peat. Marketing towards the agricultural and horticultural sectors (including private gardens) requires knowledge of plant growing requirements as well as an understanding of the needs of the different sectors. Quality declarations must be comparable with those of competing products.

Additional information regarding application etc., is necessary and the specific advantages of compost over other products should be pointed out such as:

- a high content of beneficial micro-organisms (for improved top soil structure, inhibition of plant diseases, furthering of mycorrhiza);
- a source of stable humus;
- no weeds;
- a liming effect and a slow release nitrogen fertiliser effect.

The fibres produced by many anaerobic digestion processes differ from compost in three ways:

- the content of ammonia-nitrogen is high;
- the degree of stability is low;
- only a few species of micro-organisms are present.

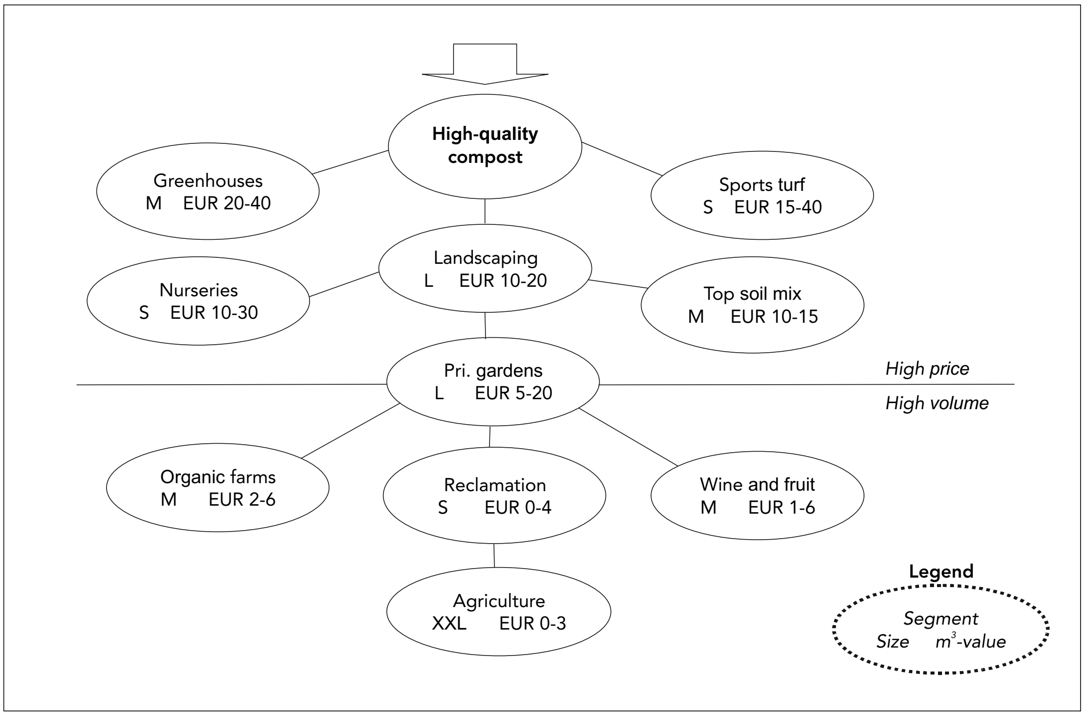
The fibres are best suited for agricultural usage, while a post-treatment composting stage is needed for general marketing in other sectors.

Knowledge concerning the seasons for compost application and focusing on possible terms of delivery is important for the timing of campaigns. A marketing plan must include some degree of personal contact between the composting plant's agronomist and the compost users.

The agricultural market is very important in regions where there is a large and rapidly expanding production of compost. The highest possible nutrient content of the compost is normative for its value within this market.

Compost low in nutrients, e.g., pure garden waste compost, is very well suited for the landscaping sector and for all sectors using compost as mulch. The demand for garden waste compost is substantial within metropolitan areas and for infrastructure constructions (e.g. vegetated areas, road verges). Present sizes of the different markets are shown in Table 9 for four European countries and the attainable price and relative market size (small to extra-extra large) available within the different sectors are illustrated in Figure 1.

Figure 1 **Attainable price and market size**



The prices listed in Figure 1 are actual prices for ready-to-use products with compost, or pure composts, when the producer sells the products to the wholesaler or to the end user *(F. Amlinger, pers. comm.; J. Barth, pers. comm.; W. Devliegher, pers. comm., Carlsbæk and Brøgger, 1995; Domela, 2000).*

Real sizes of markets Table 9

	Austria	Denmark	Flanders, B	Germany
Marketed amount (1996–98 average)				
Compost amount (1 000 tonnes)	300	280	201	4 100
Population size (mill.)	8	6	5	82
Input materials (1996-98 average in % w/w)				
BMW	51	7	21	41
Garden waste	26	88	79	59
Dewatered sewage sludge, others	23	5	0	0
Segments (% of total marketed amount in 1998)				
Private gardens	20	49	18	16
Park and landscaping, reclamation	35	34	50	37
Horticulture, greenhouses	10	2	20	12
Agriculture	30	10	12	32
Others	5	5	0	3

References: Domela, 2000; VLACO, 1999; Devliegher, 1999; F. Amlinger, pers.comm.; J. Barth, pers.comm.; W. Devliegher, pers. comm.

2.2.3. Agriculture and silviculture

The agricultural sector is a very large market paying low prices. The sector may be willing to pay for the nutrients available in compost if there is no surplus animal manure available in the neighbouring area. Organic agriculture often pays more for compost products as compared with high-input agriculture. The nutrient content of composted BMW can be high thus paying for transportation to and application on farmland up to 20–40 km away. Farmers only apply the compost for a short period during both spring and autumn, which is a key consideration when developing a production and marketing plan for a plant.

Organic farming is dependent upon supplementary phosphorous and potassium nutrients from external sources, especially when growing vegetables or if the farm is non (animal) husbandry. Within the agricultural sector, organic farming will pay the highest price for compost (assuming that local supplies of manure are insufficient). The agricultural market is sensitive towards public media discussions, and vegetable growers are often not allowed to use composted BMW due to the food producer's fear of negative consumer reactions. The establishment and maintenance of good connections with the farmers associations and the food producers is therefore recommended. The importance of continuously documenting low heavy metal content and pathogen inactivation cannot be underestimated.

A declaration targeted at the agricultural sector should comprise information about N-total, ammonia-N, nitrate-N, N-available 1. yr. (Spring, Autumn-application), P-total, K-total, Mg-total, S-total, liming effect (as $CaCO_3$ or CaO), pH, organic matter, dry matter, volume weight, visible impurities, heavy metals, possible organic pollutants, sanitary treatment and compliance with the content of possible indicator micro-organisms. Nutrient content should be stated in kg/tonne fresh weight compost. For most uses within agriculture a fairly fresh compost is preferable to a very stable compost, since the latter has a lower content of available nitrogen. The user guidelines, i.e. directions for application, should deal with the permitted amounts according to present fertilisation legislation (e.g., max 170 kg N-total per hectare per year). They should also deal with application methods and crops on the area with respect to sanitary treatment/level of indicator micro-organisms. It should be noted that the fibres produced by many anaerobic digestion processes are best applied before sowing and should be lightly worked into the topsoil. If left on the surface, a substantial part of the plant-available nitrogen will evaporate due to a high content of ammonia and a high pH-value.

Silviculture is defined as the commercial growing of trees, other than fruit trees, for timber exploitation purposes and coppicing. Regulations for compost application in silviculture are comparable to those for agricultural application though lower levels of nitrogen are needed. Application of compost is most beneficial in areas with topsoils low in organic matter (< 2 %). The establishment of forest in previous agricultural land, where high rate agricultural production took place within the last few years, does not benefit from any form of fertilisation, nor from organic fertilisers if the organic matter of the soil is sufficient.

2.2.4. Landscaping

The landscaping sector is a very important market for compost products, especially in metropolitan areas. The sector demands stable or very stable composts free of weeds, with a low level of visible impurities and with good handling properties. High prices are paid for refined compost products, e.g., topsoil mixtures/substitutes, mulches for shrubbery, topdressing for lawns and ball playing pitches. Urban topsoil is often of poor quality (low in organic matter, compacted, damaged by usage of all-purpose pesticides) therefore additional sources of humus and beneficial micro-organisms are desirable. The extended use of woody plants within this sector makes the slow release of fertiliser properties of compost an advantage. Generally, the sector prefers composts low in nutrients for most uses. Some plant species used in landscaping are sensitive to chloride and prefer low pH.

A general compost declaration for the landscaping sector should comprise the same information as for agriculture, except for nutrient content being stated in kg/m^3 and not kg/tonne. Information about electrical conductivity, content of weeds and degree of stability must be added. Mulches should have a content below 10 % (w/w) of particles < 5 mm (Carlsbæk, 1997a; BGK, 2000).

Terms of delivery (delivery within one or a few days) are very important when dealing with the landscaping market. Detailed guidelines are very important when marketing compost for the landscape sector. Recommended use for establishment tasks as well as for maintenance tasks must be stated, including possible need for supplementary nitrogen.

The reclamation of former landfills and mines, or soil sanitation of leftovers/debris from mining, can consume large amounts of, mostly, locally produced compost within a short period of time. Recommendations for soil improvement and the production of topsoil mixes with compost also apply for reclamation purposes. The landscaping market is dependent upon the level of construction activity in the region.

2.2.5. Private gardens and homes

Compost with a high content of nutrients is best suited for vegetable growing, while pure garden waste compost is well suited for perennials, bushes and trees. Many municipality-owned composting plants consider that returning compost made from the collected waste back to the households that supplied the waste is important because it encourages people to continue their participation in source separation and separate collection schemes.

Pricing of compost marketed towards the private garden sector is mostly politically controlled. Regional campaigns in spring with low (subsidised) product/transportation prices or ‘pick up a trailer full of compost for free’ are very successful and can result in outlets of amounts greater than during the rest of the year. Compost for private collection is often distributed to local locations (‘recycling depots’, ‘Waste centres’) to avoid any disturbance of the production including possible accidents as well as a way to lower the overall energy consumption for transportation.

Compost for the private garden sector must be of high visual quality and without malodours. Finely screened compost is more easily marketed than coarsely screened compost. A short guide with simple application hints is very important. Nutrient contents should be stated in kg/m^3. To ensure maximum environmental benefit it should be mentioned, that the use of compost renders any fertilisation with phosphorous and potassium (including NPK-fertilisers) superfluous. However, for low nutrient composts like garden compost, the application of additional nitrogen is still needed for the growing of vegetables and a few other plant types such as roses.

2.2.6. Fruit and wine growing

In wine growing, mulching is fairly common for soil improvement, for reduction of water evaporation and to suppress annual weeds. Composts with a very low nutrient content and a very low content of particles (< 5 mm) are best suited for mulching. The continuous but slow degradation of the mulch will supply the wine with most of the needed nutrients.

The growing of apples, pears and most stone fruits requires large quantities of potassium. The maintenance of a topsoil with a high pH is desirable. Using compost can fulfil both needs. The ground below the tree rows are kept free of weeds by the use of herbicides in high input horticulture, and by weeding or mulching with, for example, garden compost in organic horticulture. Berries have very different needs regarding nutrient levels and pH from fruit trees such as apples and pears and are often very sensitive to chloride. For berry growing, only a very small yearly supply of compost can be recommended.

The declarations on composts to be used in fruit and wine growing should contain the same information as for similar use in the landscape sector. Suggestions and information about machinery needed for the application of mulches are valuable, and a possibility to sub-let the needed machinery from the composting plant will be a competitive advantage in the marketing of compost.

2.2.7. Nurseries and greenhouses

The nursery sector can be divided into plants growing in fields and plants growing in containers/pots, and both ways of plant growing can benefit from the use of compost. Field nurseries need a supply of nutrients and of humus. They are experiencing increasing soil structural problems due to the continuing removal of both plant tops and most of the plant root system. The type of declaration needed and user directions are the same as for the agricultural sector.

Container nurseries are interested in improved growth media and it can be a well paying niche for compost producers. The compost must be of uniform high quality, stable with good structural qualities, and guaranteed free of phytotoxic elements, pathogens, weeds and visible impurities. The slow release nutrient properties of compost are valued. The declaration must include all traditional analyses of growth media, including a number of soluble/plant available nutrients. The total and available content of chloride Cl^- must be sufficiently low not to cause problems.

A few ready-made blends comparable to the traditionally used growth media are best marketed for the container-nursery niche. Physical parameters like air-filled porosity and water retention must be checked for short-term and long-term compliance with the standards and growth performance trials before marketing is recommended. Container nurseries are often specialised in growing very few plant species and know the exact needs of these species. The growth media producer must account for this. Nurseries are experiencing increasing problems with root pathogens which cannot be eliminated by use of fungicides. Disease suppressing properties are inherent in several types of compost, which can be useful to the nursery sector (Hoitink et al., 1997).

The professional greenhouse sector is probably the most difficult sector for compost products to enter with its very high demands for uniformity, quality and documentation. The greenhouse sector pays high prices for the right product, but the costs of product development and marketing are also high. The type of declarations needed for this sector are the same as those needed for the nursery sector, though often only one plant species is grown. The quality requirements for growth media to be used in hobby greenhouses or for potted indoor plants in private houses are lower, but this is counterbalanced by high packing costs and low-paying middlemen.

2.2.8. Slurry from anaerobic digestion

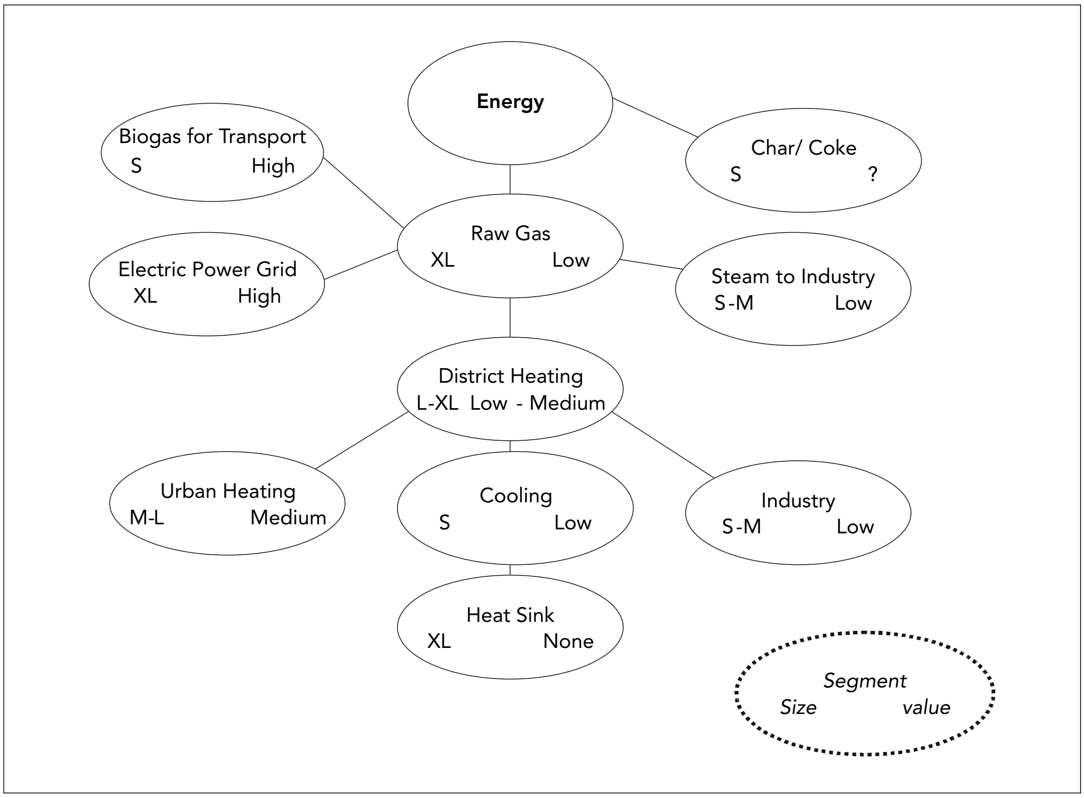
Slurry from anaerobic digestion is used in agriculture only. Due to a low content of nutrients per tonne, the slurry should be used on farms situated within a radius of 5–10 km from the anaerobic digestion facility. If the fibre fraction of the slurry is separated, the remaining thin slurry must be used on neighbouring farms; some facilities choose to discharge such slurry. A very large part of the nitrogen in digested slurry is ammonia and the pH of slurry is high. The use of the right application equipment and avoiding windy and sunny weather, when applying the slurry is therefore very important to avoid high losses of ammonia-nitrogen. Slurry from anaerobic digestion is declared for content of N-total, ammonia-N, P-total, K-total, Mg-total, S-total, liming effect (as $CaCO_3$ or CaO) pH, dry matter, organic matter, visible impurities, heavy metals, possible organic pollutants, sanitary treatment and compliance with the content of possible indicator micro-organisms. Nutrient content is stated in kg/tonne. For general considerations, see the section on marketing of compost for agriculture.

The fibres are best suited for agricultural usage, while a post-treatment composting stage is needed for general marketing into other sectors.

2.3. Energy

There are several ways of utilising energy produced from the treatment of BMW. An overview is provided in Figure 2 below, with an indication of market size (small to extra-large) and value. In the following paragraphs, the various markets for energy in different sectors are described.

Figure 2 **Overview of energy use**



2.3.1. Gas

Biogas may be used in a gas-engine or boiler at the biogas plant. Biogas can be added to the natural gas network after expensive and comprehensive gas treatment to meet natural gas quality standards. Another option is to supply an isolated network with biogas using a controlled mixture of natural gas and air as back-up. Biogas can also be compressed and used as fuel for public transport (buses).

Raw product gas from pyrolysis and gasification is not suitable for distribution. A consumer of pyrolysis or raw product gas from gasification of waste must therefore be located adjacent to the plant in order to avoid condensation of tarry substances in the pipes. The gas can be used on site, for example in a steam boiler for incineration under controlled conditions.

Contrary to pyrolysis gas, cleaned product or synthesis gas can — as for biogas — be distributed several kilometres in separate pipes and used to power an engine or even a gas turbine, but clean-up demands are very strict. Gas clean-up normally results in contaminated wastewater as a by-product, which also needs cleaning or may be returned to the process. Strict safety measures must be taken if product gas is distributed, due to the high content of carbon monoxide in the product gas. In some cases emissions of nitrogen oxides NO_x and unburned hydrocarbons may be a limiting factor depending on local legislation.

2.3.2. Electric power

It is possible to produce electricity from biogas and thermal waste treatment processes but reliable consumers with a known demand are required. Power generation can have a large impact on plant economics but this depends on tariff structures, possible subsidies, contracts for the supply of electricity to a consumer or the public power utility/ distribution company/ power procurer. Electric power production can normally be sold to the public grid, but the price, which can be obtained, depends largely on political criteria.

The power procurer is responsible for ensuring a power production meeting the power needs of a geographic area. Any contract for the supply of electricity will be arranged through negotiations with this body meaning that a competitive electricity market will exist. The price for electricity under this regime will tend towards the lowest possible price, thus encouraging only the most modern and efficient generation methods. The pool price for electricity is presently often in the range of EUR 25–35 /MWh. This price will serve as a benchmark for the negotiations. If power can be sold directly to a consumer or in countries, where non-fossil fuel utilisation (e.g. biogas) is subsidised, a payment of around EUR 50 /MWh may be achieved.

The potential revenue from sales of electricity from a treatment plant ranges typically from EUR 15 to 25 per tonne of waste, based on a net electric efficiency of 20 % and a lower calorific value of 10 MJ/kg. Compared with a gate fee of say EUR 40 per tonne for a modern WTE facility, the significance of this revenue source to the facility is apparent. The grid connection costs depend largely on the actual site location and whether the size of the plant fits the conditions and capacity of the present grid.

2.3.3. District heating

The market for heat is dependent on housing and/or industries, which can be connected to a district heating system. The economic viability of a district heating project is dependent on the location, the distance from the incinerator to the consumers, tariff structures and the heat prices of the actual market. Depending on location, housing for 20 000 people and office complexes and shops with 15–18 000 employees could represent a heat market of more than 100 000 MWh per year.

District heating may be a main product, provided that there is a sufficient heat market and an existing district-heating scheme. For new plants it is necessary to establish a district heating network, central peak load and back-up boilers. Existing supply with natural gas may inhibit the development of a district-heating scheme. If a new district-heating network has to be established the income from selling heat to the network is normally very low due to the capital cost for the network.

District heating temperatures are normally 90/45°C flow and return temperature in winter and 70/50°C during summer. District heating can also drive absorption chilling machines for cooling purposes during summer months or for industrial use and cold stores (not freezing). Waste heat in excess of demand, for example, in the summer, must be discharged using a nearby water stream or air-cooled coils. Waste heat may to some extend also be used to dry incoming waste, for example, sewage sludge, in cases where the moisture content is high.

2.3.4. Steam for process heating

Dry saturated steam can be supplied to a nearby industry as process heating provided that there is a market. Steam is normally needed at 6–10 bar and cannot be transported over longer distances due to pressure loss in the piping system. If condensate is not returned it implies a cost for water treatment for the make-up water. Returned condensate may contain harmful impurities for the steam cycle. It should be noted that steam supply to an external user results in a reduction of the electricity output from the turbine, especially in the case of condensing turbines. The potential outputs should therefore be balanced carefully in order to maximise the plant's revenue from sales of energy. The value of steam for process heating is typically negotiated with each customer and is therefore less quantifiable than the value of, for example, electricity.

2.3.5. Char/pyrolysis coke

Char from waste pyrolysis itself can be used as fuel in a waste incinerator. If inert material and solids are separated from the char it may be blown directly into the furnace of a waste incinerator (e.g. as demonstrated at the Haslev Plant in Denmark), or, alternatively, coal dust burners can be used. The combustion characteristics of the char are similar to pulverised bituminous coal. However, in Germany at present char from pyrolysis units is being disposed of or used for co-combustion in coal fired power plants. Future EU limits on maximum allowable proportions in landfilled waste will rule out the deposition of char in landfill sites.

Some producers claim that their washed char product after de-watering can be delivered to and used in cement kilns. However, until now this has been done at zero cost. Cement manufacturers present very strict acceptance criteria in relation to chlorine and alkali metals as they form a swelling gel together with silica, which can cause micro cracks in the concrete. A Danish cement manufacturer has set the following limits:

Sodium:	*Max. 0.18 mg Na_2O per kg of coke (25 MJ/kg).*
Potassium:	*Max. 0.8 mg K_2O per kg of coke (25 MJ/kg).*
Sulphur:	*0.4 -0.5 % on weight basis.*
Chlorine:	*0.005 % on weight basis.*

The produced char (or part stream thereof) may also be activated to produce activated carbon for use in flue gas cleaning of the plant itself or associated mass burn WTE incinerators. The value of activated carbon is high, about EUR 1 000 per tonne depending on the quality. However, the market for this product is relatively small.

2.4. Recyclable products from incineration and gasification

The value of all of the recyclable materials from any process will depend principally on the existence or otherwise of a market for materials. In order to find a use and market, the quality of a particular material needs to be matched to its application. Certain applications may be more suitable than others with a degree of testing and evaluation being required in all cases. The higher the quality of the material, the greater its usefulness and value, but to achieve this level an amount of refining will be necessary, reducing the net benefit to the producer. The final value of any product will be established only after a period of active marketing and trials whereby potential users may be informed and convinced of its worth. The following products are being recycled successfully at various locations:

- **washed and granulated slag/clinker** can be recycled in road construction projects as a sub-base material and also in the cement industry as a filler material. The inert slag/clinker will meet competition from the existing gravel pit, which normally can produce sufficient amounts at low cost i.e. about EUR 0.5 per tonne. Recycling of construction waste will also generate considerable amounts of gravel;
- **grit, glass and ceramics** can be recycled for back filling (dams, quarries). The value of the mixture is estimated to about EUR 2 per tonne. The value of mixed coloured glass is roughly EUR 1 per tonne;
- **ferrous metal** can be recycled to an iron smelt with a value of about EUR 10 per tonne;
- **non-ferrous metal,** especially copper and aluminium, can be recycled for smelting, but the value is very dependent on the amount of impurities as e.g. chrome. Recovered metals can be sold to the local scrap market, at market price, if the materials are considered to be of

sufficiently high quality. It is preferable to source separate metal instead of separating copper, aluminium and glass/ceramics from the slag;
- **chemical bulk**. In some cases $CaSO_4$ for gypsum board production can be produced or HCl for acid production.

2.5. Residuals from incineration

Fly ash and dry flue gas cleaning products are hazardous wastes that have to be disposed of in a controlled and environmentally acceptable manner. Sludge from flue gas cleaning products is normally treated as fly ash and often mixed and stabilised with fly ash or lime for deposition at, for instance, a hazardous waste landfill, with a dryness of 65 % dry matter. Wastewater must be fed to a water treatment plant, which will typically be part of the overall facility.

2.6. Overview of markets and products

Selection of appropriate treatment methods for biodegradable waste should be based on the criteria mentioned in Section 5.1 including an evaluation of the possible markets in the particular planning area. Table 10 provides an overview of the market options related to the products that may result from various treatments.

Overview of market options Table 10

Product	Market options
Compost	Agriculture; forestry; fruit and wine gardens; plant nurseries; private gardens; parks; landscaping; ground rehabilitation
Fibre fraction (anaerobic digestion)	Agriculture; forestry; ground rehabilitation
Liquid fertiliser	Agriculture
Electricity	Ordinary power supply system; industry
Steam	Electricity production; industry
Heated water	Ordinary district heating systems; industry
Clinker	Construction industry; civil works
Grit, glass and slag	Civil works; ground rehabilitation

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