DESCRIPTIONS OF WASTE TECHNOLOGIES –

ORGANICS PROCESSING

WA Waste Authority - Strategic Waste Infrastructure Planning

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WA WASTE AUTHORITY

STRATEGIC WASTE INFRASTRUCTURE PLANNING

Concise Descriptions of Modern Waste Technologies

Organics Processing FINAL REPORT

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CONTENTS

1 SUMMARY

Hyder Consulting has been commissioned by the Western Australia Department of Environment Regulation (DER) on behalf of the Waste Authority to provide a concise description of different best practice options for the processing of source segregated food and garden organics, which can be an integral part of a modern waste minimisation and resource recovery strategy.

This report summarises a number of key parameters and performance indicators for different organics processing technologies that have been requested by DER. It is one of a series of reports reviewing various recycling, waste treatment and disposal technologies that may be applied in the Metropolitan Perth and Peel Regions of WA. The information is presented in a concise, standardised table format that, when merged with the information on other waste and recycling technologies will allow a comparison of key parameters across the technology types and inform the development of the Waste and Recycling infrastructure Plan for the Perth and Metropolitan and Peel Region.

The purpose of the project is to provide sufficient information on each technology type to allow a comparison between various waste and recycling technologies and help to assess the potential for each option to play a role in the future Perth and Peel waste and recycling infrastructure mix. The project is intended to inform Government planning and strategic decisions.

Both composting and anaerobic digestion are well-established and proven recycling technologies for all types of municipal and commercial organic residues. As organic components (garden and food organics) usually comprise the single largest fraction in the municipal waste stream (35% to 55%) and can also make up a large proportion of commercial waste, organic recycling activities can make a significant contribution to the reduction of waste going to landfill, and to achieving recycling targets. Today, kerbside collection of source segregated garden (and food) organics, combined with the subsequent composting of these materials, is part of any modern, integrated recycling and waste management strategy. Most composting facilities in Australia co-compost municipal and commercial organic residues.

Composting and anaerobic digestion represent the degradation and stabilisation of organic residues in controlled environments, which are aerobic for composting and anaerobic for digestion. Composting can be done in the open in windrows or piles or in enclosed facilities (in-vessel and fully enclosed composting). Anaerobic digestion always takes place in enclosed containers or vessels. Anaerobic digestion is better suited for the processing of liquid and wet residues (wet digestion), although more recently developed dry digestion technologies also allow the processing of kerbside collected organics. Blending of different feedstock materials makes composting a very versatile technology that allows processing of a wide range of different input materials.

Composting of organic residues results in the generation of compost and mulch products that can be used in a wide range of applications in amenity and production horticulture, agriculture and rehabilitation. Solid digestion residues are often composted to generate usable products. Liquid digestate can be used as liquid fertiliser in agricultural applications. Anaerobic digestion also generates biogas, which can be converted into electrical and heat energy, or be used as fuel for vehicles.

Although there are different composting and anaerobic digestion technologies and system configurations, for the current project, Hyder has focussed on three main organics processing categories for detailed analysis:

1 Open composting

2 In-vessel composting (tunnel composting)

3 Anaerobic digestion (dry, discontinuous digestion)

The information presented in this report is a combination of details gained through consultation with the operators of the case study facilities and information arising from a review of relevant and available literature on the topic. Additional general information has been included based on Hyder's industry knowledge and experience.

On the basis of selection criteria agreed with DER, Hyder selected the following organics processing facilities to use as case studies.

Table 1 - Organics processing facility case studies

Type	Site	Location
Open composting	A	WA
In-vessel composting	B	NSW
Anaerobic digestion	C	Germany

This report presents key details of each reference facility based on information provided by the operators. In some cases, information was not provided due to commercial concerns. The facility information has been summarised in a table as requested by DER to enable quick comparison with other waste management technologies. Section 8 contains a 'Study Synopsis' table for organics processing technologies which summarises the parameters across the different processing options.

2 INTRODUCTION

Following release of the *Western Australian Waste Strategy*, the Western Australian Waste Authority (WAWA) and Department of Environment Regulation (DER) have established the Strategic Waste Infrastructure Planning (SWIP) Working Group, with the aim of developing a plan for the future waste disposal and recycling infrastructure needs of the Perth metropolitan and Peel regions. The Working Group will guide the development of a *Waste and Recycling infrastructure Plan for the Perth and Metropolitan and Peel Region.*

The WA Waste Strategy sets out challenging recovery targets for each of the major waste streams: municipal solid waste (MSW), commercial and industrial waste (C&I) and construction and demolition waste (C&D), for both the Perth Metro and Peel regions. One of the key objectives of the Strategy is to identify the waste technology options and infrastructure mix that will help Western Australia to achieve those targets.

Hyder Consulting has been commissioned by DER on behalf of the Waste Authority to provide a concise description of different best practice options for the **processing of source segregated food and garden organics from municipal and commercial sources,** which can be an integral part of a modern waste minimisation and resource recovery strategy. This report summarises a number of key parameters and performance indicators for different organics processing technologies that have been requested by DER. It is one of a series of reports reviewing various recycling, waste treatment and disposal technologies that may be applied in the Perth Metro and Peel Region. The information is presented in a concise, standardised table format in Section 7 and Section 8 that, when merged with the information on other waste and recycling technologies will allow a comparison of key parameters and performance indicators across the technology types and inform the development of the Government's planning process.

In this report, Hyder has focussed on three basic types of organics processing technology for detailed analysis:

1 Open composting (aerated pile)

2 In-vessel composting (tunnel composting)

3 Anaerobic digestion (dry, discontinuous batch process)

2.1 PURPOSE

The purpose of the project is to provide sufficient information on each technology type to allow a comparison with other waste and recycling technologies and help to assess the potential for each option to play a role in the future Perth and Peel waste and recycling infrastructure mix. The project is intended to inform Government planning and strategic decisions.

3 PROJECT METHODOLOGY

The information presented in this report is a combination of:

a Details gained through case studies of representative reference facilities identified by Hyder in consultation with DER; and

b Information arising from a review of relevant and available literature on the topic.

Additional general information has been included based on Hyder's industry knowledge and experience.

3.1 CASE STUDIES

Information was gathered for the case studies through direct interviews and consultations with the current operators of the selected existing facilities, and Hyder acknowledges their valuable contribution to the project.

To identify appropriate reference sites to use as case studies in the current project, Hyder has focussed on the criteria listed below. These generic criteria have been applied across all waste and recycling technologies described by Hyder, including the present study, and applied where appropriate:

- Use of proven, mature and best practice technology;
- Have been operational for at least 12 months;
- Have been operating successfully to a high standard with no known major issues or fundamental failures;
- Are generally large capacity, on a scale that would be appropriate for the Perth Metro and Peel regions;
- Have established sustainable markets for any outputs and products from the process; and
- The operators have agreed to take part in the project and provide information.

As far as possible, Hyder has selected Australian facilities (where they exist), so that the costs, regulatory drivers and environmental standards are likely to be consistent with the Western Australian context. As there is very little experience with the anaerobic digestion of source segregated garden and food organics in Australia, a dry anaerobic digestion facility in Germany was chosen to showcase this technology.

To facilitate the provision of information by operators, DER wrote an introductory letter to each selected operator to introduce the project, explain Hyder's role and provide assurance as to the protection of commercially sensitive information.

3.2 LITERATURE REVIEW

To supplement the information obtained through the case studies and provide a broader view of typical facilities, Hyder has conducted a limited review of available international literature on organics processing technologies, including composting and anaerobic digestion. Literature in this case includes:

- Technical publications;
- Published industry reports;

- Journal articles;
- Company websites; and
- Waste and recycling surveys and data reports.

Information obtained from published literature sources has been identified as such and references provided (see Section 9).

3.3 KEY PARAMETERS AND INFORMATION

Table 2 summarises the key parameters and information specified by DER. The same parameter list will be applied to each waste and recycling technology category in order to allow information to be presented in a standardised table format and therefore allow comparison across technologies.

Where relevant and representative information was obtained for the case study facilities, this is presented in the summary tables (see Sections 7 and 8). Where information was not available or there was a benefit in providing additional background, the table has been supplemented with information obtained through the literature review.

Table 2 - Key parameters

Ref	Information Parameter	Description
1	Process Description	A high level description of the process (or technology type) for managing or treating waste including its purpose, conversion processes, stages of treatment and key inputs and outputs (including energy and waste residues)
2	Feedstocks	Types of suitable feedstocks, pre-treatment requirements, broad physical and chemical characteristics, key exclusions
3	Capacity	Processing or disposal capacity (in tonnes per annum) including typical values and ranges
4	Waste Hierarchy	How and where does the technology fit into the established waste hierarchy?
5	Landfill Diversion Potential	Potential to divert waste from landfill (for example, waste recycled/recovered and waste to landfill expressed as a percentage of total waste sent to facility)
6	Products and Residuals	Identify all products, outputs and residuals from the facility / process (including any potentially beneficial outputs and energy)
7	Capital Cost	Expressed as a total cost and $ per tonne of annual capacity
8	Operational Cost	Expressed as $ per tonne of waste processed / disposed
9	Gate fees	Typical gate fees charged to customers. Note gate fees do not necessarily correlate directly with running costs and may include a profit margin and be driven by market forces (i.e., prices of alternatives)

Ref	Information Parameter	Description
10	Set-up Timeframe	Typical timeframe to establish the technology including planning, approvals, procurement, design, construction and commissioning
11	Lifespan	Typical lifespan of the technology taking into account standard maintenance and replacement practices
12	Footprint	Typical land footprint for a facility including for the core technology and any surrounding ancillary requirements (access roads, waste and product storage, buffers, etc.)
13	Buffer Zones	Extent of buffers required around the plant, including typical existing facilities and any requirements in regulation
14	Emissions Performance	Typical pollutants arising from the process (solid, liquid and gaseous) – key substances and approximate quantities / concentrations. Also high level estimates of carbon impact including direct carbon emissions and indirect emissions from electricity use
15	Environmental Performance	Compliance with regulations / permits, key environmental impacts including air, water, groundwater, noise, odour, dust, waste arisings
16	Social Impacts / Costs	Impacts on local community and neighbours, employment and local economy impacts
17	Compatibility with Existing Systems / Technologies and Supporting Systems	To what extent is the technology compatible with the existing waste management system and facilities (sorting, collection, processing, disposal), what broad changes would be required and which other technologies are required to complement the technology
18	Risks	Identification of potential risks including technical, commercial, environmental, operational and market risks
19	Local Application	Most appropriate application of the technology to the local context (metro or non-metro, medium to high density)
20	Maturity of the Technology	How long has the technology been in operation, is it considered proven and how many reference facilities exist in Australia and overseas
21	Availability	Typical annual maintenance shutdown requirements and plant availability as a proportion of the name-plate capacity
22	Penetration	Extent of existing penetration of the technology in the Perth Metro and Peel regions and within Australia (such as number / total capacities of existing facilities)
23	Benefits	Benefits of the technology (financial, environmental, social) compared with alternatives including landfill diversion performance, flexibility, future-proofing, etc.

Ref	Information Parameter	Description
24	Barriers / Constraints	Barriers to implementation including markets for outputs, policy and regulatory constraints, availability of technology and support in Australia, etc.
25	Other Relevant Information	Any other relevant information which becomes apparent during investigations

4 BACKGROUND AND OVERVIEW

The use of raw and processed organic residues (animal manures, plant matter, human excrements) was for millennia the main way for humans to replenish nutrients and maintain soil fertility and productivity in pursuit of agricultural food production. While organic residues were primarily stockpiled and aged in ancient times, the 'invention' of large-scale **composting** in a methodical manner is often attributed to Sir Albert Howard and the Indore composting process in the early 1930's [1]. In his account of the history of composting, Epstein [1] outlines that, between the 1950's and 1970's efforts in the US concentrated mainly on advancing the composting of biosolids, while in Europe, the composting of municipal solid waste (MSW) was developed. However, driven by the poor quality of MSW compost and the goal to improve resource recovery and sustainability, an agricultural university initiated the first scheme for collecting and composting source segregated municipal garden and food organics in a rural town in Germany in 1983 [2]. This project provided the blue-print for the rapid up-take and further development of kerbside organics collection and composting schemes in Germany and Europe in the 1990's and this century, and the parallel conversion or closure of MSW composting facilities.

While the original project employed open windrow composting for processing the organic residues, the rapid increase in composting facilities and the significant increase in volumes to be processed saw also the emergence of a range of different processing technologies adapted for these types of organic residues. An overview of advanced composting technologies that were available in Germany in 1992 [3], listed 11 suppliers of the following types of technologies:

- Fully enclosed
  - Agitated bed composting in large trapezoidal piles
  - Briquette composting
- In-vessel
  - Rotating drum composting
  - Agitated bed composting
  - Tunnel, channel and container composting

Haug [4] provided a comprehensive overview of composting technologies and suppliers that were used for the processing of raw materials, including MSW, biosolids, manures, etc, in the early 1990s and that were categorised as follows:

- Non-reactor composting technologies
  - Windrows
  - Aerated and non-aerated static piles
- Reactor composting technologies
  - Vertical flow processes
  - Horizontal and inclined flow processes
    - Rotating drum
    - Agitated bins or channels
    - Static bed bins
- Non-flow processes

The Food and Garden Organics Best Practice Collection Manual, which was recently published by the Federal Department of Sustainability, Environment, Water, Population and Communities [5] provides also an overview and a brief description of various organics processing options, including anaerobic digestion, combustion and gasification.

Similar to composting, **anaerobic digestion** (AD) is not a new technology, and has been used for the processing and stabilisation of organic residues for many decades. After it was discovered that anaerobic degradation of organic compounds generates a combustible gas some 200 years ago, and after the first establishment of a 'septic tank' for the treatment of wastewater in Exeter (UK) in 1897, anaerobic digestion technology was primarily employed for the processing of municipal, and later also industrial wastewater, as well as liquid animal manures [6]. While, until recently, anaerobic digestion was mainly considered as a waste treatment option in developed countries, it had far greater relevance as a source of energy in developing countries, where energy is in short supply and expensive. It is reported for example that China has the largest biogas programme in the world with over twenty five million households using biogas, accounting for over 10% of all rural households [6]. The same authors report that, by the end of 2005 there were 2,492 medium and large-scale biogas digesters in Chinese livestock and poultry farms, and 137,000 biogas digesters had been constructed for the purification of household wastewater, not to mention the millions of domestic biogas plants.

The utilisation of biogas technology for the processing of residues other than wastewater and the generation of electricity in Europe expanded only slowly during the 1990's but accelerated significantly after the turn of the century. Figure 4-1 shows developments in Germany, which reflects developments in the whole of Europe, as the AD processing capacity in Germany represents a large proportion of Europe's anaerobic digestion facilities.

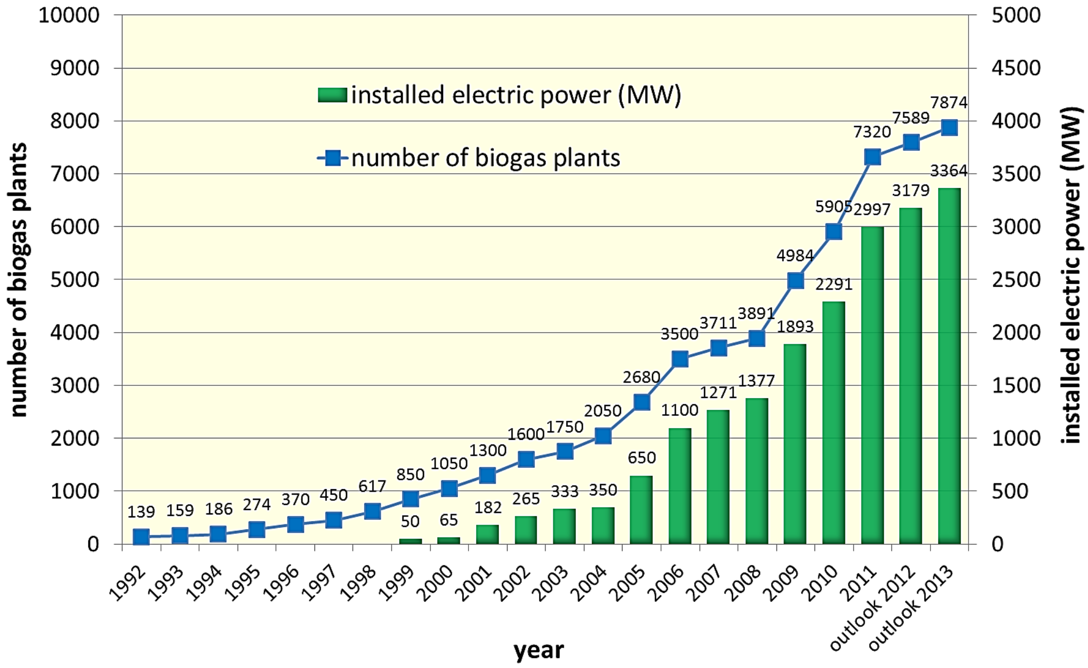

Figure 1 - Development of biogas plants (numbers and power generation capacity) in Germany (Source: [7])

However, the vast majority of AD facilities that exist in Europe today are on-farm operations that process animal manures and energy crops. Of the 5,900 AD facilities that existed in Germany in 2010, around 120 were built specifically to process source segregated garden and food organics from municipal and commercial sources, and 820 were licensed to accept these types of materials, mostly for co-fermentation with agricultural input materials [8]. Growth of anaerobic digestion capacity for the organic fraction of municipal waste, segregated and unsegregated, is in line with the overall growth in total digestion capacity (Figure 2). It is estimated that, in 2014, there will be some 220 anaerobic digestion facilities in Europe that handle more than seven million tonnes per annum of municipal organic residues (input > 3,000 tpa and >10% organics from households) [9].

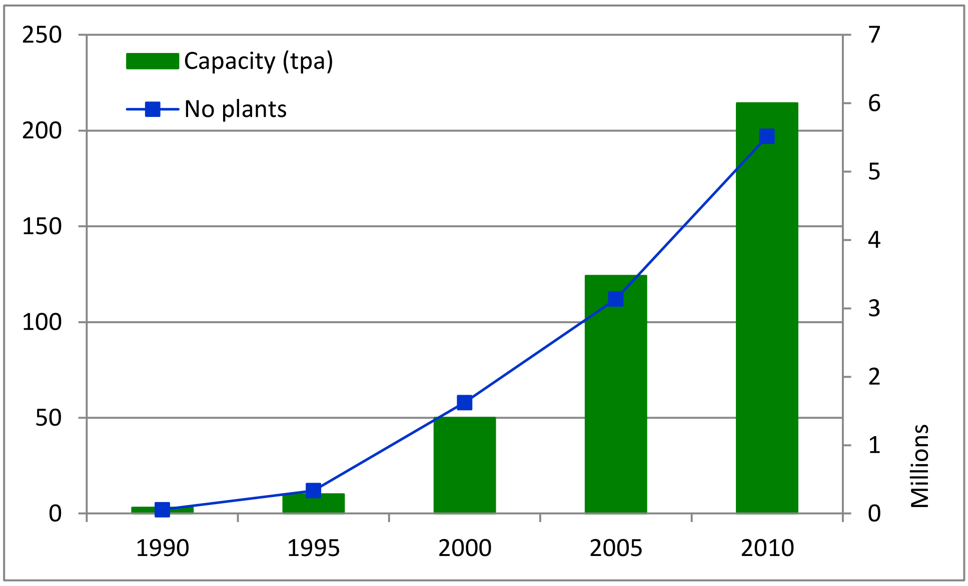

Figure 2 - Development of anaerobic digestion capacity for MSW and source segregated organics in Europe (Source: [9] modified)

The above demonstrates that, internationally, both composting and anaerobic digestion are very well established and proven technologies for the processing and conversion of municipal and commercial organic residues into useful products. The 198 composting facilities in Australia that, in 2011, processed 2.4 million tonnes of garden organics, 150,000 tonnes of food organics, 380,000 of organics in MSW and various other organic residues (total of 6.33 million tonnes) [10] are testimony to the fact that composting is also widely employed in Australia for processing organic residues. On the other hand, that is not yet the case for anaerobic digestion. Although this technology is used in wastewater treatment plants, food processing operations, and also piggeries, at present there is only one operational facility in Australia (Camellia, NSW) that processes liquid residues and sludges, as well as solid organic residues such as source segregated foods and food based material streams from commercial and industrial food preparation, processing and wholesale/retail activities. A second such plant is currently being built in Western Australia and is due to for commissioning later this year.

There is limited processing capacity in Australia using anaerobic digestion for the generation of biogas from the organic fraction of MSW. The Anaeco facility in Perth is presently under construction, and two further facilities have been built with AD capacity but no longer operate their digesters: SITA's facility at Jacks Gully (NSW) has been mothballed, and the anaerobic digestion component of Global Renewables' Eastern Creek UR-3R Facility (Sydney, NSW) is no longer in operation. In each case anaerobic digestion represents part of a comprehensive mechanical-biological treatment (MBT) system for unsorted municipal waste.

4.1 TERMINOLOGY

***Composting** is the biological decomposition and stabilisation of organic substrates, under largely aerobic conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce as final product that is stable, free of pathogens and* *plant seeds, and can be beneficially applied to land* [4]. In essence, the various composting technologies provide a variation on this theme, by trying to optimise composting conditions and improve efficiency, while also minimising detrimental effects on the environment.

Anaerobic digestion is a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. One of the end products is biogas, which can be combusted to generate electricity and heat, or can be processed into renewable natural gas and transportation fuels. Separated digested solids can be composted and applied to cropland or converted into other products, while the liquid stream is used in agriculture as fertilizer.

The anaerobic digestion process and fundamental processing technology options are presented in Section 4.3.2.

4.2 PURPOSE OF ORGANICS PROCESSING

The main objectives of processing municipal and commercial organic residues are the following:

- Reduction of waste going to landfill
- Reduction of methane emissions and leachate from landfill
- Stabilisation and pasteurisation of organic residues
- Generation of valuable products
- Utilisation of nutrients and carbon for land management purposes
- Energy generation (not all technologies)
- Cost savings (possible)

4.3 PROCESS OVERVIEW

4.3.1 COMPOSTING

Aerobic composting is a biological process in which naturally occurring microorganisms convert organic materials into a more or less soil-like product called compost. Essentially it is the same process that decays plant debris and animal residues in nature, except that in composting the conditions are controlled so that the process occurs at elevated temperatures, is more expedient and the end product more predictable. Different composting technologies offer various degrees of process control.

Biology

Like all living organisms, the aerobic microorganisms responsible for the degradation and conversion of organic compounds during composting need adequate living conditions to grow and multiply. These conditions relate to the availability of food (carbon, nitrogen and other nutrients), sufficient air (oxygen), water and hospitable environmental conditions.

Carbon, nitrogen and other nutrients

Carbon (C) contained in organic matter is the energy source and the basic building block for microbial cells. Nitrogen (N) is also very important and is, along with carbon, the element most commonly limiting microbial activity. Microorganisms also require adequate phosphorus (P), sulphur, potassium and micronutrients (e.g. iron, manganese, boron etc.) for growth and enzymatic function. These nutrients are usually present in ample quantities in compost feedstock, though phosphorus can sometimes be limiting. A carbon to phosphorous ratio of between 75:1 and 150:1 is required.

Microorganisms require about 25-30 parts of carbon by weight for each part of nitrogen used for the production of protein. Therefore, a C/N ratio of between 20:1 and 40:1 is often considered suitable for starting the composting process, depending on the make-up of the feedstock. As the composting process progresses, the C/N ratio gradually decreases and can reach 20:1 or less, depending on the C/N ratio of the original material, and duration of the composting process.

Preparing and mixing feedstock to achieve an optimum C/N ratio is rewarded with fast decomposition rates, assuming other factors are not limiting. In general, a high C/N ratio slows the rate of decomposition so that the temperature increase is limited and the time required for composting is extended. This does not necessarily mean, however, that thermophilic conditions are not reached or maintained with such feedstock, since much of the carbon present can be in a form readily available to the microorganisms and large piles may provide sufficient insulation to prompt a rise in temperature.

Feedstock with a low C/N ratio (<15:1) may decompose rapidly, but odours tend to become a problem due to rapid oxygen depletion and prevailing anaerobic conditions , resulting in the production of reduced sulphur and other odour related compounds. Furthermore, loss of nitrogen through gaseous emissions under these conditions will reduce the nutrient value of the compost product.

Oxygen

The microorganisms responsible for aerobic composting, by definition, cannot survive and grow in the absence of oxygen. However, many microorganisms are capable of growth at low oxygen concentrations, while some (the anaerobic microorganisms) are inactivated or killed in the presence of oxygen. These organisms ferment organic materials in anaerobic digestion systems (Section 4.3.2), and are responsible for much of the unpleasant odours and the release of the greenhouse gas methane in nominally aerobic systems when oxygen is depleted.

When microorganisms feed on the organic components in the waste materials to satisfy their energy and nutrient needs, oxygen is used up and carbon dioxide (CO_2), water and energy are released. The oxygen concentration in air is about 21%, but considerably lower in composting materials. The oxygen level usually decreases rapidly after the composting process commences and is governed by microbial activity and the efficiency of the aeration system. Ideally, oxygen concentrations of about 10% to 14% are required for optimum composting conditions. Aerobic microorganisms cannot function effectively at concentrations below about 5% in compost. Figure 3 demonstrates how quickly oxygen levels decline in an aerated pile after the forced aeration system is turned off.

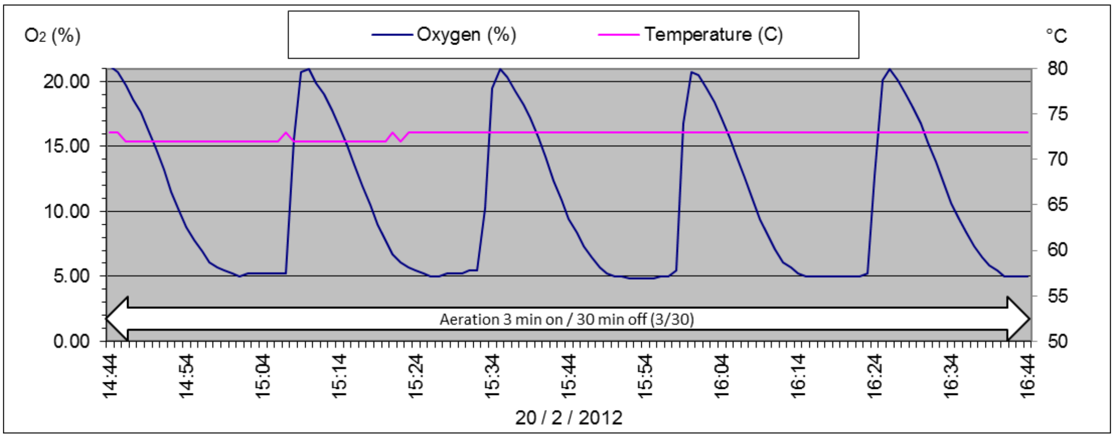

Figure 3 - Fluctuating oxygen levels in aerated pile after 17 days of composting vegetable processing residues (Source [12])

The activity of microorganisms in degrading the substrate is critical factor in determining the demand for oxygen, and hence also the level of supply (aeration) required. For example, in grass clippings very rapid microbial activity leads to a high oxygen demand, a rapid rise in temperature and anaerobic conditions as the depleted oxygen cannot be replenished fast enough through passive aeration.

In windrows, oxygen is replenished passively by convection and diffusion, driven by the differential in temperatures inside the composted material and the ambient air. Natural convection is the movement of outside air into a compost heap as a result of the concentration deficit created by the steady flow of warm air upwards through the pile and out the top (Figure 4). Diffusion then transports oxygen into the smaller pores of compost and into the water layer surrounding compost particles.

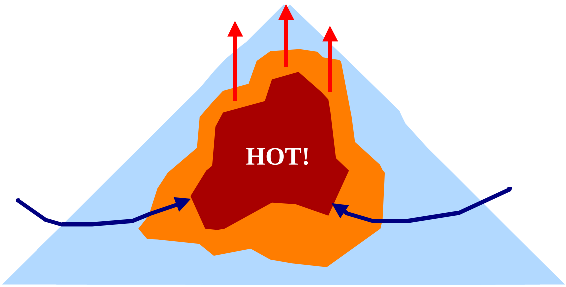

Figure 4 - Convection in a compost windrow or pile

In windrows or piles, physical turning assists convection. Turning only adds a small amount of oxygen directly, but it loosens and fluffs the material so that air can move more freely into the windrow by convection. It is possible to provide for sufficient aeration for up to six or seven days without turning, provided that careful attention is paid to achieving optimum porosity (35% - 45%) and not exceeding a bulk density of about 600 kg/m^3. As microbial activity and hence oxygen demand diminishes towards the end of the composting process, so does the need for turning. Convection can be increased by constructing piles or windrows over channels or inserting pipes that extend from outside through to the core of the heap.

Air can also be supplied mechanically with forced aeration**,** which delivers air by suction or blowing or a combination of the two. Generally, forced aeration is a feature of technologically more advanced composting systems such as fully enclosed or in-vessel systems, but it can be also used for open windrow or aerated pile composting. Reverse aeration (suction) can prevent excessive odour emissions from uncovered windrows / piles, but energy demand is considerably higher with this technology. Apart from improved process control, the use of forced aeration technology in fully or partially enclosed facilities also provides the advantage that the exhaust air can be recirculated and treated to remove odorous compounds before it is released into the environment. Forced aeration systems have a tendency to dry out composting materials, necessitating additional irrigation as a countermeasure.

Moisture

As moisture content increases in composted materials, the thickness of the layer of water surrounding each particle increases until the pore spaces between particles (beginning with the smallest ones) are filled with water. The decomposition of organic matter occurs at the interface between this water layer and the surface of the particle. Oxygen diffusion from the air-filled pore space into the water film around particles is sufficient to meet the needs of aerobic organisms when moisture content of compost is maintained below approximately 60%. At higher moisture levels, the rate of oxygen diffusion is too slow to replenish the oxygen utilised. Odorous compounds then build up in the anaerobic zone and can become detectable in the atmosphere.

However, the appropriate moisture level for the composting process is dependent upon the distribution of pore sizes and bulk density of the processed mix. Fine material will turn anaerobic at a lower moisture level than coarse material with a high proportion of structurally stable components, such as shredded garden organics.

Moisture is lost during the composting process by means of evaporation. This process facilitates the transfer of energy from inside the pile to the atmosphere, and hence is a critically important cooling mechanism that helps preventing the compost from overheating which results in reduced microbial activity. The optimum moisture content for composting is generally between 50 and 60%. A moisture content above 50% is critical for effective pathogen and weed control during the initial thermophilic stage of composting. Care must be taken to ensure that the compost does not dry out too quickly as microbial activity is severely restricted and eventually stops if moisture drops to below about 30%.

Water can be added most effectively and evenly during turning with a mechanical turner connected to the water supply. Where this in not possible, or where front-end loaders are used for turning, water can be added manually by hose, sprinklers or soaker hoses.

Temperature

The heat generated during the composting process is due to microbial activity, it is the release of surplus energy which occurs during the microbial decomposition of organic matter. Hence, the heat in composting piles can be seen as a by-product of microbial activity but it is still an important factor in eliminating pathogens and weeds during the composting process.

The temperature reached during composting depends primarily on microbial activity, which in turn is governed by the moisture content and aeration of the composting material and the availability of food for the microbes - principally carbon and nitrogen. The size of the pile determines the level of heat being preserved, hence resulting in a temperature rise. Heat builds up in composting material when the insulating properties of the mass results in the rate of heat gain being greater than the rate of heat loss.

Temperature has a self-limiting effect on microbial activity and thus the rate of degradation of organic materials. Few microorganisms remain active and survive temperatures above 65 ºC, causing a rapid reduction in the rate of composting. The highest rates of decomposition of organic materials usually occur at temperatures between 45 ºC and 55 ºC.

The different phases of composting are represented in Figure 5. It can be seen that temperature can indicate when the composting process is completed and when the product is stable or mature. However, temperatures can also rise and fall during composting as a result of other factors, such as limited moisture or air.

Temperature affects the rate of decomposition of organic materials by directly influencing the make-up of the microbial population. Bacteria, fungi and actinomycetes all play a major role in the decomposition of organic materials during aerobic composting. A dynamic food web is at work in a compost pile in which there is a succession of organisms that predominate depending primarily on temperature and the types of food available for consumption.

The composting process can be differentiated into three phases: the initial phase, the intensive decomposition phase and the curing phase, each of which shows distinct temperature regimes (Figure 5) and varying dominance of microbial populations.

The initial composting phase, which is characterised by a rapid increase in microbial activity and the first signs of a rise in temperature, is mainly due to the activity of mesophilic microorganisms consuming easily degradable compounds. As the temperature begins to rise above approximately 40 ºC, mesophilic organisms begin to die off and thermophilic organisms then begin to dominate. As temperatures increase to 50 ºC and above, thermophilic fungi and actinomycetes prevail. If the temperature reaches 65-70 ºC, the activity of those thermophilic organisms also begins to be inhibited, and mainly spore forming bacteria survive and remain active. At this point, the rate of decomposition slows. The highest rate of decomposition occurs mostly during the thermophilic stage of composting (>45 ºC), due mainly to the activity of thermophilic bacteria and the high speed of bio-chemical processes that occur in this temperature range.

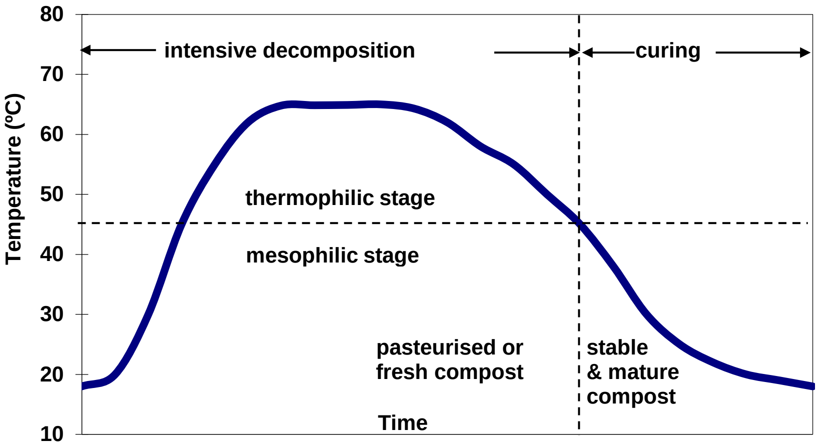

Figure 5 - Temperature development and processing stages in aerobic composting

The decomposition of organic matter is a dynamic process because different composting microorganisms have the capacity to utilise compounds of varying complexity and resistance to degradation. The breakdown of organic matter is therefore a successive reduction of complex substances to simpler compounds.

Composting microbes first consume compounds that are more 'susceptible' to degradation in preference to compounds that are more resistant. Hence, the degradation of very susceptible compounds such as sugars, starches and amino acids marks the initial stages of the composting process. Easily degradable compounds are continually consumed during the thermophilic phase but at this stage bacteria, actinomycetes and fungi consume also cellulose and hemicellulose compounds with an intermittent susceptibility to decomposition.

Once the majority of easily degradable compounds are decomposed, microbial activity and temperature decreases. As temperatures fall to 45 – 40 ºC, a mixture of mesophilic organisms returns to continue the degradation of cellulose. Lignin and lignocellulose are resistant to decomposition and can be utilised by only very few organisms such as basidiomycetes, which become very active at this stage of the composting process. During the curing and maturation phase, temperature declines further and eventually becomes identical with the ambient temperature.

Technology

Windrow composting is the dominant form of composting both in Australia and worldwide. However, there are also various other types of composting systems, which may be chosen by operators for different reasons. This section provides some basic information about the distinguishing characteristics of the main types of systems that are commercially available.

Generally speaking, most composting systems are nearly always variations of a common theme. All systems aim to control the composting process by manipulating temperature, oxygen and moisture. As far as quality of generated compost products is concerned, other control factors such as the selection, pre-treatment and mixing of the raw or composted material are most important. All composting systems are limited by the nature of the raw material they process; poor quality starting materials makes poor quality compost.

Some composting systems can more effectively deal with specific types of organic materials. For example, highly odorous material is best processed in systems with forced aeration and odour control equipment.

The oldest and most common form of composting is the turned windrow system, as this system is extremely versatile and appropriate for the processing of many organic residues. In order to maintain optimum composting conditions, temperature and aeration control is managed by physically turning the mass with either a front-end loader, an excavator or a specialised windrow turner. In windrowing, a major contribution to process control is achieved by composting for extended periods; pathogen reduction and humification occur with greater effectiveness with increasing time.

Improved process control is achieved by utilising forced aeration systems. Forced aeration improves control of both temperature and oxygen during composting but tends to dry out the material more quickly. Systems using forced aeration do not necessarily produce a compost of higher quality than mechanically turned windrow systems, but shorter processing times are usually possible. Environmental control of odours and leachate can usually be built in with systems utilising forced aeration.

Capital outlays for windrow type systems are relatively small (unless a concrete/bitumen pad is installed and/or the windrows are covered), but operating costs can be high because they are usually labour intensive. Windrow composting operations have a relatively large footprint per tonne input. Forced aeration systems are usually expensive to install, but operating costs can be lower compared to non-aerated windrow systems due to shorter processing periods. Their main advantage however may be the prevention of odour emissions which otherwise may cause problems and even threaten closure of the operation.

In many cases, the major difference between various composting technologies concerns only the first, intensive stage of composting - preliminary decomposition and pasteurisation. Generally speaking, the aim of this initial composting stage is to:

- Maximise the decomposition rate for the easily degradable organic fraction;
- Eliminate pathogens, weeds and viable plant propagules ('pasteurisation'); and
- Minimise leachate and odour emissions.

This period of intensive control and enclosure is usually employed only for about three days to three weeks in in-vessel systems. Further decomposition and curing, usually takes place in windrows or piles and may require another 8 to 10 weeks. Intensively controlled composting is extended to between four and eight weeks in fully enclosed composting systems. Yet, in most cases the composted material still requires maturing in open windrows or piles afterwards. If the composted material is sold as ‘pasteurised product’, a maturation phase is not necessary.

It should be noted that, fundamentally, compost quality is not directly related to the type of composting technology employed. It is possible to produce high quality compost products with both, windrow systems and high-tech, in-vessel or fully enclosed systems, as long as the management of the operation is of a high standard. Equally, the production of a wide range of compost products, which vary for example in the level of decomposition or other quality characteristics, is possible with each technology.

The following aspects need to be considered when assessing and comparing different processing technologies (e.g. Table 3) and different suppliers:

- Investment costs ($ / tonne throughput)
- Operating costs ($ / tonne throughput)
- Operational experience
- Options for process management
- Options for achieving desired product quality
- Risk of emitting odour / bio-aerosols and releasing leachate
- Ability to process different feedstock
- Options for expanding processing capacity
- Footprint (tonne annual throughput per square meter)
- Energy and water use.

Table 3 - High level comparison of composting technologies (Source: [5] modified)

Technology	Aeration	Air purification	Investment cost	Land area required
Vermi-composting	Passive	No, but possible	Low to medium	Large to medium
Windrowing	Turning, passive aeration	No	Low	Large to very large
Static pile	Passive	No	Low	Very large
Aerated static pile	Positive/negative forced aeration	No, but possible	Medium	Medium
In-vessel composting	Agitation, mechanical turning, forced aeration	Yes, but exceptions	Large	Medium to small
Fully enclosed composting	Agitation, mechanical turning, forced aeration	Yes	Very large	Medium to small

Operation

Composting operations that process source segregated municipal and commercial organics commonly employ some or all of the following operational units, which also represent the processing sequence:

Reception and storage of raw materials

- Reception: this can be anything from and open-air area (e.g. for vegetation residues) to an enclosed reception hall where trucks unload the organic material. An initial quality check can be carried out here, and large undesirable components can be extracted.
- Interim storage for bulking material (before or after size reduction or both).

Pre-processing

- Size reduction: vegetation residues or wood waste have to be shredded before being blended and composted.
- Bag opener (optional): depending on the quality of kerbside collected organics.
- Extraction of contamination (optional): depending on the predominant type and quantity of impurities in the received material a combination of mechanical separation equipment (e.g. magnets, screens, and eddy current separators) and manual sorting can be employed to remove “impurities”.
- Mixing: Different raw material streams are mixed to generate a composting feedstock that has required characteristics for enhancing the composting process through the composting technology which is employed.

Composting

- Open composting systems (windrowing, static pile): the entire composting process takes place in the open.
- In-vessel and fully enclosed composting systems: the initial composting phase (which can be several days to six or eight weeks) takes place in an enclosed space. Subsequently, the partially composted material is transferred to an open area (which can be under a roof) for further composting and maturation. The exhaust air from enclosed aerated composting systems is purified at least through a biofilter, and possibly also through an acid scrubber.

Product refinement

- The compost product generated is usually refined by means of screening to produce different particle size fractions. At this stage it may be necessary to employ a windsifter and/or ballistic separator to respectively remove the light and heavy fraction contaminants from the final product. It might be possible to add value to the compost by blending it with other products, adding fertiliser, or enhancing it with microorganisms.

Storage

- Temporary storage for compost and other products (i.e. metals) prior to their sale, screened oversize material and segregated impurities needs to be provided.

Figure 6 shows a flow diagram for a generic in-vessel composting facility, depicting all major operational units. The Receival area and a process for incorporating any liquid waste streams are not shown.

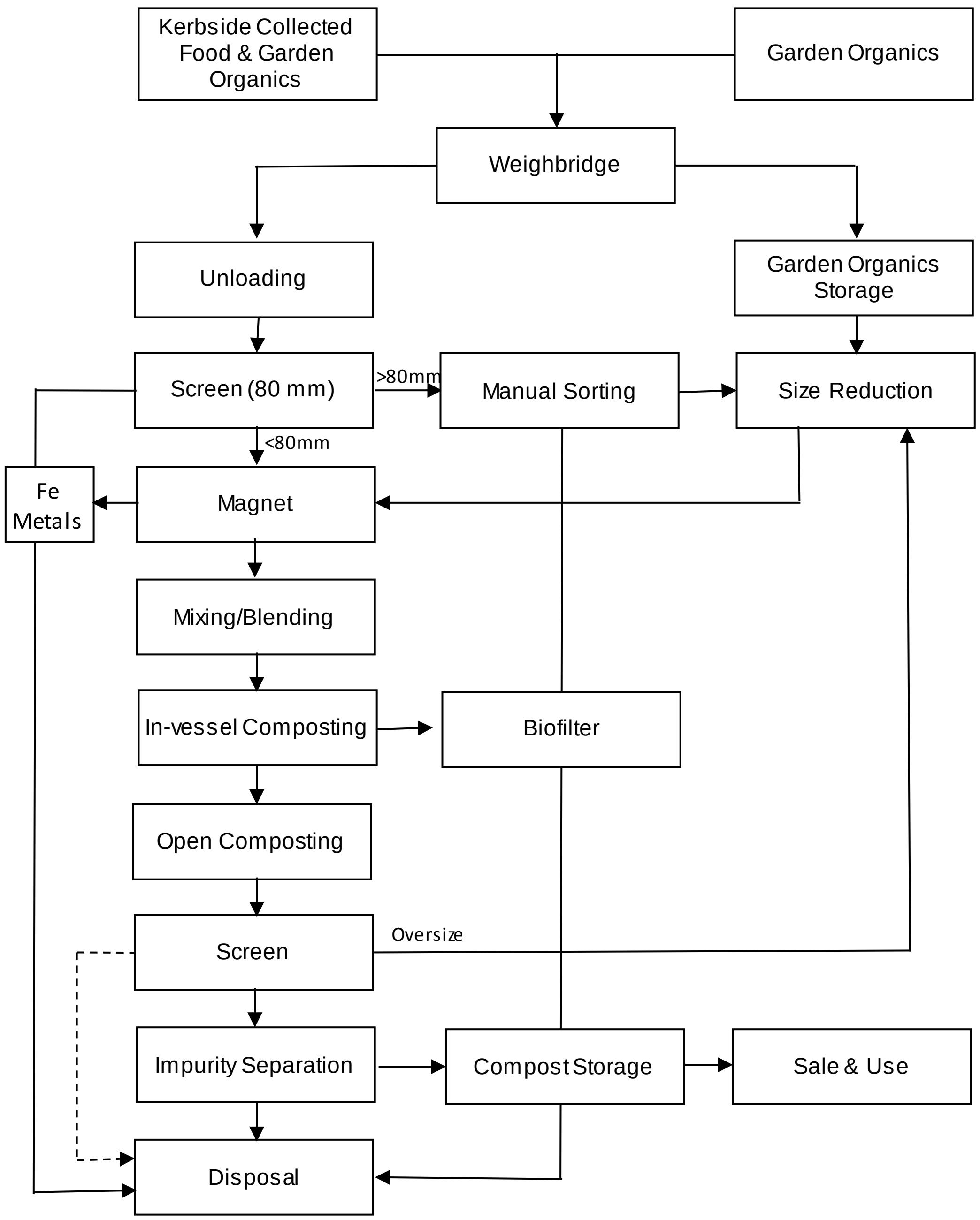

Figure 6 - Flow chart for generic in-vessel composting facility

4.3.2 ANAEROBIC DIGESTION

Anaerobic digestion represents the reduction and break down of organic carbon compounds under anaerobic conditions, an environment that is devoid of oxygen (O) and nitrate (NO3). Only a limited range of specialized micro-organisms (anaerobic bacteria) can survive in these conditions and facilitate the degradation of organic materials in a multi-stage process.

Anaerobic digestion is a sequential process, which follows four steps (Figure 7). Initially, during hydrolysis bacterial enzymes split organic polymers and convert them into more basic compounds such as sugars, amino acids or fatty acids. These compounds are further transformed into organic acids, alcohol, hydrogen and carbon dioxide during the acidification phase. Subsequently acetic acid and hydrogen is formed (acetogenesis) before methane (CH4) is generated (methanogenesis). Some methane is generated directly from carbon dioxide and hydrogen.

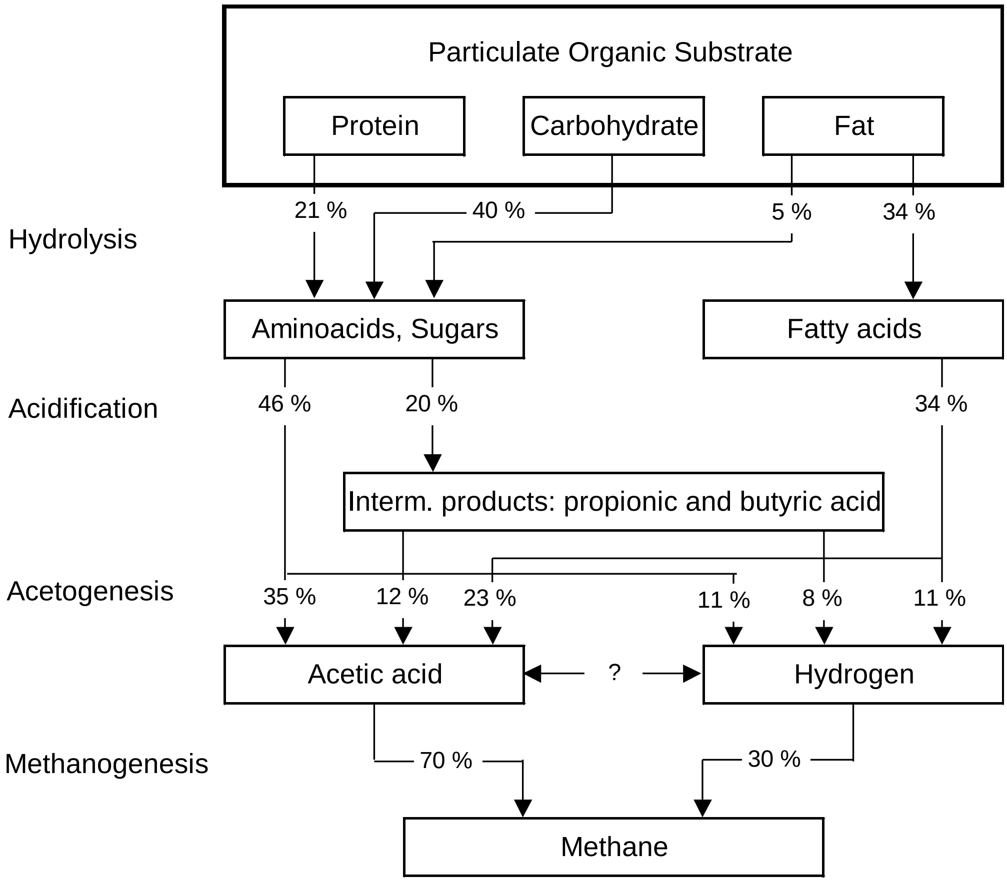

Figure 7 - Flow chart of mesophilic anaerobic degradation of organic matter (Source: 13)

Anaerobic microorganisms, compared to aerobic ones, have a relatively low growth rate and their substrate utilisation co-efficient is relatively low. These characteristics require long retention times and a high throughput of substrate to achieve sizable biomass (bacteria) growth.

Processing technologies

Fundamentally, anaerobic digestion processes can be differentiated according to (i) processing temperature, (ii) water content of input material, (iii) supply of feedstock and (iv) the biological processing phase.

Processing temperature

Temperatures below 25 °C (psychophil) tend to be uneconomical for anaerobic digestion since slow reaction times require large bioreactors.

Kerbside collected garden and food organics are often digested at the mesophilic (25 °C – 45 °C) temperature range. Microbial efficiency is relatively stable between 30 °C and 40 °C and a relatively broad spectrum of mesophilic organisms provides for the breakdown of complex organic compounds. However, mesophilic processes do not guarantee the elimination of pathogens, which is why pasteurisation needs to be accomplished before or after digestion. The minimum retention time is considered to be eight days.

Thermophilic (45 °C – 60 °C) bacteria show peak performance between 53 °C and 57 °C. However, the spectrum of available bacteria is narrow and breakdown of fats is somewhat reduced. The minimum retention time is considered to be one or two days. Pasteurisation can be achieved if retention time is sufficient.

Moisture Content and Supply of Feedstock

Based on feedstock moisture content, anaerobic digestion technologies can be differentiated into ‘dry’ and ‘wet’ processes. The choice between wet or dry digestion impacts on the efficiency of the biological processes, the quality of organic residues and the quantity and quality of wastewater generated.

Dry anaerobic digestion systems process feedstock with dry matter content of more than 20%. Dry matter content of feedstock continuously supplied into plug-flow fermenters typically ranges between 20% and 30%, while batch-operated fermenters can handle material with dry matter content of up to 50% or more.

The feedstock for **wet anaerobic digestion** systems has to have dry matter content of less than 10% to 15%. If the residues received for processing are too dry, water has to be added until a slurry is created that can be pumped and stirred, and allows for the removal of impurities via screens. The added water has to be removed and purified after digestion, unless it is utilised as liquid fertiliser.

Fermenters can be supplied with substrate continuously (wet digestion and dry plug-flow digestion) or discontinuously (dry batch digestion).

Biological Processing Phase

Focusing on the biological processes, there are two types of processing systems available; single-stage and two- or multi-stage digestion processes.

Single-stage process facilities combine all anaerobic digestion steps (see Biochemistry) in one bioreactor and are therefore relatively simple from a process-engineering point of view. However, the combination of all biological and chemical processes in a single bioreactor represents a compromise since none is operating in optimum conditions. This reduces the operating efficiency (gas yield) of such systems, which is often compensated by prolonged retention times (two to four weeks).

High performance wet digesters are unsuitable for the processing of kerbside collected garden and food organics due to their high solids content. This leaves agitated reactor vessels, percolation and plug-flow-reactors for single-stage anaerobic digestion of such materials. Agitated reactor vessels are often used for the digestion of water-amended kerbside collected organics. The content of the bioreactor is continually agitated through external pumps, propellers or by forcing gas into the reactor. Plug-flow-reactors are often used when no water is added to kerbside collected organics. The organic residues, after being innoculated with digested product, move through the digester like a plug. One of the advantages of this system is that the organic material remains in the reactor for a set time span, which is an important aspect for pasteurisation.

No agitation at all is required with percolation reactors. In this case, kerbside collected organics are commonly mixed with digested product before it enters the reactor. There, process water is percolated through the digested material. However, gas production is relatively low with this type of reactor and therefore also the level of stabilisation. Apart from being used as digesters in their own right, percolation reactors can be used also in multi stage and double phase systems to accommodate the hydrolysis process.

A summary of advantages and disadvantages of single-stage ‘wet’ and ‘dry’ anaerobic digestion systems is shown in Table 4.

Table 4 - Advantages and disadvantages of single stage wet and dry anaerobic digestion systems (Source: 14)

Criteria	Advantages	Disadvantages
Wet Digestion		
Technical	- Inspired from known process	- Short-circuiting - Sink and float phase - Abrasion with sand - Complicated pre-treatment
Biological	- Dilution of inhibitors with fresh water	- Particularly sensitive to shock loads as inhibitors spread immediately in reactor - Volatile solids lost with extraction of inerts and plastics
Economical & Environmental	- Equipment to handle slurries is cheaper (compensated by additional pre-treatment steps and large reactor volume)	- High consumption of water - Higher energy consumption for heating of large volume
Dry Digestion		
Technical	- No moving parts inside reactor - Robust (inerts and plastics need to be removed) - No short-circuiting	- Wet waste (< 20 % dry matter) cannot be treated alone
Biological	- Less volatile solids loss in pre-treatment - Higher bacterial biomass - Limited dispersion of transient peak concentrations of inhibitors	- Little possibility to dilute inhibitors with fresh water
Economical & Environmental	- Cheaper pre-treatment and smaller reactors - Very small water usage - Smaller heat requirement	- More robust and expensive waste handling equipment (compensated by smaller and simpler reactor)

In multi-stage process facilities, which represent only wet digestion technologies, the organic materials pass sequentially through several bioreactors. Environmental conditions in each bioreactor vary to create optimum conditions for the various steps in the anaerobic degradation process. Commonly, the hydrolysis and acidification phase is separated from the mesophilic or thermophilic digestion. In many cases solids are separated after hydrolysis and only the acid process water that contains suspended solids is digested and used for biogas production in high-performance reactors. This however, requires considerable resources for dewatering and insufficient separation of solids can result in a collapse of the system.

For optimum performance of the bacteria which facilitate hydrolysis through exo-enzymes, the pH has to be lower than 6.5 – 7.5, which is the optimum for methanogenic bacteria. Multi-stage process facilities require a higher level of engineering and process control than single stage processes. Reactors in multi-stage facilities are relatively small since the operation in optimum conditions and the transfer only of largely hydrolysed and easily degradable organic components into the digesters assures high levels of degradation and high throughput rates. Retention times are usually one to two weeks.

Kerbside collected organics represents a relatively heterogeneous substrate, and the rates of hydrolysis do vary between the different components. Multi-stage processes do not offer advantages for substrates where hydrolysis (in the hydrolysis reactor) is slower than methanogenisis (in the digester). Particularly mesophilic digestion processes are susceptible to acidification if bacteria biomass in the digester is insufficient to cope with high loading rates of soluble solids transferred into the digester after hydrolysis. Such problems are rarely encountered with thermophilic digestion.

Since the various bio-chemical processes involved in the anaerobic degradation of organic matter are intricately linked, the separation of the hydrolysis / acidifcation phase from the formation of acetic acid and methane may cause considerable process-engineering problems, particularly in cases where complex substrates such as kerbside collected organics are involved.

Another possibility for multi-phase anaerobic digestion processes is to separate the digestion process into a thermophilic and a mesophilic stage. The initial thermophilic digestion utilises available suspended solids and ensures pasteurisation while the subsequent mesophilic process reduces more complex organic compounds to methane.

A summary of advantages and disadvantages of multi-stage anaerobic digestion systems is shown in Table 5.

Table 5 - Advantages and disadvantages of multi-stage anaerobic digestion systems (Source: 14)

Criteria	Advantages	Disadvantages
Technical	- Design flexibility	- Complex
Biological	- More reliable for cellulose-poor food organics - Only reliable design (with biomass retention) for C/N < 20	- Smaller biogas yield (when solids not methanogenised)
Economical & Environmental	- Less heavy metals in compost (when solids not methanogenised)	- Higher investment costs

While there are many variations in the way in which anaerobic digestion facilities for solid organic residues can be built and operated, fundamentally there are only three different types of facilities, the characteristics of which are shown in Table 6.

Table 6 - Differentiation and characteristics of various types of anaerobic digestion processes (Source: 14)

Criteria	Multi-stage wet digestion process	Single-stage wet digestion process	Single-stage dry digestion process
Temperature	Mesophilic or thermophilic	Mesophilic or thermophilic	Mesophilic or thermophilic
Level of degradation	50 – 80 % of organic dry matter	40 – 60 % of organic dry matter	
Retention time	4 – 15 days	12 – 25 days	
Digester 1			
Bio-chemical process	Hydrolysis, Acidification	Hydrolysis, Acidification, Acetogenesis, Methanogenesis	
Dry matter content	5 – 15 %		25 – 50 %
Agitation	External pumps, propellers, gas forced into reactor		Propeller, percolation
Supply of material	Continuously, intermittently, batch system		
Digester 2			
Bio-chemical process	Acetogenesis, Methanogenesis		
Dry matter content	5 – 10 %		
Agitation	external pumps, propellers, biogas forced into reactor		
Supply of substrate	Continuously, intermittently		

Products

Anaerobic digestion of organic matter results in the production of biogas, solid organic residues and, depending on the type of digester used, smaller or larger quantities of surplus process water. Figure 8 shows an example of a material flow chart for a dry anaerobic digestion plant in Switzerland.

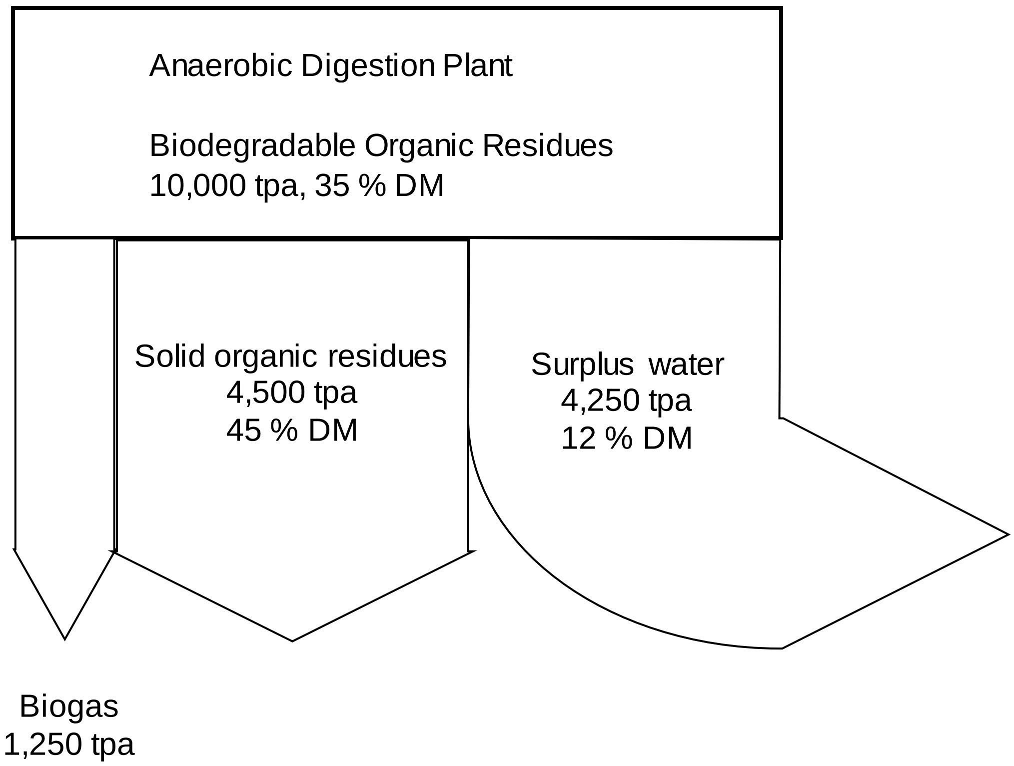

Figure 8 - Indication of material flows in a dry anaerobic digestion facility that processes kerbside collected organics
[tpa = tonnes per annum, DM = dry matter]
(Source: unknown)

The amount of biogas generated through anaerobic digestion depends primarily on the type and composition of input materials and its particle size distribution which determines the biogas potential of feedstock, and on the efficacy of the digestion process. The type of input materials to be processed in an anaerobic digestion facility will largely determine the technology that is most appropriate. Processing technologies can, for example separate processing steps and vary temperature, pH, loading rate, and hydraulic retention time to improve gas yields. Some processing technologies aim to maximise gas yield (multi-stage wet digestion), while others have comparatively low gas yield, but are more economical (single-stage, dry batch digestion).

Organic components such as sugar, starch, protein, fat, cellulose and hemicelluloses are fully or partially degraded in anaerobic conditions, while lignin and chitin are virtually non-degradable. The level of degradation of cellulose and hemicelluloses in these conditions depends largely on the lignin content of the organic material since cellulose and hemicelluloses are often intertwined in a matrix of lignin.

Anaerobic digestion results in the generation of biogas, which is composed primarily of methane (CH_4) and carbon dioxide (CO_2) plus trace gases as shown in Table 7.

Table 7- Composition (%, v/v) of biogas

Component	Range	Virgin biogas	Purified biogas
Methane (CH_4)	50 – 75	65	> 96
Carbon dioxide (CO_2)	25 – 45	35	< 4
Nitrogen (N_2)	< 2		
Oxygen (O_2)	< 2		
Hydrogen sulphide (H_2S)	< 1	max. 200 ppm	max. 5 mg/Nm^3
Ammonia (NH_3)	< 1		
Water (H_2O)	2 - 7	variable	< 10 mg/Nm^3

Note: Nm^3 = Normal cubic meter, i.e. at standardised conditions of 0 °C and 1013 mbar pressure

Biogas yields do vary according to the kind of input materials processed. While maximum potential gas yields are high (e.g. 700, 900 and 1,200 litre biogas per kg organic dry matter [L/kg DM] for proteins, carbohydrates fats) in reality between 300 and 600 L/kg DM of biogas are generated, depending on the type of material processed. As a rule of thumb it is expected that 1 tonne of kerbside collected garden and food organics generates about 100 m3 of biogas (Figure 9) with an energy content of 6 kWh/ m3 (methane content of 60 %). Consequently, a plant with a processing capacity of 10,000 tonnes per annum (tpa), which would service some 100,000 people, would generate about 1 million cubic meter biogas per year with an energy equivalent of 6 million kWh.

Although slurries from intensive animal production units lend themselves to anaerobic digestion, the gas yield from these substrates is comparatively low (Figure 9). This is one reason why co-digestion of animal manures with energy crops or non-agricultural organic residues can be seen as a favourable option. Co-digestion of agricultural and non-agricultural inputs has the added advantage that such an arrangement provides for the easy re-use of solid and liquid residues on farm and it also provides the farmer with an opportunity to generate additional income through gate fees.

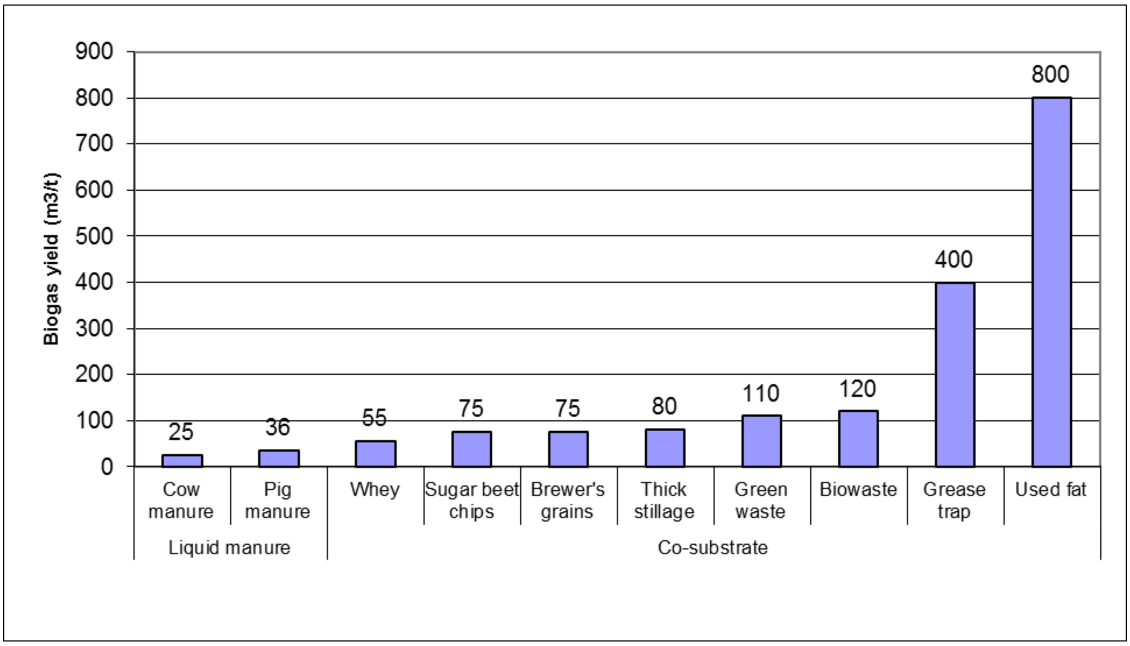

Figure 9 - Biogas Generation Potential of Various Organic Residues (Source: unknown)

Use of biogas

For many applications the quality of biogas has to be improved. The main components that may require removal is water vapour and gases such as carbon dioxide, hydrogen sulphide and halogenated compounds. The intended use of the purified gas determines which components need to be removed and to what degree, so that the gas will comply with quality requirements for the intended application, and not cause damage to machinery or harm to the environment or humans. The International Energy Agency (Task 24) provides an overview of available technologies for biogas purification [15].

The various ways in which biogas can be utilised is shown in Figure 10.

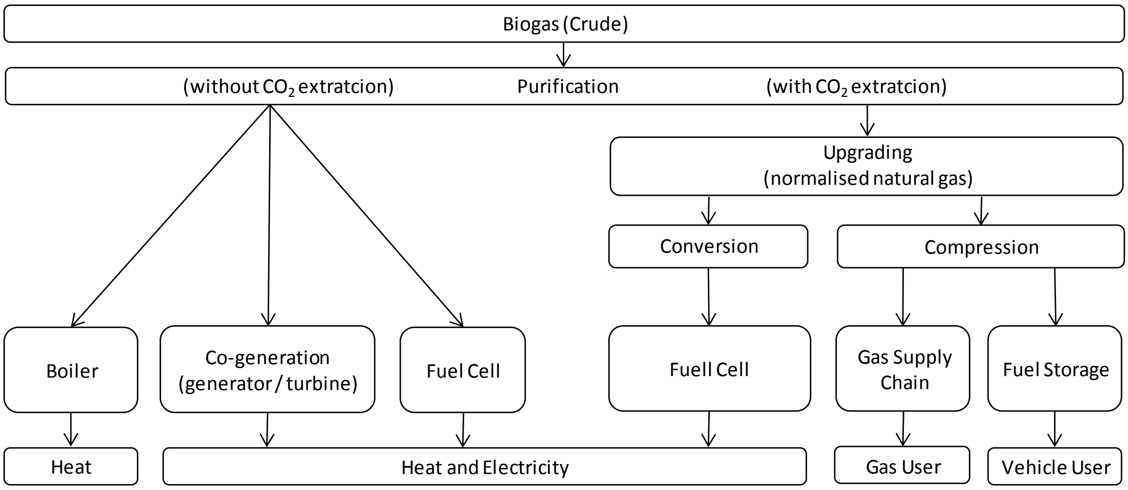

Figure 10 - Potential uses for biogas (Source: [16])

Biogas, or products generated from biogas (electricity, heat, fuel), can be utilised on-site where it is generated, or the products can be exported for external use. The preferred option for biogas use depends on internal demand for electricity and heat, and the location of the plant. Ideally, the digester should be located where not only electricity but also process heat can be utilised, or where the upgraded gas can be fed into a gas pipeline and the existing gas supply chain. Where biogas is converted on-site, combined heat and power (CHP) plants are the favoured option. The extensive experience with this technology (gas motor in combination with electricity generator) is a major advantage. Total efficiency of a CHP unit is about 80% to 85%, which is split into electrical efficiency (33% - 45%) and heat efficiency (35% - 56%). This is demonstrated in an example for biogas generation from kerbside collected organics and use of a CHP unit for energy generation (Table 8). The example shows that energy output from the CHP unit is about 80%. However, more than half of the available energy is low-grade heat energy, which is more difficult to find a use for in Western Australia than in cooler European conditions. However, it is technically possible to utilise excess heat for cooling purposes.

Table 8 - Energy balance for biogas generation from kerbside collected organics and gas use in a combined heat and power plant (Source: unknown)

Criteria	Value	
Biogas yield	Approx. 100 Nm^3 / t kerbside collected organics *	
Energy content	Approx. 6 kWh / Nm^3 biogas (methane content of 65 %)	
Energy yield (kWh / t)		
Total thermal energy	600	
After conversion in combined heat and power plant		
Electrical energy (33 %)	198	
Heat energy (58 %)	348	
Loss (9 %)	54	
Balance (kWh / t)		
	Electricity	Heat
Energy production	198	348
Energy consumption digester	48	48
Energy surplus	150	300

* Nm^3 = 1 m^3 at 1013 mbar and 0ºC

On a broader scale, 20% to 30% of the energy produced is used for operating the anaerobic digestion facility and 8% to 12% is lost. This results in a gross surplus of 58% to 72% of the energy produced. However, energy consumption for the curing phase and vehicle movements have to be accounted for, resulting in a net energy surplus of between 30% and 45 %.

The use of gas turbines for electricity generation, due to their low efficiency (26% - 33%), is only feasible if large quantities of biogas are generated. On the other hand, fuel cells promise to provide a highly efficient (40% - 55%) means of utilising the energy captured in methane by means of an electro-chemical conversion of the thermal energy contained in hydrogen into electrical energy.

Once biogas is processed so it resembles the characteristics of natural gas, it is called bio methane, and can be used as fuel for vehicles. This application is of particular interest where local authorities can utilise their own gas for council vehicles such as waste collection vehicles or buses. It is also possible to supply bio methane into the existing gas supply networks. Governments in Europe have high hopes that production of bio methane will further advance the importance of biogas in reducing the use of fossil fuels. In 2012, there were 83 bio methane generation facilities in Germany.

Solid Organic Residues

Solid organic residues (or solid digestate), which are not composted or cured after anaerobic digestion, have limited application. This is due to potential odour problems and possible agronomic constraints. Digested organic residues contain most nitrogen as ammonium. In order to avoid substantial nitrogen losses through volatilisation such materials should be incorporated into the soil upon application. Even though the C/N ratio of solid digestate may not be very high, anaerobically digested residues can cause nitrogen draw-down due to the fact that lignin is not broken down in anaerobic conditions. Therefore, the use of raw digestate may have to be supplemented by the use of additional nitrogen, particularly if plant growth is to be supported. It is not recommended to apply raw digestate immediately prior to sowing or planting.

Digestate that has been composted and cured after anaerobic digestion is found not to be very different from composted kerbside collected organics that has not been digested. Wet digestion systems and dry digestion technologies, where considerable leaching occurs, generate digestate that that has relatively low electrical conductivity. Consequently, these materials have good potential for being utilised in high value horticultural products.

Surplus water

Wet digestion systems have to deal with high quantities of excess process water, while dry digestion systems generate relatively small quantities. The liquid residues are often also called digestate or ‘liquor’. Generally, the liquor has a high nutrient loading and can also have high solids content. As far as possible, liquor is used as ‘liquid fertiliser’ for agricultural application. Where this is not possible, or not all year round, excess water has to be treated and purified before it can be discharged to a wastewater treatment plant.

Manufacturers and operators of anaerobic digestion facilities try to minimise the generation of excess process water.

Operation

The operational set-up of anaerobic digestion facilities is similar to that of composting operations, but includes additional components such as the addition of water, the digestion process and de-watering for wet digestion systems. Dry digestion requires less additional operational components.

Anaerobic digestion facilities that process source segregated municipal and commercial organics commonly employ some or all of the following operational units, which also represent the normal sequence of processing. Wet digestion requires more processing steps than dry digestion, which is noted where applicable. Figure 11 shows the key operational components of a wet digestion facility without post-processing, which could include dewatering, liquor storage and composting.

Figure 11 - Operational components of a wet digestion facility (excluding post-processing) (Source: [17])

Reception and storage of raw materials

- Reception of solids usually takes place in an enclosed reception hall where trucks unload the organic material. An initial quality check can be carried out here, and large undesirable contaminants can be extracted.
- Reception of liquids (wet AD only) occurs through pumping liquid residues into a storage tank.
- Interim storage of bulking material for composting (before or after size reduction, or both).
- Pre-processing
- Bag opener (optional): depending on the quality of kerbside collected organics and other pre-processing steps.
- Extraction of impurities (optional): depending on the predominant type and quantity of impurities in the material received, a combination of mechanical separation equipment (e.g. magnets, screens, and eddy current separators) and manual sorting can be employed to remove impurities.
- Particle size reduction (wet AD only): kerbside collected organics are shredded to facilitate production of a pumpable liquid suspension.
- Screening (wet AD only): The shredded material needs to be screened to ensure no oversize particles which could obstruct subsequent operations.
- Addition of water and processing aides (wet AD only): Water needs to be added to create a pumpable suspension. The amount of water that needs to be added depends on the moisture content of the solid organics that are processed, and on the ratio of liquid and solid residues accepted at the facility. Sodium hydroxide is often also added to facilitate anaerobic degradation of organic compounds.
- Pasteurisation of the input material (optional): where solid digestate is not composted or where liquid digestate is utilised in agriculture/horticulture, it might be necessary to pasteurise (65 – 70 °C for 1 hour) the input material before it enters the digester.
- Mixing and homogenising: Different raw material streams (e.g. shredded kerbside collected organics, liquid residues, sludges) are mixed and homogenised to generate feedstock that suits the requirements of the technology employed, and has the characteristics desired for enhancing the digestion process and generating high biogas yields.

- Incoming liquid raw materials have to be stored in a buffer tank.

Digestion

The actual digestion process takes place in a fully enclosed vertical or horizontal vessel that allows in- and outflow of raw/processed materials in continuous systems or filling and emptying of batch operated systems, while also ensuring that the generated biogas is captured. The length of time for which material is kept in the digester (retention time) varies between technologies.

The digestion unit can include

- Mixing devices; material inside wet digestion units can be mixed and stirred mechanically (propellers), hydraulically (pumps) or pneumatically (gas insertion) , while material in dry digesters can be mixed (and moved) only mechanically (impeller)
- Heating devices, which maintain elevated temperatures in thermophilic (> 45 °C) and possibly also mesophilic (25 °C – 45 °C) systems.

Biogas purification and conditioning

Depending on the intended use of the biogas generated, purification may include removal of moisture, hydrogen sulphide, carbon dioxide, halogenated hydrocarbons, siloxan, oxygen and nitrogen [15]. Furthermore, the purified gas has to be pressurized to various degrees to suit its intended use.

Use of biogas

Unless all biogas is used offsite, the gas is usually converted into electrical and/or heat energy by means of a boiler or a combined heat and power plant. The generated heat and electricity is fully or partially utilised on-site, and, as far as possible, surplus energy is sold for external use. Purification and upgrading of biogas for use in vehicles or as substitute for natural gas usually in large (centralised) facilities is also possible.

Dewatering

Except for batch operated dry digesters, the processed material has relatively high moisture content as it leaves the digester, and is therefore dewatered. Solids and liquids can be separated with the help of roller -, belt - or screw presses, or with centrifuges. The separated materials are digestate and liquor.

Processing of digestate

Digestate is usually processed, stabilised and matured by means of composting. To achieve proper composting conditions, the digestate has to be mixed with organic residues that are relatively dry and provide good pore space in the mixed material to facilitate aerobic composting conditions. Composting can take place in open systems, or in a combination of in-vessel and open composting. As with composting operations (see Section 4.3.1), the compost produced may have to be refined (screening, removal of impurities). Subsequently, a storage area has to be provided for unscreened and/or screened compost products.

Liquor storage and use

Wet digestion systems in particular generate large quantities of liquor, which has to be captured in a storage tank. Some of the available liquor is recirculated and used for increasing moisture content of feedstock to the desired level, or for percolation of digested material. Furthermore, it might be possible to evaporate some liquor via the composting process. Digestion facilities aim to supply all surplus liquor to farmers for use in agricultural enterprises. If or when that is not possible, surplus liquor usually has to be treated and purified prior to delivery to a wastewater treatment plant.

Figure 12 shows an operational flow chart for a generic wet anaerobic digestion facility.

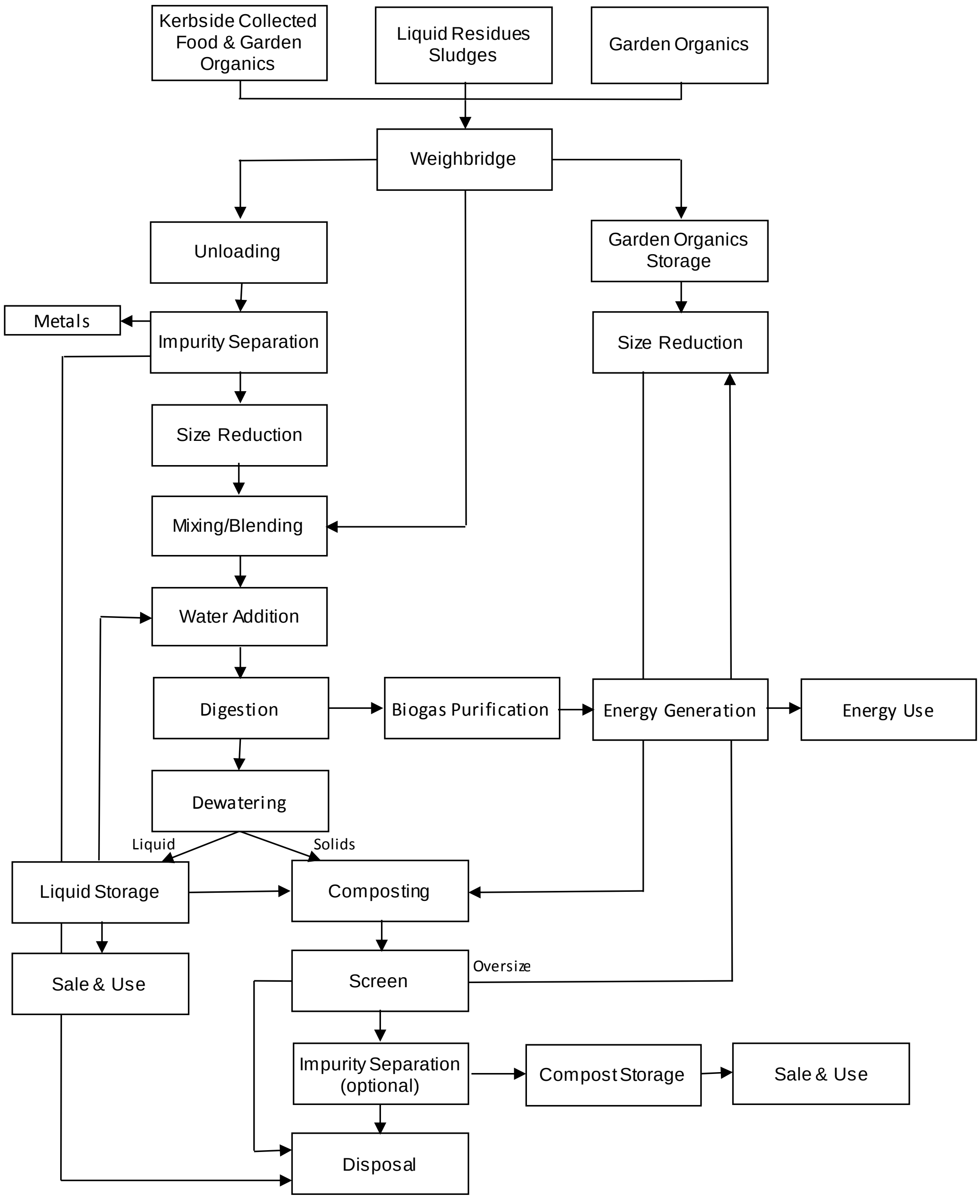

Figure 12 - Flow chart for generic wet anaerobic digestion facility

5 SPECIFIC INFORMATION

5.1 PROCESS DESCRIPTION AND OPERATION

The underlying bio-chemical processes that drive the composting and anaerobic digestion processes, different processing technologies, and generic operational models, were outlined in Sections 4.3.1and 4.3.2. The following discussion provides specific information about actual operating facilities.

5.2 CAPACITY AND FOOTPRINT

5.2.1 CAPACITY

The processing capacity of composting and anaerobic digestion facilities can vary widely, more so for composting than for anaerobic digestion facilities. In Europe, particularly in Austria and Switzerland there are many small decentralised composting facilities that process both garden organics and food and garden organics. At the other end of the spectrum, the composting facility in Wijster (Netherlands) processes around 330,000 tpa of source segregated organics [18]. A recent survey of organics processing facilities in Germany (capacity > 1,000 tpa) showed that composting facilities processed between 1,700 tpa and 90,000 tpa, with a median of 10,000 tpa [19]. The survey also showed that large plants process a higher proportion of food and garden organics than smaller ones. The average amount of organics processed in Australian composting facilities is considerably higher, with State averages ranging between about 20,000 tpa and 50,000 tpa (Table 9).

Table 9 - Average number and sizes of composting facilities in Australia in 2011
Calculated from [10]

	NSW	WA	SA	VIC	QLD	National
Number facilities	61	29	33	33	42	198
Total capacity (tonnes)	1,789,000	733,000	637,000	999,000	2,173,000	6,331,000
Average capacity (tpa)	29,328	25,276	19,303	30,273	51,738	31,975

Due to a combination of technical issues (mainly wet and continuous dry digestion) and economic considerations (relatively high investment costs, economies of scale), anaerobic digestion facilities for kerbside collected organics tended in the past to have a minimum size of 15,000 to 20,000 tpa. This has changed with the emergence of modular, garage-like dry anaerobic digestion units, which have markedly reduced investment costs, and make smaller operations feasible. The survey of organics processing facilities in Germany mentioned above (capacity > 1,000 tpa) showed that anaerobic digestion facilities processed between 3,700 tpa and 112,000 tpa, with a median of 17,900 tpa [19]. In comparison, the Earth Power wet digester in Sydney has a processing capacity of 80,000 tpa, and the new facility that is currently being built by Richgro in Western Australia, apparently also a wet digester, will have capacity to handle up to 35,000 tpa.

5.2.2 FOOTPRINT

When designing a composting operation, adequate space has to be allocated to pre-processing, processing and post-processing activities, including associated materials handling equipment and manoeuvring. Space for aeration equipment, exhaust air purification (biofilter), leachate pond, workshop and admin/staff rooms may also have to be taken into account. Typically, about two thirds of the total area is occupied by the composting pad. Factors such as the total amount (volume) of material to be processed, the duration of the composting process, the use of intensive, aerated composting technologies, the dimensions and separation of windrows/piles (determined by mode of turning), and requirements for buffers, will determine the overall area requirements.

According to data from various existing facilities [20], the footprint of dry anaerobic digestion facilities ranges from 0.15 to 0.40 m^2 per tonne of input per year and that of wet digestion facilities is somewhat lower, ranging between 0.10 and 0.25 m^2 per tonne of input per year.

5.3 FEEDSTOCK

A wide variety of organic residues can be composted, although not always on their own. The ability to blend dry and moist, carbon-rich and nutrient-rich materials, makes composting a very versatile processing option. The choice of processing technology for a given application depends largely on the chemical and physical properties of the materials to be processed (see Figure 13). As a general rule, organic residues with high carbon density and low moisture content (such as wood) are better suited to combustion whereas putrescible residues with high moisture content (such as food) are better suited for anaerobic digestion. Vegetation residues on their own can be easily and cheaply composted in open windrows in small decentralised facilities to minimise transport costs and environmental impacts. Putrescible organic residues that have high odour and leachate potential are often composted using in-vessel or fully enclosed composting facilities.

Wet anaerobic digestion technologies are designed for processing residues with high moisture content, including liquids and sludges. Dry anaerobic digestion technologies can also handle drier residues, including kerbside collected garden and food organics.

All feedstock should contain minimal levels of non-biodegradable impurities, such as plastic, metals, glass, stones, rocks, etc, as their presence can result in machinery breakdown and impact negatively on product quality. Removal is of these contaminants is costly. The feedstock should be also free of elevated levels of heavy metals and other chemical contaminants, as these may limit the use of the final products. The quality of the final product is highly dependent upon the quality of the feedstock.

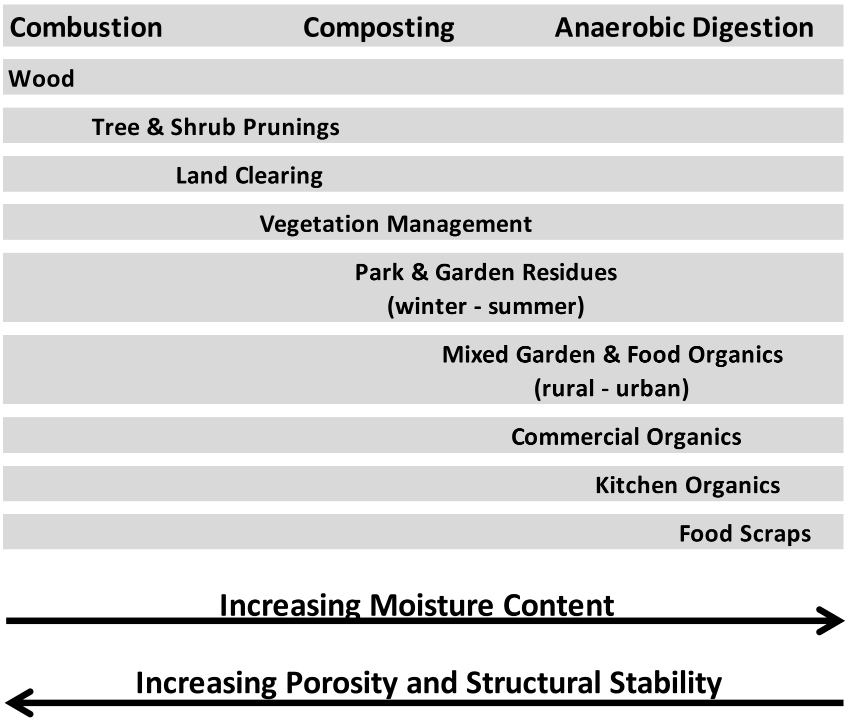

Figure 13 - Processing options for different types of organic residues (modified from [21])

5.4 PRODUCTS AND RESIDUALS

All organics processing facilities generate products designed for sale and beneficial use, but they also generate undesirable residuals and emissions.

Products

Composting operations generate pasteurised, composted or matured compost products. In most cases these composts are subsequently refined and turned into various products by means of screening, extracting impurities (air/ballistic separator), blending, and the addition of fertilisers and/or microorganisms.

Most anaerobic digestion facilities also generate compost from their solid residues after dewatering, although it is possible to directly utilise liquid digestate containing low levels of dry matter in agriculture. Dewatering of digestate results in the generation of a liquor, some of which can be evaporated via composting, while the rest is used in agricultural applications. Some liquor might have to be purified and disposed of at a wastewater treatment plant.

Anaerobic digestion facilities also generate biogas, which, in most cases, is subsequently used to generate electrical and/or heat energy. It is also possible to use the biogas as fuel for vehicles, or to supplement natural gas supplies.

Residuals

Residuals from organics processing facilities consist of primarily extracted impurities and oversize material, leachate and gaseous emissions.

The amount of impurities and oversize material (after screening) depends on the quality of input material, including the particle size distribution of shredded woody residues. Oversize volumes can be significant and require considerable storage capacity. Oversize material usually contains large pieces of timber and wood, rocks as well as other impurities.

Leachate

Depending on the moisture content of the feedstock and subsequent irrigation requirements and practices, composting can generate leachate. Open composting facilities also have to deal with run-off from the composting pad, which has to be impermeable for surface water (in accordance with EPA specifications). Leachate and run-off water is usually captured and contained in a leachate dam, which needs to be aerated to prevent it from becoming anaerobic and a source of odour emissions. The leachate and run-off water collected is usually evaporated via the composting process.

Emissions

Gases that are emitted during the composting process are primarily carbon dioxide and water vapour. However, depending on feedstock characteristics, management and control of the composting process, and the stage it is in, the following gases can also be emitted from composting operations:

- Ammonia;
- Methane;
- Nitrous oxide;
- Carbon monoxide;
- Hydrogen sulphide; and
- Trace gases containing odorous compounds.

Methane emissions from many anaerobic digestion facilities are higher than those from composting operations, and are mainly caused by leakage of the generated methane, and anaerobic material being exposed to the atmosphere after digestion.

Exhaust air from in-vessel and fully enclosed facilities is usually purified by means of a biofilter, and possibly also by an acid scrubber.

5.5 RESOURCE RECOVERY POTENTIAL

Organics processing facilities that handle kerbside collected garden and food organics can potentially deliver very high levels of landfill diversion and resource recovery. This potential can be achieved if the input material supplied does not contain impurities, and if all biodegradable materials can be utilised to generate biogas, produce compost or mulch products, and generate energy by burning woody residues.

The proportion of impurities in kerbside collected organics diminishes the level of resource recovery in organic processing facilities. Garden and food organics collected in rural and regional areas tend to contain fewer impurities than those from cities and densely populated area. There are examples where co-collected garden and food organics are very clean with less than 1% (w/w) impurities (e.g. Lismore City Council), but there are also examples where the collected material contains up to 10% (w/w) or more of undesirable components. Common impurity levels range between 2% (w/w) and 5% (w/w).

5.6 COSTS AND INCOMES

Costs of both composting and anaerobic digestion are likely to exhibit considerable variation. The key variable for composting, in terms of process, is likely to be whether the process is carried out inside a building or vessel, or in open air. This affects also aerial land requirements and associated purchase costs. Pollution control equipment, front and/or back-end separation technologies and techniques to reduce odours also affect the costs of processing technologies. The costs of marketing compost products are also an important consideration.

Different anaerobic digestion technologies will have different costs. In co-digestion facilities, materials which are treated alongside the source-separated organics may affect costs, e.g. through increased need for pre-treatment or waste water treatment, or through changes in the quantity and quality of digestate and biogas generated, and subsequent revenue streams. Subsidy regimes for renewable energy may have an important role to play.

5.6.1 CAPITAL AND OPERATING COSTS

Composting

The capital cost per throughput tonne for composting facilities with minimum processing capacity of 50,000 tpa ranges between $52[1] and $62 for windrowing, between $104 and $156 for enclosed windrowing, and between $312 and $520 for in-vessel composting, according to an undated Canadian publication [22]. An example from the USA suggests that investment costs of $97 and $204 per tonne input are necessary for establishing windrow and covered aerated pile composting facilities with annual processing capacities of 40,000 tpa (Table 10). Investment costs cited for in-vessel and enclosed composting facilities in Europe [24] range widely between $40 and more than $300 to $500 per tonne input (Table 11). However, the accuracy of values above $400 per tonne is questionable, as figures could not be verified and may refer to facilities that incorporate more processes than only composting. A 2002 model for a best practice enclosed composting facility (composting for 21 days in enclosed, aerated windrows with air purification, and 60 day maturation in open windrows) in Europe with a capacity of 20,000 tpa resulted in estimated investment costs of $198[2] per tonne input [25].

When considering operating costs, it is necessary to specify whether depreciation and financing costs are included or not. The operating and maintenance costs for open windrow and aerated covered pile composting shown in Table 10 do not include depreciation and finance costs, and amount to approximately $13 and $24.50 per tonne input, respectively. The best practice model [25] mentioned above showed that depreciation (civil works: 10 and 20 years, equipment: 8 years) and finance costs (6%) amounted to $25.74 per tonne input, while operating and maintenance costs amounted to $61.30, bringing the total to $87.04 per tonne input. However, all other operating costs presented in the *Economic Analysis of Options for Managing Biodegradable Municipal Waste* [25] do not include depreciation and finance costs. The 2002 report cites a considerable number of operating costs for sophisticated composting operations that, broadly speaking, ranged between $54 and $135 per tonne input. However, the report stated that operating costs for open windrow composting facilities can be as low as $27 to $35 per tonne input, making it one of the cheapest options for managing municipal organics. The above spectrum of processing costs for kerbside collected organics ($54 to $135 per tonne input) was confirmed in a more recent (2009) German study [26]. The authors point out that (i) improved technology increases costs, (ii) economies of scale decrease costs, and (iii) oversupply of processing capacity results in reduced processing charges. At the time,

[1] at an exchange rate of CAD1.00 = AUD1.04

[2] at exchange rate of €1.00 = AUD1.35

construction and operation of composting facilities for kerbside collected organics was offered at costs that translated into processing costs between $40 and $70 per tonne. Respective figures for garden organics processing facilities ranged between $20 and $40 per tonne.

Table 10 - Investment and operating costs for 36,000 tpa open windrow and covered aerated pile composting facilities in USA
Adapted from [23] and converted at exchange rate of USD1.00 = AUD1.00

CAPITAL COSTS		OPERATING AND MAINTENANCE COSTS	
Open windrow composting			
Category	**Amount**	**Category**	**Amount**
Paving	$1,100,000	Labour	$187,000
Grading	$82,500	Overhead	$77,000
Fencing	$22,000	Windrow turner	$27,500
Building	$550,000	Tub grinder	$55,000
Leachate system	$110,000	Screens	$5,500
Engineering cost	$550,000	Front end loader	$5,500
Tub Grinder	$275,000	Building	$5,500
Windrow turner	$220,000	Site lease	$110,000
Legal	$165,000	**Total**	**$473,000**
Screens	$220,000	**Costs per tonne**	**$13.14**
Front end loader	$198,000		
Total	**$3,492,500**		
Costs per tonne	**$97.01**		
Covered aerated piles (GORE)			
Category	**Amount**	**Category**	**Amount**
General	$150,000	General & Administration	$75,000
Site Work	$150,000	Insurance	$50,000
Paving	$1,000,000	Fuel/ Supplies	$50,000
Concrete	$600,000	Contracted Services	$10,000
Buildings	$500,000	Labour	$250,000
Leachate System	$100,000	Repairs and Maintenance	$100,000
Storm Water System	$300,000	Electricity	$20,000
Electrical Equipment	$400,000	Accounting and Legal	$25,000
Equipment	$1,500,000	Residual Disposal	$20,000
Engineering	$200,000	Host Benefits	$35,000
Legal	$200,000	Site Lease	$100,000
Gore Cover System	$2,250,000	Cover Replacement Cost (2 /year)	$150,000
Total	**$7,350,000**	**Total**	**$885,000**
Costs per tonne	**$204.17**	**Costs per tonne**	**$24.58**

Table 11 - Examples of capital and operating costs for European composting facilities
Adapted from [24] and converted at exchange rate of €1.00 = AUD1.35

Technology provider	Location	Capacity (tpa)	Technology	Total Investment ($ M)	Capital Cost per Tonne Input ($/t)	Operating Costs ($/t)
	Ipswich, UK	17,200	In vessel composting of SSO[3]	2.5	145.8	
Horstmann		20,000	Tunnel composting, RDF[4] production	2.8	141.8	
		20,000	In vessel composting of SSO		40.5 - 121.5	54 - 108
		20,000	In vessel composting of SSO	0.9 - 1.6	47.3 - 81	
SRS	Inverboyndle, UK	25,000	In vessel composting	5.1	202.5	70.9 - 79.7
		40,000	In vessel composting	16.2 - 21.6	405 - 540	31.1 - 82.4
Horstmann		<50,000	Composting		130 - 277	
Linde	Linz, Austria	50,000	Tunnel composting	25.7	513.0	
Alpheco		50,000	Batch tunnel system	6.8	135.0	
		>50,000	Composting		51.3 - 416	36.5 - 128.3
		60,000	In vessel composting of SSO		270.0	40.5 - 47.3
VKW		75,000	Fully enclosed composting	20.9	279.5	45.9

[3] SSO = source segregated organics
[4] RDF = refuse derived fuel

Table 12 - Examples of investment and operational costs for anaerobic digestion facilities in Europe Adapted from [24] and converted at exchange rate of €1.00 = AUD1.35

Technology provider	Location	Capacity (tpa)	Technology	Total Investment ($ M)	Investment per Tonne Input ($/t)	Operational Costs ($/t)
		10,000 - 20,000	Anaerobic Digestion (AD)		405 - 540	
		20,000	Anaerobic Digestion of SSO			29.7 - 36.5
Passavant		20,000	Anaerobic Digestion	16.74	837	
		25,000	Anaerobic Digestion		317 - 331	
Valorga		25,000	Anaerobic Digestion	20.79	832	
BEKON		25,000	Dry Anaerobic Digestion	10.8 - 12.2	432 - 486	
Passavant		40,000	Anaerobic Digestion	25.65	641	
	Ashford	40,000	Anaerobic Digestion	15.93	398	
	Vaasa	40,000	Anaerobic Digestion	8.37	209	53
		<50,000	Anaerobic Digestion		296 - 776	43
		50,000	Anaerobic Digestion	14.9 - 39.8	297 - 797	35.1 - 81
		50,000 – 60,000	Anaerobic Digestion	18.2 - 47.3	365 - 787	51
Oaktech		75,000	Anaerobic Digestion	23.76	317	
		75,000	Anaerobic Digestion		182 - 243	
		100,000	Anaerobic Digestion	10.1 - 24.3	101 - 243	28
Hese	Leicestershire, UK	110,000	Hydrolysis and AD	60.75	533	
		120,000	Wet AD without post composting	27 - 40.5	225 - 338	
		120,000	Wet AD with post composting	33.8 - 49.3	281 - 410	

Anaerobic Digestion

Many of the fundamentals applicable for composting facilities apply equally for anaerobic digestion plants. Investment costs for standalone anaerobic digestion facilities are higher than for facilities that are integrated into existing composting operations, as, in the latter case, existing infrastructure and space can be utilised for post AD processing activities (composting, screening).

Generally, capital costs for batch AD facilities are lower than for continuously fed wet and dry operations. Investment costs cited for various anaerobic digestion facilities in Europe [24] range widely between $100 to over $800 per tonne input (Table 12). Examples are presented in Table 13 for continuous and batch dry digestion facilities in Germany with a processing capacity of 18,000 tpa. These result in capital costs of $463 and $305 respectively per tonne input [26].

Table 13 - Examples of investment and operating costs for two types of anaerobic digestion facilities in Germany
Adapted from [26] and converted at exchange rate of €1.00 = AUD1.35. (Excludes land purchase, site development and profit margin.)

	Continuous Dry AD (Plug & Flow)	Discontinuous Dry AD (Batch Garage Fermenter)
Investment	$9,058,500 *$463 / t input*	$5,494,500 *$305 / t input*
Processing costs	$678,240 *$37.68 / t input*	$486,570 *$26.87 / t input*
Capital costs (12 yrs, 5%)	$939,600 *$52.20 / t input*	$619,650 *$34.43 / t input*
Income (without sale of digestate / compost)	$980,280 *$50.46 / t input*	$695,520 *$38.64 / t input*
Treatment costs - digestion	$709,560 *$39.42 / t input*	$407,700 *$22.65 / t input*
Treatment costs - composting	$357,750 $19.88 / t input	$619,650 *$34.43 / t input*
Treatment costs - total	$1,067,300 *$59.30 t input*	$1,027,350 *$57.08 / t input*

Operating costs in the above examples (Table 13) amounted to about $27 and $38 respectively per tonne input for the batch and continuous digestion facility. If capital costs are also considered, processing costs increase to about $61 for the batch and $90 for the continuous digestion system. Total treatment costs for the two systems, including digestion, composting and income from the sale of digestion products (including 50% of surplus heat) are similar at $57 and $59 per tonne input for the batch and continuous digestion facility respectively.

Retrofitting existing composting facilities with an additional anaerobic digestion plant is expected to increase operating costs by $54 to $74 per tonne input. Increased operating costs will be partially offset by revenue generated through the sale of gas/electricity/heat.

5.6.2 INCOME

Composting

Income is usually generated from gate fees and the sale of generated compost and mulch products.

Anaerobic Digestion

Income is usually generated from gate fees and the sale of compost and mulch products, and possibly from liquor (liquid digestate) sales. Additionally, the sale of biogas, electricity and heat energy can generate considerable income.

5.7 RISKS

There are several key environmental risks associated with the processing of organic residues. The predominant risk is from odour emissions causing an environmental nuisance to sensitive receptors located in close proximity to the processing facilities. The forcible closure of organics processing facilities is primarily due to odour complaints. History has shown that not only open composting facilities, but also in-vessel and fully enclosed facilities can be the source of odour emissions and complaints. This can occur due to inadequate choice of location, and failure or poor performance of the processing / aeration and/or air purification technology.

Most composting operations emit some methane and/or nitrous oxide, which are greenhouse gases (GHG). Methane emissions are elevated when the composting process is not managed correctly. GHG emission measurements at composting facilities that process different feedstocks, employ different processing technologies and generate pasteurised and mature compost provided the following results [27]:

- Receival and mechanical processing add approximately 5.8 kg CO_2-e per tonne wet feedstock to biological GHG emissions.
- Production of mature compost from mixed garden and kitchen organics in turned windrows/piles generates 67% and 126% higher GHG emissions than when the same type of feedstock is composted in a fully enclosed facility or in an in-vessel composting facility respectively. Methane emissions in particular are higher from turned windrows/piles than from (partially) enclosed and aerated systems.
- GHG emissions are reduced by 50% when garden organics are composted in windrows/piles on their own rather than together with food organics.
- The production of pasteurised rather than mature compost in fully enclosed and in-vessel composting facilities reduces GHG emissions to about one third and one quarter respectively. This is primarily due to avoided nitrous oxide emissions from the maturation stage.
- Composting in aerated piles with semi-permeable compost covers represents the technology with the lowest GHG emissions.

Anaerobic digestion facilities can have higher GHG emissions than composting facilities, due to methane leakage and handling of anaerobic materials outside the digester [27].

Pollution of ground and/or surface water by leachate and run-off represents a potential risk for all organics processing facilities. However, in most cases these risks are minimised by operating on impermeable surfaces, by having leachate and trap dams, and by diverting external overland flow away from the facility. The Western Australian Department of Water has published a *Water Quality Protection Note* [28], which advises on the adverse effects upon water quality which poorly managed facilities that store and/or recycle organic material can have. This note advises on relevant environmental issues and makes recommendations as to best practice.

Sophisticated composting and anaerobic digestion technologies inherently have a higher technical and operating risk.

All landfill diversion and recycling activities have to compete with the costs of landfilling, which, when low, can be a major barrier to the expansion of organics recycling activities. However, landfill levies are increasing in most States, and the carbon pricing mechanism also has had an impact on landfill costs. As a result, alternatives such as composting and anaerobic digestion of organic residues have become more economically feasible, and this includes the application of more sophisticated and dearer technologies. Most organics processing facilities are able to derive income from gate fees and from the sale of their products. However, those processing facilities that do not have contractual feedstock supply arrangements with local governments or other large generators of organic residues, or that are only able to derive income from product sales, face markedly higher economic risks. Prolonged periods of severe weather (drought, flood) can adversely affect feedstock supply, production and sales, and pose severe financial strains on processors.

The availability of Government incentives and subsidies can make certain activities or processing technologies financially attractive, but there is an attendant risk that the activities and technologies will no longer be viable if the Government support is withdrawn.

At present, most recycled organic products are supplied into the urban and landscaping markets. The entire organics recycling industry faces the challenge of expanding the market into agricultural and horticultural sectors, which also means competition from cheap unprocessed animal manures. Achieving this goal depends to a large degree on proximity to these markets (transport costs), availability of appropriate products at affordable prices, and skills in engaging with these market sectors. Quality, price and efficacy are key determinants for farmers whether to use (buy) compost and mulch products or not. Elevated levels of physical and chemical contaminants diminish the value of recycled organic products, and limit their use.

Fires can occur at composting facilities. Measures need to be in place to prevent fires and to manage any incident should it occur. A fire prevention and control plan should be implemented, which includes such measures as temperature and moisture monitoring.

It should be recognised that operating an anaerobic digester involves the production and handling of methane, a potentially explosive gas. Consequently, adequate safety measures have to be put in place and adhered to during operational procedures.

5.8 ENVIRONMENTAL CONSIDERATIONS

Organics processing facilities handling more than 1,000 tpa require a licence to operate to be granted by the state regulatory authorities. The licence contains conditions under which the facility must operate, stipulating for example the types of organic residues that can be received and processed, the maximum amount of residues that can be received, end product quality requirements, and environmental monitoring requirements. The organics processing facilities must have a management plan in place which addresses an environmental monitoring program for the facility. The operations must comply with the regulatory framework and have control measures in place to minimise potentially detrimental impacts caused by the organics processing facility.

The common environmental receptors that are susceptible to impacts from organics processing facilities include water (groundwater, surface water and stormwater) and air. Nuisance from odour, birds, rodents and pests, windblown litter and visual impacts, traffic movements and dust can also negatively impact neighbours and local communities.

There are a number of control measures usually required to protect the environment from impacts associated with the operation of organics processing facilities, including the storage of raw materials and finished products. These include buffer zones, impermeable surface, drainage and storage dams, dust suppression and environmental monitoring.

Buffer zones are a regulatory requirement around organics processing facilities, with the extent of the buffer specified by the jurisdiction and considered on a case by case basis during the planning approvals stage. Buffer zones are used to control odour and visual amenity issues to local communities, and to provide protection for environmental features such as watercourses. Generally, buffer distances pertain to the distance from the processing facility to features such as: significant environmental or conservation value sites, residential areas and watercourses. Organics processing facilities cannot be situated within a drinking water supply catchment or overlying a drinking water aquifer.

Stormwater diversion and wastewater drainage must be designed to manage flood risks and avoid adverse effects from leachate and contamination from site run-off. In Western Australia it is prescribed that the capacity of the wastewater management system and holding ponds should be designed to (i) handle a 72 hour duration, 1 in 10 year ARI (Average Recurrence Interval) critical rainfall event without overflow, and (ii) have sufficient storage freeboard for a 90th percentile wet year and any wave action without overflowing trap dams must be adequate [28]. Organics processing facilities might be required to sample groundwater in order to monitoring leaching and to safeguard water quality.

Local communities are aware that recycling and waste treatment is an essential component to urban community living. Opposition to the construction or expansion of organics recycling facilities is usually contained, unless there is a history of odour or other problems that affects the community. It is essential to provide the community with confidence that adequate environmental controls will be in place. Information must be provided on the positive benefits that the facility will bring, such as the provision of direct and indirect employment opportunities.

5.9 SET-UP TIME

Notwithstanding the fact that composting and anaerobic digestion are proven technologies, typical set-up times can vary significantly. For instance, a composting facility can take between one and five years from seeking planning approval to commissioning. Long delays can be caused by differences in opinion between the regulatory body and the applicant, and by community opposition to the planned development.

5.10 TECHNOLOGY BENEFITS AND BARRIERS

Composting is proven technology for processing, stabilising and pasteurising organic residues, and converting them into valuable products. Anaerobic digestion has been used for more than 30 years for processing municipal and commercial organics, with significant advances being made in dry digestion during the past 10 years delivering markedly lower investment and operating costs than in wet digesters. Adequate experience with these newer technologies has demonstrated that dry anaerobic digestion is also a proven organics processing technology.

Composting and anaerobic digestion facilities can operate for a short or long period, depending on investment, amortisation and depreciation. Machinery used in organics processing facilities is usually depreciated over a seven or eight year time frame, while buildings and fixtures are depreciated over 15 or 20 years. Facilities can expand and/or be upgraded either with more sophisticated composting technology, or with anaerobic digestion facilities, as was seen in several European countries over the past 10 years. Organics processing facilities are often established on the fringe of urban areas, where, over time they can face problems due to encroachment of residential areas.

Open windrow composting is a relatively cheap and versatile means of processing organic residues. Feedstock with a low proportion of putrescible components, such as garden organics, can usually be easily composted in open windrows, as long as rainfall is not excessive. The risk of odour and leachate emissions increases markedly with increasing levels of putrescible and wet residues being co-composted. And this is where advanced composting and digestion technologies become advantageous and might be prescribed by regulatory authorities.

As outlined previously, the size of organics processing facilities can vary greatly, ranging from small operations that handle only a few thousand tonnes per annum to those that can process 100,000 tpa or more. The vast majority of input material is converted into recycled organic products that are utilised beneficially for soil management purposes in urban or rural environments. Only a small proportion (1% - 10%) of input material, non-biodegradable impurities, cannot be recycled.

The nation-wide recycling of 5.8 million tonnes of organic residues in 2011 resulted in the recovery of plant nutrients representing 29,000 tonnes of urea, 2,900 tonnes of superphosphate and 14,500 tonnes of potassium sulphate [29].

In 2011, the Australian Organics Recycling Industry comprised approximately 120 businesses which had invested more than half a billion dollars, turned over around $600 million per year and employed the equivalent of 1,900 full-time people in addition to creating jobs in transport, distribution and product application [29]. These organics recycling activities also sequestered and abated more than 7.3 million tonnes of carbon dioxide equivalent of potential and actual GHG emissions, through diversion of organic matter from landfill, storage of carbon in the soil and avoided fertiliser use.

Life cycle assessment studies of various waste management options have shown that both organics recycling activities considered here are more favourable than landfilling. Anaerobic digestion is more favourable than composting from a GHG perspective due to the generation of surplus electrical and heat energy, while composting requires energy input in the form of diesel fuel and electricity. Virtually all plant nutrients contained in the input material remains available in the solid and liquid digestate for plant production and land management purposes.

In large urban areas, there is competition for feedstock between organics processing companies, as gate fees represent a significant source of income for such businesses. The affordability and competitiveness of advanced composting or digestion technology is largely determined by competing landfill costs and landfill levies, which are set by State Governments. For example, at this stage there are only open windrow composting facilities in South East Queensland due to low landfill costs and the lack of a landfill levy.

Composting and anaerobic digestion as a means of recycling municipal and commercial organic residues have a positive image within the community. Likewise, compost as a product has a positive image, as long as contamination levels are low.

However, there are some disadvantages and constraints to organics recycling via composting and anaerobic digestion:

- The most severe drawback is probably the risk of odour emissions causing environmental nuisance and complaints from neighbours.
- Processing of source segregated food and garden organics requires the establishment of a successful kerbside organics collection scheme with high participation and presentation rates, and low levels of contamination.

- Sophisticated composting and anaerobic digestion technologies often require sizable investments and incur high processing costs.
- Large quantities of surplus water can be a problem in wet digestion facilities.

Economic viability of anaerobic digestion facilities depend to some degree on returns for the sale of surplus electricity and available bonuses for renewable energy. Overall efficiency of anaerobic digestion facilities depends on the use/sale of surplus heat, which is difficult in Australia. This is exacerbated by the fact that AD facilities are often removed from housing and other industries.

5.11 EXISTING FACILITIES

According to the 2011 Organics Recycling Industry Statistics [10], there were 198 commercial organics processing facilities in Australia, 29 of which were located in Western Australia (see Table 5-1). These 29 facilities handled a total of 733,000 tonnes of organic residues, comprising, among other materials, about 200,000 tonnes of garden organics, 14,000 tonnes of source segregated food organics, 163,000 tonnes of organics in MSW, and 60,000 tonnes of biosolids, grit, oil, grease trap and organic sludges.

6 CASE STUDY DETAILS

On the basis of the selection criteria set out in Section 3.1, Hyder selected the organics processing facilities outlined in Table 14 to use as case studies.

Table 14 - Organics processing case studies

Type	Site	Location
Open composting	A	WA
In-vessel composting	B	NSW
Anaerobic digestion	C	Germany

This section provides a brief description of each facility, including the key features that make them representative case studies of best practice organics processing technologies, and how they satisfy the criteria set out in Section 3.1.

Case Study 1 – Site A, Open composting, WA

This composting facility is located in a rural area at the edge of an expansive metropolitan area in Western Australia. The privately owned composting facility was established in 1997 at Western Australia's largest intensive piggery. Since the late 1990's, piggery wastes have been co-composted with garden organics from the local community. This was accomplished with turned windrows, employing initially a tractor driven turner, and subsequently a self-propelled machine.

In 2009, the composting company assisted the local authority in a kerbside organics collection trial, covering 2,000 households, to demonstrate the feasibility of kerbside organics collections. In 2010 the composting company co-operated with their local Water Corporation to develop new processes, products and markets for composted recycled biosolids, which had been previously landfilled. This involved the research and investment in a mobile aerated floor composting system (Figure 14). This system was selected for its low capital cost, flexibility in use and adaptability to fit into the existing management systems. Design, simplicity, process control, cost of production and energy/GHG savings were all deciding factors. According to National Greenhouse Accounting rules for composting processes, employing this advanced composting technology saved over 6,000 tonnes per annum of CO_2 –equivalents. The project attracted funding under the Federal government's '*Re-Tooling for Climate Change*' program and enabled processing of 100% of the community's vegetation residues together with its biosolids.

The company holds two licenses, one for storage, reprocessing and treatment of liquid waste and one for compost manufacturing and soil blending. The operation accepts third party liquid wastes such as piggery and milk processing effluent, and currently has a nominal capacity to process 50,000 tpa of liquids together with 48,000 tpa of solid organic wastes.

Figure 14 - Mobile Aerated Floor (MAF) composting technology used for aerated pile composting (Source: http://www.maf-compostingsystems.de)

Case Study 2 – Site B, In-vessel Composting, NSW

This composting facility is situated in a local government area in North Eastern NSW covering about 10,400 km^2 and home to about 50,000 people. 2005/06 data showed a total of about 47,300 tonnes of waste was generated, with 19,400 tonnes being domestic waste. The average landfill diversion rate was 38.6%. A fortnightly garden organics kerbside collection service yielded 4,550 tonnes, and self-hauled garden organics amounted to 5,500 tonne.

The garden organics were composted at the regional landfill site, which has an extensive buffer zone. The new tunnel composting facility (3 tunnels) built at the existing composting site became operational in July 2012. It was established as a BOOT (Build – Own – Operate – Transfer) project.

To service the facility, existing kerbside collection services (weekly for residual waste and alternate fortnightly for recyclables and garden organics) were changed to provide weekly garden and food organics collection and alternating fortnightly waste and recycling collection.

Case Study 3 – Site C, Anaerobic Digestion, Germany

The anaerobic digestion facility described here is located in a rural district in northern Germany, covering around 2,200 km^2 and home to around 270,000 people. A kerbside collection service for garden and food organics was introduced in 1995. Although less than 50% of households made use of the organics collection service (they could gain an exemption from the otherwise mandatory service by undertaking home composting), about 22,000 tonne of food and garden organics was collected in 2007. This represented an average annual yield of 81 kg per capita, significantly higher than the average for Germany (50 kg per capita).

Initially employing only tunnel composting systems, the facility was expanded in 2008 by the installation of a mesophilic dry batch anaerobic digester system as well as additional composting tunnels. The system consists of ten garage-type digesters (28m long, 6m wide and 5m high) with a capacity of 30,000 tpa and five tunnel composting units of similar dimensions (25m long, 4.5m wide and 4.5m high) also with a 30,000 tpa capacity. A holding tank for percolation water (1,000 m^3), two combined heat and power units (525 kW each) and a biofilter were also established.

The anaerobic digestion process was selected on the basis of the following criteria:

- High tolerance towards elevated levels of impurities and sand,
- No pulping of feedstock, no automated transportation of materials, and no dewatering to ensure high reliability and low down time,
- Lower processing costs than those incurred by continuous digestion systems, brought on by lower maintenance, labour and energy costs,
- Positive energy balance.

Figure 15 provides an aerial view of the facility, and a diagram of the digestion process is presented in Figure 16.

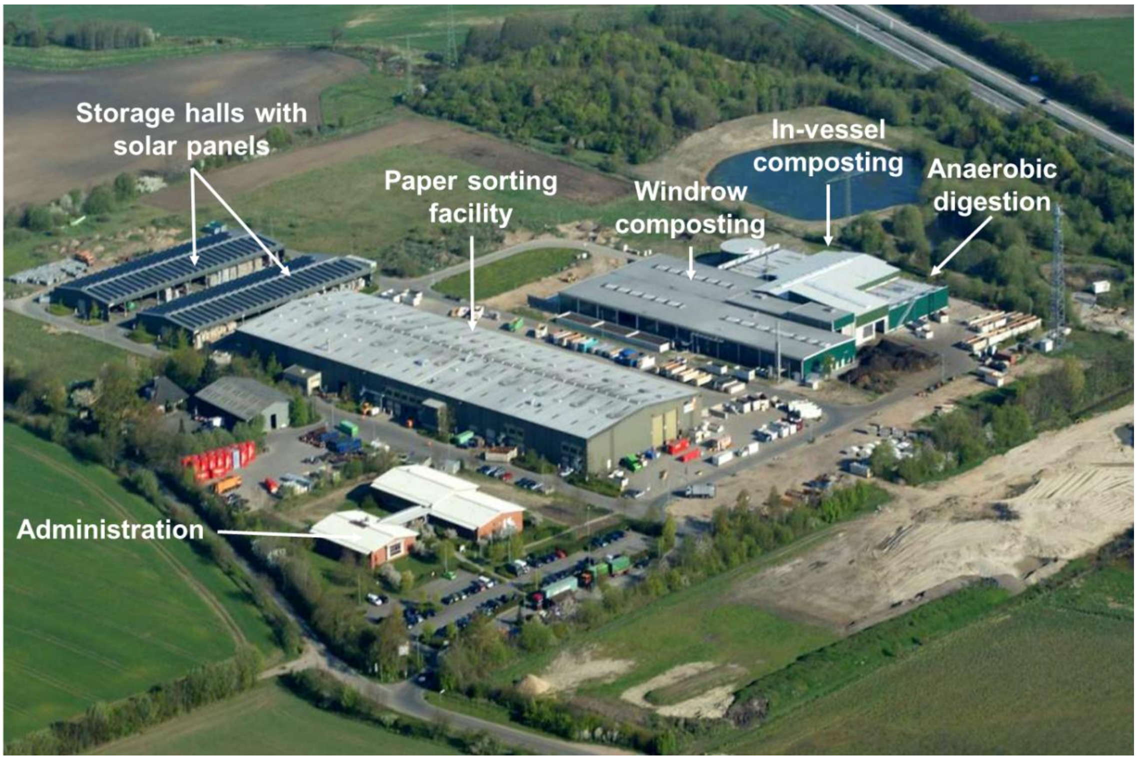

Figure 15 - Recycling centre incorporating organics processing facility with anaerobic digestion and in-vessel / open composting

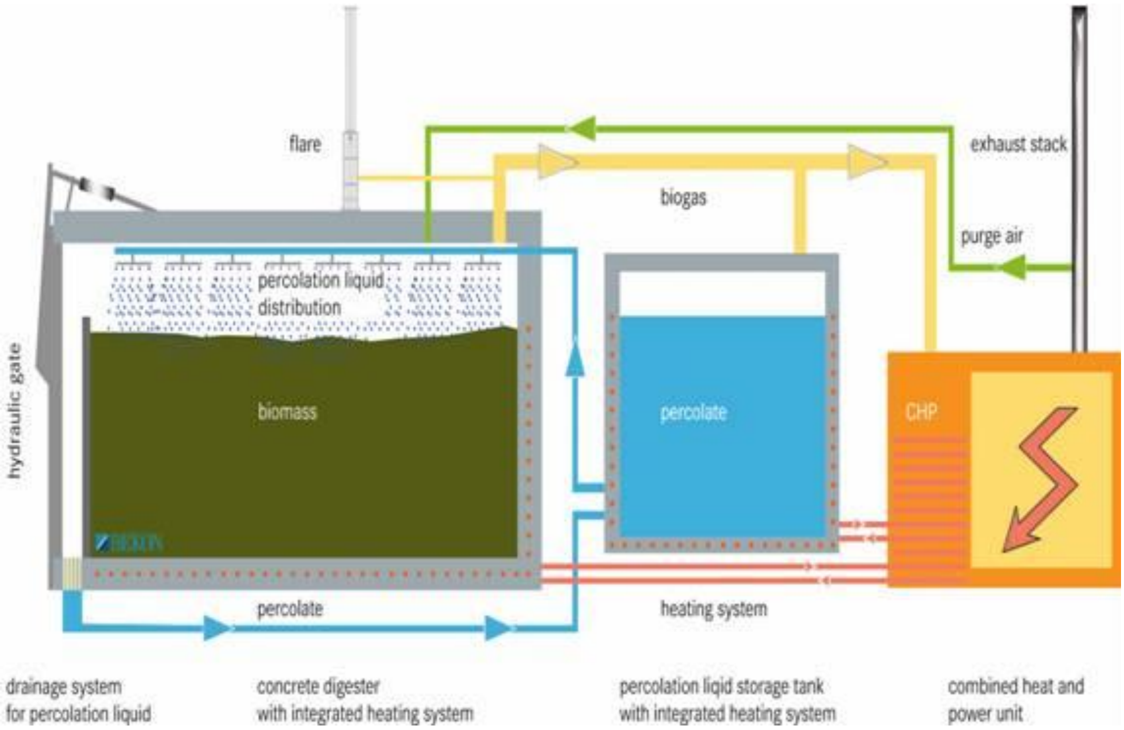

Figure 16 - Schematic view of BEKON dry discontinuous anaerobic digestion unit

The facility operator has advised that operational difficulties were initially experienced and this resulted in the incorporation of design changes as listed below in Table 15.

Table 15 - Differences between designed and actual operation of digestion and composting facility

Criteria	Design	Actual
Anaerobic Digestion		
Loading and unloading of digester	Wheeled loader	Wheeled loader
Total input per load into digester	460 tonne	400 tonne
Input fresh kerbside collected organics	230 tonne	230 tonne
Addition of digestate	50% (w/w) or 230 tonne	40% (w/w) or 170 tonne
Drainage inside the digester	No	Yes HDPE landfill drainage pipes
Gas yield	100 m^3/tonne	88 m^3/tonne
Amount of percolation water used	150 m^3 per batch	90 -110 m^3 per batch
Moisture content of digestate	64% - 70%	53% - 57%
Methane content of biogas	55%	55%
H_2S content of raw gas (before and after introduction of air into digester)	150 - 220 ppm	30 - 90 ppm
Operation of CHP units	Continuous use of both units	Increased capacity of one machine (625 kW), now

Criteria	Design	Actual
		alternating operation
Electricity production	6 Mio. kWh/a	< 5 Mio. kWh/a
Use of electricity (proportion of yield)	5 %	5 %
Use of heat (proportion of yield)	15 %	15 %
Output of CHP units	> 700 kW	< 600 kW
Plant availability	> 95 %	> 95 %
Composting		
Loading and unloading of tunnel	Wheeled loader	Wheeled loader
Total input per load into tunnel	230 tonne	200 to 210 tonne into two tunnels plus partially composted material
Proportion of digestate in input	100 %	60 %
Tunnel composting	Intensive composting of digestate for one week without introduction (inoculation) of partially composted material	Preliminary composting for one week, designed primarily to reduce moisture by about 40%; digestate is mixed with partially composted material
Windrow composting	Curing for 2 to 3 weeks	Intensive composting and curing for 2 to 3 weeks
Turning of windrows	Wheeled loader	Windrow turner
Pasteurisation	During tunnel composting	During tunnel and windrow composting
Type of compost generated	Mainly mature compost	Mainly mature compost
Status of compost quality assurance	Seal of approval for fresh and mature compost	Seal of approval for fresh and mature compost
Plant availability	100%	100%
Total organics processing facility[5]		
Digestion processing principle	Digestion of all incoming materials	Digestion of a proportion of incoming materials
Electricity use and costs[6]		750.000 kWh - $162,000
Diesel use and costs[2]		36.000 L – $64,800
Costs for maintenance and repair[2]		$337,500
Number of staff[7]	5	5.5

5 All figures are based on 2011 data when 35,200 tonne of input material was processed

6 Costs were converted from Euro to Dollars at an exchange rate of €1.00 = AUD1.35

7 Including replacement labour for holidays and sick days

7 SUMMARY OF WASTE TECHNOLOGY FEATURES

In the project brief, DER identified a number of key features and parameters to be identified for each technology type and case study. This information has been collated in the following summary (Table 16). By collating information in this standardised and summary format, a comparison of different recycling and waste management technologies should be simplified.

Table 16 - Summary Features – Organics Processing Technologies

Technology	1	2	3	4	5	6
	Process	Feedstock (type and tonnes)	Annual processing capacity (t/yr)	Place in waste hierarchy	Landfill diversion potential (%)	Products and residuals
Lit. Review Composting and Digestion	See Section 4.3.1	Blending of different feedstocks allows composting of virtually all organic residues as long as the feedstock mix is compatible with the composting process	From a few thousand to more than 100,000 tpa	Composting represents 'recycling' in the waste hierarchy.	Depending on the level of impurities contained in the feedstock, between 90% and 99% of material delivered to the facility is diverted from landfill	Recycled organic products, comprising compost, mulch, soil blends, growing media. Residuals are non-biodegradable impurities contained in the feedstock.
	See Section 4.3.2	Wet digestion: Liquid and wet feedstock, sludges. Addition of water might be necessary to create pumpable substrate. Dry digestion: Drier organic residues, including kerbside collected food/garden organics.	From about 10,000 tpa to more than 100,000 tpa	Anaerobic digestion represents 'recycling' as well as 'energy recovery' in the waste hierarchy.		Recycled organic products as above, plus liquid digestate, electricity and heat. Residuals are non-biodegradable impurities contained in the feedstock.
Organics Processing A, Open Composting, WA	Solid and liquid organic residue processing facility with ISO 9001 certification. Open aerated pile composting Process consists of: ▪ Incoming materials are assessed and	Most organic waste streams and some inorganic waste steams can be processed. A risk management process is conducted for each prospective feed. Chemical and physical contaminants are the	Licensed for 125,000 tpa of solid waste and 60,000 tpa of liquid waste. Current nominated throughputs are 50,000 t and 50,000 t respectively. Solid waste throughput	The facility recycles organic residues as products for direct beneficial re-use in soil management and as inputs for further value-adding processes.	>99.5% of the inputs are recycled. Less than 0.5% goes to landfill and this represents the physical contaminants which are screened out during the process. Diversion is dependent upon the quality of input	The quality of the feedstock will determine the end use and market. A range of composted products are manufactured. Typically these are mulches, used on the soil surface,

Technology	1 Process	2 Feedstock (type and tonnes)	3 Annual processing capacity (t/yr)	4 Place in waste hierarchy	5 Landfill diversion potential (%)	6 Products and residuals
	weighed ▪ Materials might be stored temporarily ▪ Various materials are blended and mixed ▪ Blended material is established in aerated pile and composted until ready for use ▪ Screening Production of quality assured fit-for-purpose composted products. Technology used has been turned windrows with recent conversion to aerated static piles.	most likely reason to reject a waste stream. Generally, all organic components can be composted. Even hydrocarbons and other problematic organic molecules can be broken down with the correct process. The technology employed can be used for kerbside collected source separated organics.	can be increased considerably with relatively low capital investment which will reduce the capital cost per tonne of waste processed.		materials.	and soil conditioning products used to build soil. Value-added products are also manufactured using the composted products as feedstock for other manufacturing process. There are very few residuals.
Organics Processing B, In-vessel Composting, NSW	Kerbside collected food and garden organics processing facility. The facility uses 3 aerated tunnels with SCADA process control system. The receivals	The facility can accept most organic material including garden and food organics from both domestic and commercial sources. Biosolids are not	Currently the facility processes 8,000 tpa, but has a capacity to handle 12,000 to 14,000 tpa.	The facility recycles organic residues from municipal and commercial sources that would otherwise go to landfill.	All incoming material except for physical contaminants is diverted from landfill. Residual waste from the facility accounts for less than 1% of the feed.	Compost is the primary product (representing 99% of the feed). Residuals disposed to landfill represent 1% of the feed (the contaminants)..

Technology	1	2	3	4	5	6
	Process	Feedstock (type and tonnes)	Annual processing capacity (t/yr)	Place in waste hierarchy	Landfill diversion potential (%)	Products and residuals
	area is covered and a biofilter incorporated. The shredded organic material remains in the tunnel for a minimum of 14 days. Composting/ pasteurising managed by an automatic control system. The material is then placed in open windrows for curing for a minimum of 21 days, after which it is screened to remove oversize material. All handling of the organic material is done by a loader.	currently processed although the facility is capable of doing so.				
Organics Processing C, Anaerobic Digestion, Germany	Combined anaerobic digestion and composting facility. Kerbside collected organics are mixed with digested material and digested without pre-processing in a garage-type batch dry digester	Feedstock is comprised almost exclusively of kerbside collected garden and food organics. A small quantity of shredded garden organics is utilised via composting. No biosolids or other	Currently the facility has a digestion capacity of 30,000 tpa and a composting capacity of 40,000 tpa. Processing technology for both technologies will be increased to 50,000 tpa. In 2012, 42,000 t of	The facility recycles municipal garden and food organics which otherwise would go to landfill. Biogas is converted into electrical and heat energy, which are used on-site and off-site.	94% of all incoming material is recycled and utilised, while 6% are impurities and rejects that are sent to landfill.	The organics recycling facility generates the following products annually: Electricity: ca. 5 million kWh Heat energy: ca. 6 million kWh Compost: 14,000

Technology	1	2	3	4	5	6
	Process	Feedstock (type and tonnes)	Annual processing capacity (t/yr)	Place in waste hierarchy	Landfill diversion potential (%)	Products and residuals
	for 4 weeks. Subsequently, the material is mixed with partially composted material and composted in aerated tunnels for one week. Afterwards, the material is composted for further 2 to 3 weeks in open windrows, before it is screened.	sludges are processed. Commercial organics are also not processed since generators of energy-rich residues are able to sell such materials to commercial digestion plants, or at least dispose of it for free, while the council owned facility has to charge standard processing fees. Input materials are not pre-processed, but digester input is mixed with digested material and compost input (tunnel) is mixed with composted material.	input material was processed. 30,000 t of kerbside collected organics were digested and 10,000 t of kerbside collected organics plus 1,500 t of garden organics by-passed digestion and were only composted. Hence, the facility operates a ‘partial digestion system’ which is necessary for operational reasons.			tonnes Firewood: 500 tonnes Impurities: 2,500 tonnes (6% of 35,000 tonnes)

Technology	7 Markets and end use	8 Capital costs
Lit. Review Composting Digestion	Composting operations generate pasteurised, composted or matured compost and mulch products for a range of diverse markets. See Section 5.4	$52 - $97/t for windrowing, $100 - $200/t for enclosed windrowing, $100 - $400/t for in-vessel composting. See Section 5.6.1
	Most anaerobic digestion facilities generate compost and liquid digestate or liquor. Furthermore, anaerobic digestion facilities generate also biogas, which, in most cases is turned into electrical and/or heat energy. See Section 5.4	$100 - $800/t See Section 5.6.1

Technology	7 Markets and end use	8 Capital costs
Organics Processing A, Open Composting, WA	Composted products are used as follows: 50-60% urban amenity, including for parklands and sporting facilities 30-40% agricultural and horticultural applications 10% environmental – rehabilitation and bioremediation. Well composted products can improve the water holding properties of sandy soils, and enhance nutrient use efficiencies, resulting in a marked reduction in rates of fertiliser use. These combined benefits deliver protection of groundwater resources in irrigated systems and the avoidance of wasteful and potentially polluting nutrient leaching. Value added products that can be used at 'micro' rates of 50 kg/ha in cereal crops are also available. These products allow farmers to reduce the application of inorganic fertiliser by 50%. Cost savings pay for the recycled organic product.	TOTAL COST OF PRODUCTION Actual costs can vary widely. The estimated production costs using open turned windrows are \$25-\$45/m^3 of finished product. Assuming bulk density of 0.6t/m^3, loss of 40% of the input materials and production costs of \$35/m^3, this represents about \$21.50/m^3 of input material. It costs more to produce mature than pasteurised compost products because it takes longer and because shrinkage is higher (there is less final product to 'pay for' higher costs). On the other hand, mature products have a greater market value and a higher environmental value in terms of water and nutrient use efficiency in the receiving soils. The company believes that, compared to windrow composting, use of aerated static piles delivered identifiable savings of 10% on the costs of production: • Reduced finance and depreciation costs of equipment • Fuel savings (ca. 1,000 L per week) • Repairs and maintenance. The operator estimated that investment costs can be recovered within 3 years. Other important cost savings are space utilisation efficiency (only half the space is needed) and reduced labour costs. CAPITAL COSTS SEPARATE FROM TOTAL COSTS Capital costs can be 20-30% of production costs so if production costs for a turned windrow are \$35/ input tonne then the capital component of this should be \$7-\$10/input tonne. Capital costs for the aerated pile system range between \$8 and \$15/t, depending on efficiency of equipment utilisation.

Technology	7 Markets and end use	8 Capital costs
Organics Processing B, In-vessel Composting, NSW	Bulk landscaping	Capital costs for establishing the facility amounted to \$6m, or about \$750 per tonne input at 8,000 tpa, and \$500 at 12,000 tpa.
Organics Processing C, Anaerobic Digestion, Germany	90% of the compost generated is supplied into agriculture for free or for a token price (e.g. \$1/m^3). The operator plans to increase the price slowly, to recoup more of the inherent value of compost which amounts to between \$27 and \$40 per cubic meter. The retail price for compost is \$17.55/m^3. To date there has been only one instance requiring the disposal of excess water. Usually water is evaporated in the composting process during dry periods. Electricity and heat energy is used within the entire recycling centre.	Capital costs for building the anaerobic digestion facility, including five composting tunnels in 2007 amounted to around \$6.75 million. This equates to capital costs of \$225 per tonne input. Costs for rectifying shortcomings in the design of the facility are not known.

Technology	9	10	11
	Operating costs	Gate fees	Set-up timeframe
Lit. Review Composting Digestion	Without depreciation & finance: $13 - $35/t for open windrowing $24/t for enclosed windrowing $40 - $135/t for in-vessel / enclosed composting Depreciation & finance amounted to $25.74 or 29.6% of total processing cost in one example See Section 5.6.1	No information	One to five years
	Dry digestion: $27 - $38/t $60 - 90/t with capital costs $55 - $60t when income from sale of products is considered See Section 5.6.1	No information	No information

Technology	9	10	11
	Operating costs	Gate fees	Set-up timeframe
Organics Processing A, Open Composting, WA	OPERATING COSTS (separate from Total Costs) Operating costs are estimated to range between $20 and $28/t of input material. However, the above costs do not include overhead costs for staff training, office services, sales, marketing and other administration costs. As a rule of thumb these can be 50% of production costs. So to calculate the real costs of getting a product to market and servicing the customers another $10-$14/ tonne of input should be added. This gives a total cost per tonne of input material of : Operational $20-$28 Capital $7-$10 Overheads $10-$14 TOTAL $37-$52	Gate fees vary from $30/t to $100/t depending on the type and quantity of material and the degree of difficulty in processing. Most wastes are in the range of $30 to $70/t	If building today, it is expected that a new facility can be developed in 2 – 4 years. Expected process is; ▪ Acquire land: 12 -24 months ▪ Design and drawings: in parallel with land acquisition ▪ LGA planning and building permissions: 6-12 months ▪ DER Works approval/ building/ DER licensing: 12-24 months
Organics Processing B, In-vessel Composting, NSW	Operating costs amount to approximately $70 per tonne.	Gate fee for self-haul garden organics is $100 per tonne	Design, approval, construction and commissioning took only 12 months. It should be noted the process was expedited since an open windrow composting facility previously existed on the site.

Technology	9	10	11
	Operating costs	Gate fees	Set-up timeframe
Organics Processing C, Anaerobic Digestion, Germany	Operating costs amount to approximately $60 per tonne input	The gate fee for self-hauled organic residues amounts to $70 per tonne. The fortnightly kerbside organics collection service, which includes processing, incurs the following annual costs, Residents: 120 L: $40.50 240 L: $76.14 Commercial: 120 L: $34.02 240 L: $64.00 660 L: $242.00 (only light material)	It should take two to three years to establish the facility. Planning and obtaining building and operating permits should take one to two years, the construction phase should take about one year, and start-up and commissioning should take six to twelve months.

Technology	12 Lifespan	13 Technology/ facility footprint	14 Buffer zones	15 Emissions	16 Environmental impacts
Lit. Review Composting Digestion	Composting and anaerobic digestion facilities can operate for short or long periods. Machinery used in organics processing facilities is usually depreciated over a seven or eight year time frame, while buildings and fixtures are depreciated over 15 or 20 years.	Windrow composting: 0.5 – 1.5 m^2/t input In-vessel composting: 0.1 – 1.3 m^2/t input Dry anaerobic digestion: 0.15 – 0.4 m^2/t input Wet anaerobic digestion: 0.1 – 0.25 m^2/t input	Buffer zones are a regulatory requirement around organics processing facilities, with the extent of the buffer specified by the jurisdiction on a case by case basis during the planning approvals stage. Environmental regulations usually stipulate minimum buffer zones.	Composting can generate leachate, which has high organic and nutrient loading, and has to be captured and treated or re-used. Run-off from the composting pad during rain periods has to be captured and re-used also. Gases emitted during the composting process comprise primarily CO_2 and water vapour. However, the following gases can be emitted also: CH_4, N_2O, CO, H_2S, and trace gases including odourous compounds. CH_4 emissions from anaerobic digestion facilities can be higher than those from composting operations, due to gas leakage and handling of anaerobic material outside the digester. Exhaust air from in-vessel and fully enclosed facilities is usually purified by means of a biofilter, possibly also by an acid scrubber.	The main potential detrimental environmental impacts from organics processing facilities are emissions to air (GHG, odour, ammonia, dust, bio aerosols), to ground and surface water (leachate, run-off), and to a lesser degree to land (windblown debris). Recycling and use of recycled organic products for land management and soil improvement purposes also have significant beneficial effects. Environmental benefits obtained through anaerobic digestion are even higher as this technology also provides electrical and heat energy, thereby avoiding the use of fossil fuels.

Technology	12 Lifespan	13 Technology/ facility footprint	14 Buffer zones	15 Emissions	16 Environmental impacts
Organics Processing A, Open Composting, WA	The expected lifespan of the facility is 30-50 years. The facility was built in 1997 and is operating today. A similar facility built in 1990 in Victoria is still operating. The simple design, technology and construction mean that the facility is adaptable to process improvements and new changes in technology. Footprint and capacity expansion can be achieved by relatively simple means.	The composting facility has an 8 ha hardstand area and water storage covers about 5 ha. The recent change in processing technology from turned windrows to aerated static piles means that the facility is currently greatly under-utilised. The area leased for the composting operation is about 80 ha on a rural property of about 400 ha.	The design buffer for windrow composting was 1000m. The owners anticipated encroachment over time would result in pressure to invest in improved composting technology to avoid creating an odour nuisance. This led to the aerated static pile composting. It would be possible now to reduce the width of the buffer zones.	There are no liquid or solid discharges from the facility. The rural location provides a good buffer. Improving technology (aerated piles) will reduce the risk of nuisance odours in the future. Through a *Re-Tooling for Climate Change* project, 7,000 tpa of CO_2-e avoided GHG emissions were demonstrated.	The facility complies with the usual range of compliance conditions stipulated in the DER licence. These include monitoring ground water bores and reporting of volumes processed.
Organics Processing B, In-vessel Composting, NSW	Minimum of 20 years	The footprint of the building that houses the composting tunnels is 1,750 m^2, while the whole site measures approximately 12 ha. The remaining site area provides space for windrows and compost storage, leachate and stormwater management and a leachate irrigation area.	The minimum buffer zone is 500 metres, which is easily exceeded at this site.	Leachate from the open maturation windrows is the main emission of concern which needs to be managed. The estimated carbon impact is 4.3 tonnes of CO_2-e per 100 tonnes of organic residues processed.	The EPA Licence stipulates operating conditions. Key monitoring and operating requirements are the type and maximum quantity of wastes that can be received, leachate quality & discharge rate, stormwater quality, noise levels, dust emissions and effluent application to land. The key compliance issue is leachate management. The bio-filter controls odour emissions.

Technology	12	13	14	15	16
	Lifespan	Technology/ facility footprint	Buffer zones	Emissions	Environmental impacts
Organics Processing C, Anaerobic Digestion, Germany	25 years	3 ha	The distance to residential properties has to be at least 500 m. The facility satisfies this criterion.	Excess percolation water, leachate and run-off are not discharged but collected on-site and re-used. Gaseous emissions that have detrimental environmental impacts comprise CH_4, N_2O and NH_3. (NH_3 emissions are considered a problem as it is a poisonous gas that contributes to soil acidification and eutrophication of water bodies.) A federally funded study demonstrated that the most environmentally friendly means of processing kerbside collected garden and food organics is anaerobic digestion. Voluntary benchmarking has shown that the facility has higher CH_4 emissions than expected, mainly due to the discontinuous operation of the digester, and leakage of biogas with low CH_4 content.	Environmental impacts are minimal due to collection and re-use of all effluent, exhaust air purification via a biofilter, and use of a flare for burning biogas with low methane content. There are plans to equip the facility with 2,000 m^3 gas storage, to allow blending of methane-rich and methane-poor gas.

Technology	17	18	19	20	21
	Social impacts	Integration into a wider waste management strategy	Risks	Location	Maturity of technology
Lit. Review Composting Digestion	In 2011, more than 6.3 million tonnes of municipal, commercial and agricultural organic residues were processed and converted into valuable products. This activity saved landfill space, recovered large quantities of plant nutrients and sequestered / abated more than 7.3m tonnes of CO_2-e of potential and actual GHG emissions. In the same year, the Organics Recycling Industry had invested more than half a billion dollars and employed the equivalent of 1,900 full-time people in addition to creating jobs in transport, distribution and product application.	Source separation of municipal and commercial garden and food organics in combination with composting / anaerobic digestion and the subsequent beneficial use of compost, has become a key part of a modern integrated waste management system. Source segregation and recycling of organics is an important tool for reducing the amount of waste that is landfilled, and for reducing the detrimental environmental effects of landfills.	Risks for compost facilities: • Odour emissions • Leachate and run-off polluting ground and surface water • CH_4 emissions from poorly managed processes. • Low competing landfill prices • Insecure feedstock supply • Lack of gate fees • Prolonged severe weather • Compost market failure • Competition from cheap manures • Fire Risks for AD facilities: • Odour emissions (less than composting) • GHG emissions from CH_4 leakage • Fire or explosion from CH_4 leakage The financial risks are similar to those for composting, but might be reduced due to additional revenue generated from the sale of electricity.	Composting facilities processing primarily organic residues from urban sources are usually located at the fringe of urban areas, sometimes adjacent to landfills or other recycling facilities. There are examples where anaerobic digestion facilities were established in industrial estates, but this might not be ideal where digestate is composted. Digestion facilities are often co-located at composting facilities.	Composting is a very mature and well proven technology for the conversion of a wide range of organic residues into valuable products. The composting technologies considered here, i.e. windrow, tunnel and aerated pile composting, have been deployed and used successfully many times. Anaerobic digestion of liquid and solid organic residues is by now an equally well established organics processing technology. Significant advances with dry digestion technologies have been made over the past 10 years.

Technology	17	18	19	20	21
	Social impacts	Integration into a wider waste management strategy	Risks	Location	Maturity of technology
Organics Processing A, Open Composting, WA	The facility is located on a rural property in order to better manage the increased risk to the community of traffic and odour impacts. The operation provides full time employment for 25 people as well as local contractors. They host visitors and actively engage in local economic, environmental and social initiatives, participating in local committees and events. (The local senior high school run a part of their curriculum on-site, providing students with the opportunity to engage in agricultural and environmental projects.)	The company is built on long-term strategic relationships and provides reliable recycling services to many commercial clients, including the food industry. These services have extended to businesses in the waste management sector., and the operator expects the emerging push towards diversion of organic waste from landfill will create a need for local government to form increasing direct relationships with service providers.	Urban encroachment Change in government policy can have unintended consequences Poor management that sensitises neighbours The low capital cost lowers the commercial and financial risk. The simplicity of the system and the training which is readily available minimise the technical risk and the need for highly skilled operators to run the plant. The plant can be operated by staff competent in machine operation and farming or growing crops.	This type of operation should be conducted on the urban fringe or in rural areas. It should be noted that the facility's life may be reduced as population grows and encroachment occurs.	Experiences for over 30 years in making compost using windrows and turning technology demonstrates the maturity of the technology and the operators. The owner's Victorian operation, built in 1990, is still operational. The facility has been operating for over 15 years using turners. The aerated pile composting system was introduced 3 years ago. This system has been used commercially overseas since the 1970's. There are more than 10 facilities using the same technology in Australia. The system is robust, reliable, and easy to maintain and operate.
Organics Processing B, In-vessel Composting, NSW	The composting facility does not have any known negative impacts on the community. It provides employment for approximately 5 full time staff, plus indirect employment within the community.	The organics processing facility is a key component of an integrated waste and recycling collection and processing system. This includes a 3 bin kerbside collection service with a	The key risks for the composting facility are: • management system failure, • high contamination levels, • lack of products market,	The facility is considered suitable for any area that has a minimum of 6,000 tonnes of organic feedstock per year available, and an appropriate area for locating the composting operation. The	This tunnel composting facility has been operational for 11 months. However the technology is very mature, with tunnel and box composting systems having operated in Europe and North

Technology	17	18	19	20	21
	Social impacts	Integration into a wider waste management strategy	Risks	Location	Maturity of technology
		weekly organics collection covering also food organics. The strategy is currently diverting 66% of domestic waste from landfill. Key drivers for the strategy are the State landfill levy and the carbon pricing mechanism.	• excess leachate.	facility can be located at a landfill site, as long as the ground does not subside.	America for at least 20 to 30 years. There are at least three other operating tunnel composting facilities in Australia, and two more are being designed or build.
Organics Processing C, Anaerobic Digestion, Germany	To date, the facility has not caused any known negative impacts on the community. As evidenced by the fact that no objections were raised against plans to expand the processing capacity to 50,000 tpa. The anaerobic digestion facility enjoys a very positive image in the community. The facility provides employment, renewable energy, and taxes for the local authority.	The anaerobic digestion facility is an integral part of the Shire's waste management and recycling strategy. The organics processing facility supports the mandatory use of the organics bin, which was introduced in 1995. Segregation of organics at source in combination with AD results in low organics collection fees, and reduced overall waste management and recycling charges. Source segregation and processing of organic residues supports legislation that prohibits landfilling of	The facility does not see any specific risks, as long as it is able to comply with all legal and regulatory requirements. So far, this has been achieved. Security of feedstock supply is seen as the main operational risk. Commercial AD facilities are able to source energy-rich feedstocks by offering low or no gate fees, or even pay the supplier for delivering them. This is not an option for the publicly owned facility.	The operators consider it possible to establish an anaerobic digestion facility in a business park or an industrial area, as long as the distance to residential properties is at least 500 m and 300 m to commercial buildings.	This anaerobic digestion facility has been operational since the end of 2008. Although batch dry digestion technology (garage-type systems) is a more recent development, it has been readily accepted by the market. The technology supplier for this facility (BEKON) has installed another 23 facilities over the past six years. Comparable dry digestion systems are available from a number of suppliers.

Technology	17	18	19	20	21
	Social impacts	Integration into a wider waste management strategy	Risks	Location	Maturity of technology
		non-stabilised waste materials. Generation of electricity via anaerobic digestion takes advantage of price premiums for electricity supply from renewable resources. The existing organics collection and processing system could be further improved through the following measures: Mandatory use of organics bins for residents and businesses without ‘easy’ exemptions, Mandatory energy generation from kerbside collected organics Mandatory installation of gas storage capacity to reduce methane leakage			

Technology	22	23	24	25	26
	Availability	Penetration	Benefits	Barriers / constraints	Other
Lit. Review Composting Digestion	Due to open composting's flexibility and simplicity, availability is commonly 100%. Forced and scheduled repair and maintenance shut-downs increase with increasing technology sophistication. The more moving parts the technology has, the greater the likelihood of break-downs. Emergency plans en sure incoming material is composted by other means, or diverted to other processing facilities. Continuous AD facilities have to be shut down regularly for maintenance. Modular batch systems can be maintained without shutting down the entire facility. Biological imbalance (acidification) can force the shut-down of wet AD facilities, and necessitate emptying the digester to allow for a new process start up.	There are 198 commercial composting facilities in Australia and 29 in Western Australia, the vast majority of which employ open windrow composting. Although anaerobic digestion is widely used in Europe for the processing of source segregated municipal and commercial organic residues, at present there is only one such facility operational in Australia, and a second one is under construction. Both Australian facilities are wet digesters: no dry digester operate in Australia yet	**Benefits of Composting:** ▪ Sizable reduction of waste going to landfill ▪ Prevention of detrimental emissions from landfills (leachate, GHGs) ▪ More sustainable, and often cheaper waste management ▪ Conversion of 'waste' into valuable products ▪ Generation of employment and business opportunities ▪ Recycling of plant nutrients and carbon ▪ Horticultural and agricultural benefits through soil improvement. ▪ GHG emissions reduction **Additional benefits of AD:** ▪ GHG emissions reduction ▪ Small footprint ▪ Renewable heat and electrical energy ▪ Liquid digestate provides nutrients in a form readily available for plants	Disadvantages and constraints to organics recycling via composting and anaerobic digestion are: ▪ Odour risks ▪ Processing of source segregated food and garden organics requires the establishment of a successful kerbside organics collection scheme ▪ Sophisticated composting and anaerobic digestion technologies often require sizable investments and incur high processing costs ▪ Surplus water from wet digestion systems ▪ The price which can be agreed for electricity sales ▪ The availability of a local market for heat energy.	

Technology	22 Availability	23 Penetration	24 Benefits	25 Barriers / constraints	26 Other
Organics Processing A, Open Composting, WA	The MAF aeration system can be operational 100% of the time. The low system cost means it is possible to carry a large spares inventory. The design of the system uses parts which are readily available throughout Australia. This makes it particularly appropriate for regional and rural communities.	Apart from this facility, which operates in the Perth/Peel region, there are another 10 or so facilities around Australia using the same aerated pile composting technology. This network of operators is a useful source of information and process improvement ideas	The carbon in organic residues represents energy captured from the sun by plants. Returning this energy to the soil to drive microbial processes and create a healthy soil is vital for soil health and productive farming. Benefits increase with mature compost. Additional benefits include better use of scarce water resources and reduced use of fossil-fuel intensive artificial fertilisers and pesticides.	Composting is technically undervalued and perceived to be a simple “agricultural” process. Competition from MBT facilities which do not require high levels of source separation in the community. Note that the operator perceives MBT organic products as not being of the same level of quality. Energy from waste plants are seen by the operator as potentially competing for feedstock.	
Organics Processing B, In-vessel Composting, NSW	As the facility operates three tunnels which are independent of each other, there should be no maintenance requirements that would require total shutdown.	None of the 29 composting operations in WA employ tunnel composting technology. However, there are at least three other operational tunnel composting facilities in NSW and Victoria, and two more are being designed or built.	Mature, simple technology. Flexibility of increasing capacity by adding additional tunnels.	Relatively high costs for smaller communities and the need to develop markets for compost products are seen as major barriers for the uptake of this technology.	

Technology	22	23	24	25	26
	Availability	Penetration	Benefits	Barriers / constraints	Other
Organics Processing C, Anaerobic Digestion, Germany	Overall availability is 100% for composting and > 95% for anaerobic digestion. The modular nature of both the anaerobic digestion and the composting systems provide the opportunity to carry out maintenance work successively without the need to shut down the entire facility. Regular maintenance is required for the combined heat and power unit, but this does not affect operation of the AD system.	To date, no dry, discontinuous anaerobic digestion facility is operating in Australia.	The benefits and advantages of this AD technology compared to others are: ▪ Very robust, can tolerate impurities and sand ▪ It is a 'low-tech' AD facility ▪ No pre and post processing required ▪ Apart from the AD system itself, it is possible to employ standard machinery such as wheeled loader, screen, and windrow turner. ▪ Use of modular 'garage-like' fermenters provide a great deal of flexibility. ▪ Relatively low investment and operating costs compared to other treatment options.	The main barriers for the uptake of this technology are seen as: ▪ Prejudice ▪ Lack of knowledge concerning state of the art anaerobic digestion when organics processing technologies are chosen. ▪ Processing of organic residues via dry anaerobic digestion is more expensive than composting.	Important aspects for the successful establishment and operation of the AD facility: ▪ Good and diligent supervision of construction actives ▪ Start-up through skilled and experienced staff Depending on the proportion of food and garden organics, woody vegetation residues should by-pass the digestion phase and be composted only.

8 STUDY SYNOPSIS

Technology	1	2	3
	Process	Feedstock (type and tonnes)	Annual processing capacity (t/yr.)
Organics Processing Technology Synopsis	Composting represents the degradation and stabilisation of organic residues in controlled aerobic conditions, while anaerobic digestion is the equivalent in anaerobic conditions. Both processes are driven by sequential bio-chemical reactions that are governed by the availability of food substrates and energy (carbon) and environmental conditions (moisture, oxygen, temperature, pH). The various composting and digestion technologies aim to provide optimum conditions for these biochemical processes, and to accelerate them. The composting process can take place entirely in the open (windrow and pile composting) or the initial decomposition phase can take place in enclosed buildings or vessels. Fundamentally, the processing steps in all composting facilities are similar: (i) delivery and weighing, (ii) extraction of impurities and particle size reduction (both optional), (iii) blending and preparation of feedstock, (iv) intensive composting, (v) maturation, (vi) screening and extraction of impurities, (vii) value adding and sale. Anaerobic digestion facilities comprise the following additional processing steps: (i) addition of water to feedstock / percolation, (ii) dewatering, (iii) use of liquid digestate, (iv) purification and use of biogas via CHP unit.	The type of organic residues an organics processing facility can accept and handle are determined by the facility's approvals and licence. In turn, the risk profile of feedstock that can be processed, governs the licensing and operating conditions. The ability to blend different feedstock materials combined with the significant loss of moisture during the composting process makes composting a very versatile option for processing a wide range of solid and liquid residues. The showcased open composting facility for example processes roughly the same amount of solid and liquid input materials. However, liquid and very wet feedstock is better suited for wet anaerobic digestion. Kerbside collected garden and food organics can be composted or they can be processed via dry anaerobic digestion. Garden organics and vegetation residues are best suited for composting, particularly if they contain a high proportion of woody components. Depending on feedstock and processing technology, it might be necessary to extract impurities and reduce particle size. In the case of anaerobic digestion, water might have to be added	The annual processing capacity is determined by the facility's development approval and license. There are no regulatory limits on the actual processing capacity of a facility, as long as the environmental management plan can demonstrate that the operation will not have significant detrimental effects on the environment. The actual size of operations is most likely determined by the availability of adequate land, supply of feedstock, willingness of suppliers to pay a gate fee, and markets with propensity to pay for products. The current annual processing capacities at facilities that were showcased ranged between 8,000 and 48,000 tpa. The average annual processing capacity of commercial composting facilities in Australia is 32,000 tpa.

Technology	4 Place in Waste Hierarchy	5 Landfill diversion potential (%)	6 Products and residuals
Organics Processing Technology Synopsis	Composting and anaerobic digestion represent organics recycling activities. The separate collection and composting/digestion of municipal and commercial organic residues represent a key component in reducing the amount of waste going to landfill. Organic recycling activities recycle plant nutrients and organic matter (or carbon), mimicking natural nutrient and carbon cycles. In addition, anaerobic digestion also supplies renewable energy via the generation of biogas, which is subsequently used for electricity and heat generation, or as fuel.	Between approximately 90% and 99% of all source segregated organic residues that are delivered to organics processing facilities are utilised and diverted from landfill. The level of non-biodegradable impurities in the input materials determines the amount of materials that cannot be recycled and have to be landfilled. Impurity levels at facilities that were showcased ranged between 0.5% and 6%. The level of landfill diversion as a proportion of the entire waste stream is governed by the success of the collection scheme, but is independent of the chosen processing technology.	Composting facilities generate various compost and mulch products, which can be used as generic products, or blended and value-added. Anaerobic digestion facilities usually compost solid digestate to create compost products. Liquid digestate is mostly utilised as liquid fertiliser in agricultural applications. The biogas generated is usually converted into electricity and heat energy, although it is possible to utilise it as fuel for vehicles, or to feed it into the gas grid. Residuals are mainly comprised of impurities, rocks, and oversize pieces of wood. These materials are often stockpiled on-site or disposed of at landfill. Leachate at composting sites is usually re-used and evaporated via the composting process. Surplus water at wet digestion facilities has to be processed on-site or off-site before it can be discharged. Both composting and digestion facilities emit gases, such as methane, nitrous oxide, ammonia, and trace gases, including odorous components.

Technology	7	8	9
	Markets and end use	Capital Costs	Operating Costs
Organics Processing Technology Synopsis	Composting operations generate pasteurised, composted or matured compost and mulch products for a range of diverse markets. Most anaerobic digestion facilities generate compost and liquid digestate, as well as biogas, which is usually turned into electrical and heat energy. The three showcased facilities supply the urban amenity market (55%, 100%, 10%), agricultural and horticultural markets (35%, 0%, 90%) and the rehab and bioremediation market (10%, 0%, 0%).	The literature suggested the following capital cost: <u>Composting</u>: Windrowing $52 - $97/t Enclosed windrows $100 - $200/t In-vessel composting $100 - $400/t <u>Anaerobic digestion</u>: $100 - $800/t The showcase facilities provided the following capital cost estimates: Open composting (cost of production) - windrowing $35.80/t - aerated pile composting $32.20/t In-vessel composting $600/t Anaerobic digestion $225/t	The literature suggested the following operating costs (without depreciation & finance costs): <u>Composting</u>: Windrowing $15 - $35/t Enclosed windrows $24/t In-vessel/enclosed composting $40 - $135/t <u>Dry anaerobic digestion</u>: $27 - $38/t The showcase facilities provided the following operating cost estimates: Open composting (without capital costs) - windrowing/aerated pile $32 - $46/t In-vessel composting $70/t Anaerobic digestion $60/t

Technology	10 Gate Fees	11 Set-up timeframe	12 Lifespan
Organics Processing Technology Synopsis	Gate fees vary depending on the type and quantity of material and the degree of difficulty in processing. Generally speaking, gate fees at organics recycling facilities need to be considerably lower than landfill fees, in order to make the recycling of organics attractive. The showcased facilities charge the following gate fees: Open composting $30 - $70/t In-vessel composting $100/t Anaerobic digestion $70/t	The set-up timeframe for an organics processing facility should be between 1 and 5 years. Opposition to a proposed facility can greatly prolong the process. The set-up timeframes for the showcased facilities were as follows: Open composting 2 – 4 years In-vessel composting 1 year (at existing site) Anaerobic digestion 2 – 3 years	Composting and anaerobic digestion facilities can operate for short or long periods. Machinery used in organics processing facilities is usually depreciated over a seven or eight year time frame, while buildings and fixtures are depreciated over 15 or 20 years. The expected lifespans for the showcased facilities were as follows: Open composting 30 – 50 years In-vessel composting Minimum of 20 years Anaerobic digestion 25 years

Technology	13	14	15
	Technology Footprint	Buffer	Emissions
Organics Processing Technology Synopsis	The absolute footprint for composting and anaerobic digestion facilities vary depending on annual throughput. However, the footprint per unit throughput also varies depending on the technology employed. The literature suggested the following footprints: <u>Composting</u>: Windrowing 0.5 – 1.5 m^2/t input In-vessel composting 0.1 – 1.3 m^2/t input <u>Anaerobic digestion</u>: dry digestion 0.15 – 0.4 m^2/t input Wet digestion 0.1 – 0.25 m^2/t input The showcased facilities occupied the following areas: Open composting - total 80 ha - hardstand for composting 8 ha - water storage 5 ha In-vessel composting - total 12 ha - tunnels 0.175 ha Anaerobic digestion - total 3 ha	Buffer zones for organics processing facilities are considered on a case by case basis during the planning approvals stage. They are a regulatory requirement and the extent of the buffer is specified by the jurisdiction. There can be different buffer distances and conditions between the facility and residential dwellings, commercial enterprises, watercourses, and drinking water catchment areas or aquifers. The showcased facilities had the following buffer zones or complied with regulatory requirements: Open composting 1,000m In-vessel composting 500m Anaerobic digestion 500m (residential)	Organics processing facilities can generate the following emissions: • Leachate • Run-off • Benign gases (CO_2, water vapour) • Non-benign gases (methane, nitrous oxide, carbon monoxide, hydrogen sulphide, and odour compounds) • Bio aerosols • Dust Leachate and run-off is usually collected and evaporated via composting or treated. Exhaust air from in-vessel and fully enclosed facilities is usually purified

Technology	16 Environmental impacts	17 Social impacts	18 Integration into a wider waste management strategy
Organics Processing Technology Synopsis	The main potential adverse environmental impacts from organics processing facilities are emissions to air (GHG, odour, ammonia, dust, bio aerosols), to ground and surface water (leachate, run-off), and to a lesser degree to land (windblown debris). Environmental licenses stipulate key monitoring and operating requirements, and usually cover the type and maximum quantity of residues that can be received and processed, leachate quality, effluent quality and discharge rates, stormwater quality, noise levels, and odour dust emissions. However, recycling and use of recycled organic products for land management and soil improvement purposes has also significant beneficial effects. Environmental benefits obtained through anaerobic digestion are even higher as this technology provides also electrical and heat energy, avoiding fossil fuel usage. The showcased facilities reported the following emissions as being currently of concern: Open composting — odour In-vessel composting — leachate from the maturation area Anaerobic digestion — methane and ammonia	Organics recycling activities save landfill space, recover large quantities of plant nutrients and sequester / abate GHG emissions. The Organics Recycling Industry has invested significant amounts of money and employs close to 2,000 full-time people nationwide, in addition to creating jobs in transport, distribution and product application.	Today, the source segregation of municipal and commercial garden and food organics, in combination with composting or anaerobic digestion and the subsequent beneficial use of compost, is a key part of modern integrated recycling and waste management systems. Source segregation and recycling of organics is an important tool for reducing the amount of waste that is landfilled, and for reducing detrimental environmental effects of landfills.

<table>
<tr><th rowspan="2">Technology</th><th>19</th><th>20</th></tr>
<tr><th>Risks</th><th>Applicability to local context</th></tr>
<tr><td>Organics Processing Technology Synopsis</td><td>There are a wide range of potential risks associated with organics processing.
<u>Composting</u>
• Odour emissions
• Ground- and/or surface water pollution
• Methane emissions
• Low landfill prices
• Insecure feedstock supply
• Lack of gate fees
• Prolonged severe weather
• Market failure
• Competition from cheap manures.
• Fire
<u>Anaerobic digestion</u>
• Odour emissions
• Leakage of methane
• Financial risks might be reduced due to sale of electricity.
• Methane explosion
The showcase facilities considered the following risks as being important:
<u>Open composting</u>
• Urban encroachment
• Change in government policy with unknown consequences
• Poor management that sensitises neighbours
<u>In-vessel composting</u>
• Management system failure
• High contamination levels
• Lack of market for generated products
• Excess leachate
<u>Anaerobic digestion</u>
• Insecure feedstock supply</td><td>It is quite common for large-scale organics processing facilities to be located at the fringes of urban areas, away from settlements, but close enough to service the them.

It might be possible to locate anaerobic digestion facilities in industrial estates, but this is not necessarily ideal where digestate is composted. Digestion facilities are often co-located at composting facilities.

The showcase facilities expressed the following opinions concerning location of their type of facility:

<u>Open composting</u>
It is possible to conduct such an operation on the urban fringe, but a rural setting is better.

<u>In-vessel composting</u>
The facility can be located where there is adequate feedstock (> 6,000 tpa).

<u>Anaerobic digestion</u>
The facility can be established in a business park or an industrial area, as long as there are adequate buffer distances (500 m to residential and 300 m to commercial buildings).</td></tr>
</table>

Technology	21	22	23
	Technology maturity	Availability rate	Regional penetration
Organics Processing Technology Synopsis	Composting is a very mature and well proven technology for the conversion of a wide range of organic residues into valuable products. Anaerobic digestion of liquid and solid organic residues is by now an equally well established organics processing technology. The last 10 years saw significant advances for dry digestion technology.	Availability of open composting facilities is commonly 100%. Forced and scheduled repair and maintenance shut-downs increase with increasing sophistication of the composting technology employed. Continuous AD facilities have to be shut down regularly to maintain the facility in good working order. Maintenance work in modular batch systems can be carried out without shutting down the entire facility. Biological imbalance (acidification) can force the shut-down of wet AD facilities, and necessitate that the digester is emptied. The showcase facilities reported the following availability rates: <u>Open composting</u> 100% <u>In-vessel composting</u> 100% (modular system) <u>Anaerobic digestion</u> • Anaerobic digestion: >95% (modular system) • Composting: 100% (modular system) • CHP unit requires regular maintenance, but this does not affect operation of the digester.	There are 198 commercial composting facilities in Australia and 29 in Western Australia, the vast majority of which employ open composting. The showcase open composting facility is located in the Perth / Peel region. At present there is only one operational AD facility in Australia that processes source segregated municipal and commercial organic residues. A second such facility is currently being built in WA. Both facilities are wet digesters, with no dry digester in operation yet in Australia.

Technology	24	25	26
	Benefits	Barriers	Other
Organics Processing Technology Synopsis	The recycling of source segregated municipal and commercial organics through composting provides a range of benefits: ▪ Sizable reduction of waste going to landfill ▪ Prevention of detrimental emissions from landfills (leachate, GHGs) ▪ More sustainable, and often cheaper waste management ▪ Conversion of 'waste' into valuable products ▪ Generation of employment and business opportunities ▪ Recycling of plant nutrients and carbon ▪ Supply of soil improvement and land management products to the landscaping and horticultural/agricultural industries ▪ Reduction of GHG emissions Anaerobic digestion offers the following additional benefits: ▪ Allows processing of liquid residues (wet digestion) ▪ Small footprint ▪ Generation of biogas, which is converted into renewable electrical and heat energy ▪ Liquid digestate provides nutrients in a plant available form	Barriers to the expansion of organic recycling schemes via composting and AD are: ▪ The risk of odour emissions ▪ Processing of source segregated food and garden organics requires the establishment of a successful kerbside organics collection scheme. ▪ Sophisticated composting and anaerobic digestion technologies often require sizable investments and incur high processing costs. ▪ Large quantities of surplus water can be a problem in wet digestion facilities. ▪ Economic viability of anaerobic digestion facilities depend on returns from the sale of surplus electricity and available bonuses for renewable energy. The showcase facilities noted the following barriers to the uptake of their technology as important: Open composting ▪ Composting seen as too simple. In-vessel composting ▪ Relatively high costs for small communities. ▪ The need to develop a market for generated compost products. Anaerobic digestion ▪ Prejudice. ▪ Lack of knowledge about state of the art in AD. ▪ AD is more expensive than composting	Commercial composters invest their own money in systems and technologies that have to work. Most are successful in doing what they are doing for many years. Important lessons for the successful establishment and operation of an AD facility include: ▪ Good and diligent supervision of construction activities ▪ Start-up through skilled and experienced staff Depending on the proportion of food and garden organics, woody vegetation residues should by-pass the digestion phase and be composted only.

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