

A photograph of two workers in a recycling facility. They are wearing white hard hats, safety glasses, and high-visibility yellow vests over dark blue long-sleeved shirts. The worker in the foreground is also wearing blue earmuffs and a communication device. They are standing in front of a large pile of sorted waste materials, with green metal structures and conveyor belts visible in the background.

Resource Recovery

TECHNOLOGY GUIDE

TECHNOLOGIES WHICH CAN INCREASE RECOVERY AND RECYCLING IN VICTORIA

Resource Recovery Technology Guide
© Sustainability Victoria 2018 RRE009

Authorised and published by
Sustainability Victoria,
Level 28, Urban Workshop
50 Lonsdale Street Melbourne
Victoria 3000 Australia

Accessibility
This document is available in PDF
and Word format on the internet at
www.sustainability.vic.gov.au

ISBN 978-1-920825-37-9 (Print)
ISBN 978-1-920825-36-2 (PDF)

Publication co-produced with Arcadis Australia Pacific Pty Ltd, Frith Resource Management
and Reincarnate Consulting (peer review)

Resource Recovery Technology Guide should be attributed to Sustainability Victoria.

While reasonable efforts have been made to ensure that the contents of this publication are factually correct, Sustainability Victoria gives no warranty regarding its accuracy, completeness, currency or suitability for any particular purpose and to the extent permitted by law, does not accept any liability for loss or damages incurred as a result of reliance placed upon the content of this publication. This publication is provided on the basis that all persons accessing it undertake responsibility for assessing the relevance and accuracy of its content.

Resource Recovery Technology Guide should be attributed to Sustainability Victoria.

Resource Recovery Technology Guide is licensed under a Creative Commons Attribution 4.0 Australia licence. In essence, you are free to copy, distribute and adapt the work, as long as you attribute the work and abide by the other licence terms. To view a copy of this licence, visit: <http://creativecommons.org/licenses/by/4.0/>



Contents

1 Introduction	1
1.1 Why recover waste resources?	1
1.2 Victoria's planning framework to develop resource recovery infrastructure	1
1.3 Who is this guide intended for?	2
1.4 What is the guide aiming to achieve?	4
1.5 What does this guide contain?	4
1.6 Opportunities and constraints for resource recovery in Victoria	4
1.7 Related guidance information on resource recovery	5
2 Waste and Material Streams	7
2.1 Commingled Recyclables	7
2.2 Organics (including timber)	8
2.3 Tyres and rubber	11
2.4 Plastics	13
2.5 E-waste	15
2.6 Glass Fines	16
2.7 Concrete and Brick	17
2.8 Mixed Residuals	18
3 Current Resource Recovery Technologies	21
3.1 Technologies overview	22
3.2 Sorting solutions	25
3.2.1 Clean MRF	25
3.2.2 Mixed Waste MRF	29
3.2.3 Mechanical biological treatment (MBT)	33
3.2.4 E-waste recycling	37
3.3 Biological treatment solutions	39
3.3.1 Aerobic Processing	39
3.3.2 Anaerobic processes	50
3.4 Thermal treatment solutions	53
3.4.1 Combustion	54
3.4.2 Gasification	58
3.4.3 Dehydrators	61
3.5 Reprocessing technologies	62
3.5.1 Shredding of timber waste	62
3.5.2 Mechanical recovery of rubber products	64
3.5.3 Plastics reprocessing	66
3.5.4 Glass fines beneficiation	68
3.5.5 Concrete and brick reprocessing	71

4 Emerging Resource Recovery technologies	73
4.1 Mechanical heat treatment (MHT)	73
4.2 Pyrolysis	76
4.3 Plasma gasification	79
4.4 Torrefaction	82
4.5 Advanced fuel production	82
4.5.1 Fermentation	82
4.5.2 Gas-to-Liquids	82
4.5.3 Hydrothermal Liquefaction	83
5 Technology Summary	84
6 Delivering Resource Recovery Solutions	87
6.1 Managing environmental impacts	87
6.1.1 Site suitability and separation distances	87
6.1.2 Sources and control of emissions	87
6.1.3 Planning and approvals	88
6.2 Managing community impacts	95
6.2.1 Jobs and employment	95
6.2.2 Community and stakeholder engagement	95
6.3 Management of outputs and residues	96
6.3.1 Markets for products	96
6.3.2 Disposal of process residues	96
6.4 Procurement and ownership	97
6.4.1 Collaborative procurement	97
6.4.2 Procurement options	97
6.4.3 Working with solution providers	98
6.4.4 Contract arrangements	98
6.4.5 Bankability of resource recovery solutions	99
6.5 Managing risks	100
6.5.1 Identifying Project Risks	100
6.5.2 Mitigating Project Risks	102
6.5.3 Assessing Technology Risks	102
7 Sources of further information	103

Glossary and abbreviations

Term	Definition
Aerobic	In the presence of oxygen.
Aerated static pile composting	Also called aerated static windrow composting. Forced aeration method of composting in which a free-standing pile is aerated by a fan blowing air through perforated pipes located beneath the pile.
Amenity	The quality of a local environment in relation to health and pleasantness.
Anaerobic	In the absence of oxygen. Composting systems subject to anaerobic conditions often produce odourous compounds. Anaerobic conditions are employed in anaerobic digestion systems.
Anaerobic Digestion (AD)	Anaerobic digestion, the biological breakdown by microorganisms of organic matter in the absence of oxygen, producing biogas (a mixture of carbon dioxide and methane) and digestate (a nutrient-rich residue).
Best practice	Best practice represents the current 'state-of-the-art' and aims to produce outcomes consistent with the community's social, economic and environmental expectations. Continuous improvement is an important component of best practice.
Beneficiation (of glass fines)	An advanced sorting process used to separate different colours of container glass fines from contaminants to produce cullet for reprocessing.
Biogas	A gas produced by AD processing of organic waste. Biogas is around 50–60 per cent methane and the remainder mostly carbon dioxide.
Biomethane	An upgraded/purified form of biogas, biomethane is typically 95–99 per cent methane (CH ₄) and so can be used as a direct substitute for natural gas.
Buffer distance	Also known as separation distance. The distance between a waste facility and residential or other sensitive land use.
C&I waste	Commercial and Industrial waste, includes waste produced by a wide variety of businesses and industries. In the context of organic waste, key sources include manufacturing (particularly food and beverage manufacturing), accommodation and food services, retail and wholesale trade, and healthcare and social assistance sectors.
C&D waste	Construction and demolition waste, waste generated from residential and commercial construction and demolition activities e.g. bricks and concrete, timber, and residual waste.
C:N ratio	Carbon to nitrogen ratio, the weight ratio of organic carbon (C) to that of total nitrogen (N) in an organic material. This is a key quality parameter for feedstocks to most biological processing systems.
Commingled recyclables	Also known as 'mixed recyclables', materials combined generally for the purposes of collection, mainly through municipal collection services. Includes plastic bottles, other plastics, paper, glass and metal containers. Commingled recyclable materials require sorting after collection before they can be recycled.
Compost	An organic product that has undergone controlled aerobic and thermophilic biological transformation through the composting process to achieve pasteurisation and reduce phytotoxic compounds, and achieved a specified level of maturity required for compost.
Composting	The process whereby organic materials are microbiologically transformed under controlled aerobic conditions to achieve pasteurisation and a specified level of maturity.
Contamination	Materials and items within a recycling process that are not readily recycled by that process. Contaminants within this context include physical and non-biodegradable materials (metals, glass, plastics, etc.), chemical compounds and/or biological agents that can have a detrimental impact on the quality of any recycled organic products manufactured from organic waste.
Cullet	Sorted glass feedstock resulting from the recovery of mixed container glass. Generally consists of sorted streams of amber, flint and green glass of particle size greater than 5–10 mm.
DELWP	Victorian Department of Environment, Land, Water and Planning
Digestate	A nutrient-rich solid and liquid residue remaining after the anaerobic digestion (AD) of a biodegradable feedstock.

Term	Definition
EPA	Environment Protection Authority Victoria
E-waste	E-waste comprises of electronic equipment with a plug or battery that requires a current to operate and that has reached end of life. It includes televisions, computers, monitors and whitegoods such as fridges and washing machines.
FOGO service	FOGO stands for Food Organics + Garden Organics, and generally refers to a kerbside collection service of combined food and garden waste, mostly from domestic / municipal sources in one collection bin (usually the green-lidded bin).
Gasification	Thermal technology that converts material into combustible gases by partial oxidation under the application of heat, leaving a solid ash or slag residue.
Groundwater	Any water contained in or occurring in a geological structure or formation or an artificial landfill.
Infrastructure	Infrastructure in the context of this Guide refers to waste and resource recovery infrastructure only, of the type discussed in this Guide.
In-vessel composting (IVC)	Composting technology involving the use of a fully enclosed chamber or vessel in which the composting process is controlled by regulating the rate of mechanical aeration. Aeration assists in heat removal, temperature control and oxygenation of the mass. Aeration is provided to the chamber by a blower fan which can work in a positive (blowing) and/or negative (sucking) mode. Rate of aeration can be controlled with temperature, oxygen or carbon dioxide feedback signals.
Leachate	Liquid released by waste, or contaminated water that has percolated through or drained from waste, and containing dissolved or suspended material from the waste.
Maturation (of compost)	The final stage of composting where the temperature is shown to decline and stabilise to an extent that it can be safely used on land and come into direct contact with plants without any negative effects.
MBT	Mechanical Biological Treatment - a group of waste processing technologies that use mechanical sorting of mixed residual waste combined with biological treatment of the organic fraction, to recover resources.
MRF	Materials Recovery Facility – a purely mechanical processing system for waste. A clean MRF separates commingled dry recyclables into saleable material streams. A dirty MRF processes mixed residual wastes to extract recyclables, an organic fraction and/or a refuse derived fuel output.
MSW	Municipal Solid Waste, which is primarily the waste and recyclables generated by households and collected by councils, but may also include other council generated wastes.
OHS	Occupational Health and Safety
Open windrow composting	A type of outdoor composting process where organic materials are piled in to windrows and are turned for aeration.
Parasitic load	The proportion or amount of electricity generated that is used to meet the internal energy requirements of the plant. The net electrical output is the total power generation minus the parasitic load.
Pasteurised product	An organic product that has been pasteurised or sanitised by subjection to high temperatures for a period of time (e.g. 55 degrees Celsius for at least 3 days) to destroy pathogens, pests and weeds.
Prescribed Industrial Waste (PIW)	As defined in the Environment Protection (Industrial Waste Resource) Regulations 2009. These wastes require careful management and regulation because of their potential impact on human health or the environment.
Processing facilities	Facilities which either receive materials directly from collection systems or from recovery facilities for further sorting and/or processing to provide material for use in the generation of new products.
Product stewardship	A concept of shared responsibility by all sectors involved in the manufacture, distribution, use and disposal of products, which seeks to ensure value is recovered from products at the end of life.
Putrescible waste	Putrescible waste is waste containing matter that readily decomposes such as food, garden waste and other organics. MSW from household collections and some C&I waste (if it contains organics) are typically considered putrescible.
Pyrolysis	Thermal breakdown of waste in the absence of air, to produce char, pyrolysis oil and syngas (e.g. the conversion of wood into charcoal).

Term	Definition
RDF	Refuse Derived Fuel, also called Process Engineered Fuel (PEF). RDF is a solid fuel produced after processing of waste (e.g. in a dirty MRF or MBT plant) to increase the calorific value, homogenise the material, remove recyclable materials, remove inert materials, and remove hazardous contaminants.
Recyclables	While this term strictly applies to all materials that may be recycled, in this Guide the term is generally used to refer to the recyclable containers and paper/cardboard component of kerbside waste e.g. it excludes food and garden organics.
Reprocessing	Changing the physical structure and properties of a waste material that would otherwise have been sent to landfill to add value to the processed material and prepare it for reuse. Without reprocessing, the beneficial use of waste materials would be lost.
Reprocessing facilities	Also known as 'Reprocessors', facility that changes the physical structure and properties of a waste material that would otherwise be sent to landfill to add financial value to the processed material. Without reprocessing the beneficial use of the material would be lost.
Residual waste	Residual material that remains after any source separation or reprocessing activities of recyclable materials or organics. Waste that is left over after suitable materials have been recovered for reuse and recycling. This generally means the environmental or economic costs of further separating and cleaning the waste are greater than any potential benefit of doing so.
Resource recovery	The process of obtaining matter or energy from discarded materials.
RO	Recycled Organics – a broad term for beneficial products recovered from organic wastes and mostly used as soil conditioners or mulch.
RWRRIP	Regional Waste and Resource Recovery Implementation Plan (Regional Implementation Plan), published by each of the seven waste and resource recovery regions of Victoria.
SEPP	State Environment Protection Policy, subordinate legislation under the provisions of the Environment Protection Act 1970 to provide more detailed requirements and guidance for the application of the Act.
Shredding	Mechanical processing of materials to reduced particle size.
Social licence to operate	The concept of a 'social licence to operate' has evolved from broader concepts of 'corporate social responsibility' and is based on the idea that a business not only needs appropriate government or regulatory approval but also a 'social licence'. The social licence is the acceptance that is continually granted to industry and facility operators by the local community or other stakeholders to operate.
Soil conditioner	Any composted or pasteurised product suitable for adding to soils. This also includes products termed 'soil amendment', 'soil additive', 'soil improver' and similar, but excludes polymers that do not biodegrade, such as plastics, rubber and coatings. Soil conditioners may be either 'composted soil conditioners' or 'pasteurised soil conditioners'.
Source separation	The practice of segregating materials into discrete material streams prior to collection by, or delivery to, processing facilities.
SV	Sustainability Victoria
SWRRIP	Statewide Waste and Resource Recovery Infrastructure Plan, published by Sustainability Victoria.
Technology	Technology in the context of this Guide refers to resource recovery technologies of the type discussed in this document. It may include individual items of equipment or complete processing plants, which may be classified as mechanical, biological or thermal processes (or combination of).
tpa	Tonnes per annum, the most common measure of waste flows and capacity of a waste treatment facility.
Waste to energy	Waste to energy, also interchangeably termed 'energy from waste'. A collection of treatment processes and technologies used to generate a usable form of energy (e.g. electricity, heat and fuels) from waste materials. Waste to energy technologies can be divided into two broad categories: biological and thermal treatment.
Windrow	Elongated, prism-shaped pile where shredded organic waste undergoes biodegradation.
VPP	Victorian Planning Provisions, provide a framework for the development of all planning schemes in Victoria.

Using this Guide

This Guide has been designed to assist a variety of interested stakeholders – existing resource recovery facility operators, local and state government, regulators, investors and funding agencies, waste generators, communities and community groups – in understanding the technologies, application and implementation requirements that apply to the recovery and processing of various waste material streams.

The Guide provides a summary of the key requirements, waste material streams and technologies, costs and planning involved in any resource recovery solution. All information in this guide is advisory only, and information specific to each scenario should be sought to inform decisions.

You don't have to read the Guide from start to finish; you can jump from one section to another to follow your interests or information needs.

If you need help with any of the contents of this Guide or have additional questions, refer to the list of resources provided in Section 5 of this Guide, or contact Sustainability Victoria on +61 3 8626 8700.

1 Introduction

1.1 Why recover waste resources?

Discarded materials should not just be considered 'waste'. Embodied in these materials is the energy, water, raw virgin materials and other inputs used in their manufacture and transport. Recycled materials and products often compare very favourably to virgin materials in terms of performance and application, and are generally better from an environmental point of view – requiring much less energy and other inputs to recycle them and return them to the economy than it takes to source, transport, process and manufacture with virgin materials.

Recovering and recycling wastes materials helps to reduce Victoria's reliance on landfill and delivers environmental and local amenity benefits to the community, providing jobs and economic growth in the process. Reprocessing facilities provide new employment opportunities including skilled jobs in the design, construction and operation. The entire waste and resource recovery sector is estimated to contribute over \$4 billion to our economy and employ over 12,000 Victorians¹.

At the state level, landfill levies have been adopted to encourage the diversion of waste from landfill, along with improved landfill standards and restriction of airspace as policy drivers to aid in increasing resource recovery. Material recovery and recycling help to avoid these costs, delivering financial and economic benefits to local councils, residents and businesses.

The National Greenhouse and Energy Report estimates that in 2016, management of residual waste in landfills nationally generated 8.9 million tonnes of CO₂-e, accounting for 1.6 per cent of Australia's total greenhouse gases². While the emissions generated by the waste and resource recovery system contributes only a small fraction of Australia's total emissions, the emissions from landfills are predominantly methane (CH₄) which is potent greenhouse gas, and so it is important that these emissions are managed and reduced where possible.

Victoria's population is growing and so too is the amount of waste each person generates. In 2015–16, 8.5 million tonnes of valuable material was recovered from waste streams in Victoria, representing a 67 per cent recovery rate³. The technology covered in this Guide targets the remaining 33 per cent and may help boost Victoria's recovery rate.

1.2 Victoria's planning framework to develop resource recovery infrastructure

The Victorian Statewide Waste and Resource Recovery Infrastructure Plan (SWRRIP) recognises that there is a need to increase resource recovery in Victoria to reduce our reliance on landfill and to reuse these valuable waste resources in a sustainable way. The SWRRIP provides Victoria with the long term vision and roadmap to guide future planning for waste and resource recovery infrastructure to achieve an integrated waste management system.

The SWRRIP focuses on the development of a network of spokes to support the flow of materials to processing hubs. The SWRRIP recognises the current resource recovery technology in Victoria and seeks to protect processing hubs (areas), including those of state significance, in the land use planning system to ensure these hubs survive and thrive in Victoria's changing planning landscape. The plan also provides scope for future changes and flexibility to incorporate emerging technologies on Victoria's path to achieve an integrated waste management system.

Specifically, the SWRRIP recognises organics (including timber), glass and plastics, e-waste, tyres and rubber, and concrete, brick & asphalt, as materials with the opportunity for greater recovery and that advancements in technology will likely handle residual waste from households and C&I sources, capturing recoverable components and helping to reduce the amount of residual waste going to landfill.

The SWRRIP is supported by the Victorian Market Development Strategy for Recovered Resources (Market Development Strategy), the Victorian Organics Resource Recovery Strategy (VORRS), and the seven regional waste and resource recovery implementation plans (Regional Implementation Plans).

The Regional Implementation Plans have a shorter time horizon (10 years) and identify waste and resource recovery infrastructure and service needs at local and regional level for each of the seven waste and resource recovery regions in Victoria. These plans are a key tool to enable the regions to strategically plan for and implement the processing capacity they require, whether in or beyond the region, and recognises where the processing capacity of a region is less than the current or future predicted volumes of waste resources within the region.

The Regional Implementation Plans are focused on the priority materials covered in this Guide. In particular, all Regional Implementation Plans list diversion, aggregation and recovery of organics, plastics, e-waste, and tyres as a strategic priority, recognising that there is an opportunity to implement advanced technology to meet local processing capacity needs rather than send these materials to Melbourne for processing. Currently, the majority of the waste and material streams generated in the state stay in Victoria for recovery and management and around 86 per cent of the reprocessing occurs in metropolitan Melbourne. In response to international market demand, around 17 per cent of recovered materials are exported overseas for reprocessing, including significant volumes of scrap metal waste, cardboard and paper⁴.

The regional waste and resource recovery groups are actively supporting the development of innovative and viable opportunities to increase recovery of priority material streams, and assisting the development of markets for recycled materials.

This Guide is a key tool in achieving the goals of the SWRRIP and Regional Implementation Plans.

1 Department of the Environment and Energy, Centre for International Economics, Headline economic value for waste and materials efficiency in Australia. October 2017.
2 Quarterly Update of Australia's National Greenhouse Gas Inventory: December 2016, <http://www.environment.gov.au/climate-change/greenhouse-gas-measurement/publications/quarterly-update-australias-national-greenhouse-gas-inventory-dec-2016>
3 Victorian Statewide Waste and Resource Recovery Infrastructure Plan (SWRRIP), Sustainability Victoria, 2015.

4 Victorian Statewide Waste and Resource Recovery Infrastructure Plan (SWRRIP), Sustainability Victoria, 2015, <http://www.sustainability.vic.gov.au/our-priorities/statewide-waste-planning/2015-2020-priorities/statewide-waste-and-resource-recovery-infrastructure-plan>

1.3 Who is this guide intended for?

This Guide is intended to serve a broad audience of stakeholders with varying information needs. It provides an overview of resource recovery technologies which will be useful for readers who have a general understanding of resource recovery and waste processing technologies. It does not include all reprocessing technologies; however further technologies may be researched and published by SV in future.

The Guide is aimed at project developers, operators, council officers and elected members, waste generators, planners, regulators, investors, and the general community who may be involved in, or have an interest in:

- learning about the characteristics of different material processing technologies
- understanding how waste can be recovered and the challenges involved
- assessing technology options and planning future infrastructure
- developing new resource recovery infrastructure
- upgrading existing facilities with more advanced technologies
- specifying and procuring facilities and services
- approving and regulating resource recovery facilities
- investing in or financing resource recovery projects

Table 1 highlights the likely information needs of the key audiences and links to the relevant sections within the Guide for easy navigation.

TABLE 1: KEY AUDIENCES AND RELEVANT SECTIONS WITHIN THE GUIDE

Key audience	Priority Information needs
<ul style="list-style-type: none"> Existing resource recovery processors looking to upgrade operations 	<ul style="list-style-type: none"> Overview of material streams and the opportunities and constraints for resource recovery of each stream (Section 2) Current technologies (Section 3) and emerging technologies (Section 4) Considerations for development of resource recovery solutions (Section 6), including markets for products and managing residues (Section 6.3) Procurement and ownership options (Section 6.4), and bankability (Section 6.4.5) Managing risks, including project and technology risks (Section 6.5)
<ul style="list-style-type: none"> Those interested in developing a resource recovery processing facility 	<ul style="list-style-type: none"> Understanding the various material streams and the opportunities and constraints for resource recovery of each stream (Section 2) Current technologies (Section 3) and emerging technologies (Section 4) Considerations for management of a resource recovery solutions (Section 3), including markets for products and managing residues (Section 6.3) Planning and environmental approvals (Section 6.1.3) Procurement and ownership options (Section 6.4), and bankability (Section 6.4.5) Managing risks, including project and technology risks (Section 6.5)
<ul style="list-style-type: none"> Local governments and regional Waste and Resource Recovery Groups procuring resource recovery processing services 	<ul style="list-style-type: none"> Understanding the various material streams and the opportunities and constraints for resource recovery of each stream (Section 2) Current technologies (Section 3) and emerging technologies (Section 4) Planning and environmental approvals (Section 6.1.3) Procurement and ownership options (Section 6.4), and bankability (Section 6.4.5) Managing community impacts (Section 6.2), including jobs and employment (Section 6.2.1) and stakeholder engagement (Section 6.2.2) Managing risks, including project and technology risks (Section 6.5)
<ul style="list-style-type: none"> Local and state government planning agencies assessing facilities 	<ul style="list-style-type: none"> Current technologies (Section 3) and emerging technologies (Section 4) Markets for products and managing residues (Section 6.3) Considerations for management of a resource recovery solutions (Section 3) including managing community impacts (Section 6.2)
<ul style="list-style-type: none"> Regulators and other government agencies 	<ul style="list-style-type: none"> Current technologies (Section 3) and emerging technologies (Section 4) Markets for products and managing residues (Section 6.3) Considerations for management of a resource recovery solutions (Section 3), including managing community impacts (Section 6.2) Managing risks, including project and technology risks (Section 6.5)
<ul style="list-style-type: none"> Investors and funders considering investing in resource recovery solutions 	<ul style="list-style-type: none"> Current technologies (Section 3) and emerging technologies (Section 4) Considerations for management of a resource recovery solutions (Section 3), including markets for products and managing residues (Section 6.3) Planning and environmental approvals (Section 6.1.3) and managing community impacts (Section 6.2) Procurement and ownership options (Section 6.4), and bankability (Section 6.4.5)
<ul style="list-style-type: none"> Waste generators, particularly businesses and institutions generating large quantities of waste resources 	<ul style="list-style-type: none"> Why recover waste resources? (Section 1.1) Understanding the various material streams and the opportunities and constraints for resource recovery of each stream (Section 2) Current technologies (Section 3) and emerging technologies (Section 4)
<ul style="list-style-type: none"> Communities and community groups 	<ul style="list-style-type: none"> Why recover waste resources? (Section 1.1) Understanding the various material streams and the opportunities and constraints for resource recovery of each stream (Section 2) Current technologies (Section 3) and emerging technologies (Section 4) Planning and environmental approvals (Section 6.1.3) Managing community impacts (Section 6.2), including jobs and employment (Section 6.2.1) and stakeholder engagement (Section 6.2.2) Markets for products and managing residues (Section 6.3)

This Guide is intended to serve as an introductory overview of the current state of resource recovery technologies in Victoria and has been designed to inform options discussions by identifying areas that need to be considered and questions that need to be asked. However, the ultimate technology choice will be situation-specific and dependent on a range of factors outside the scope of the Guide.

This Guide is designed to provide evidence-based, objective and pragmatic advice to readers, without giving preference to any particular approach or technology. Sustainability Victoria (SV) and the Victorian Government does not endorse the technologies covered in the Guide.

The Guide provides statements about the typical effectiveness of individual technology solutions in managing different waste material streams, and case studies of facilities in Australia and internationally. It is acknowledged that there are many technology variations and specific cases that will contradict the assessments in this Guide, and valid exceptions to these statements that are difficult to capture in a broad ranging document. This Guide provides preliminary information only and specific advice will be required to inform decisions.

1.4 What is the guide aiming to achieve?

This Guide aims to support its key audiences and users in understanding current and emerging resource recovery technologies and their application to different material streams, as well as management of environmental and community impacts, managing risks, stimulating markets for recycled products, and outlining the different models of procurement and ownership.

- › This Guide promotes, informs and centralises the information surrounding technologies in the resource recovery sector, and in doing so enables evidence-based decisions and supports the achievement of the goals of the SWRRIP by providing information on technologies recognised in the plan. Sustainability Victoria may in future publish additional material for further technologies consistent with the SWRRIP.
- › This Guide helps to ensure private and public investment in waste and resource recovery infrastructure aligns with the SWRRIP (and Regional Implementation Plans) to meet the needs of Victorians now and in the future.

1.5 What does this guide contain?

This Guide contains:

- › An overview of how resource recovery fits within the Victorian Government's plan for waste and resource recovery infrastructure in the state (Section 1).
- › Information on material streams that may be suitable feedstocks for resource recovery technologies, including mixed residual waste, mixed recycled materials, organics, tyres, plastics, e-waste, glass fines, and concrete and brick materials (Section 2).
- › Information on current and emerging resource recovery technologies (Section 3).
- › Managing environmental and community impacts of resource recovery technologies, managing risks, markets for recycled products and managing residues from processing, and models of procurement and ownership (Section 4).
- › Further source of information including other publications by Sustainability Victoria, legislation and regulations, standards and other sources of information (Section 5).

1.6 Opportunities and constraints for resource recovery in Victoria

As Victoria's population grows and with it the amount of waste generated, there are growing opportunities to increase diversion of resources from landfill. But these opportunities are subject to the state of the market, economic changes and fluctuations in supply and demand. The unique mix of opportunities and constraints has seen various recovered resources thrive and struggle at various times. The purpose of this guide is not to provide in-depth detail of the opportunities and constraints to resource recovery in Victoria. Further information about these can be found on the Sustainability Victoria webpage.

An overview of general constraints and opportunities to resource recovery in Victoria is presented in Table 2.

TABLE 2: CONSTRAINTS AND OPPORTUNITIES TO INCREASING RESOURCE RECOVERY IN VICTORIA

Opportunities	Constraints
<ul style="list-style-type: none"> › Volumes of waste generated allow harnessing of economies of scale for resource recovery solutions › There is support from Government with priority material streams supported by the SWRRIP and Regional Implementation Plans › Emerging technology is becoming available to tackle difficult materials streams which are challenging to manage currently › There is an opportunity to build on community knowledge, expectation and desire for sustainability to support new technology and innovations in resource recovery › Increased resource recovery supports generation of local jobs and employment › Market development for recovered resources, including ongoing research and development (R&D), and product specifications for products made from recovered resources are boosting industry confidence to use these products 	<ul style="list-style-type: none"> › High costs associated with collection, processing/technology, and transport › Long transport distances to/from regional Victoria add significant cost to regional resource recovery solutions › Contamination of recyclable materials by other wastes, particularly organic waste, creates recovery challenges › Current limitations of collection systems which may be lacking for certain streams or may favour commingling of recyclable materials, leading to contamination of those materials › Comparatively low cost of landfill and other competing lower value pathways make it difficult for advanced recovery solutions to be commercially viable › High availability and relatively low cost of some virgin materials make it difficult for recovered materials to compete › Perceived or real quality issues with recycled products deter the market from buying/using these materials in preference to products made from virgin materials › Volatile commodity markets can result in uncertain and fluctuating values for recovered materials, impacting financial stability of operators and leading to material stockpiling in low price periods › The available processing capacity of industry does not match the amount of waste generated in some regions of Victoria › Limited supply of suitable land near Melbourne for resource recovery facilities, which require appropriate industrial zoning and buffers to avoid impacts on local communities.

1.7 Related guidance information on resource recovery

This Guide covers a broad range of resource recovery technologies applicable to a number of material streams including information on mechanical and thermal processes. It is complemented by *The Guide to Biological Recovery of Organics* (Sustainability Victoria, 2018) which specifically covers biological processing technologies for organic waste complements this guide.

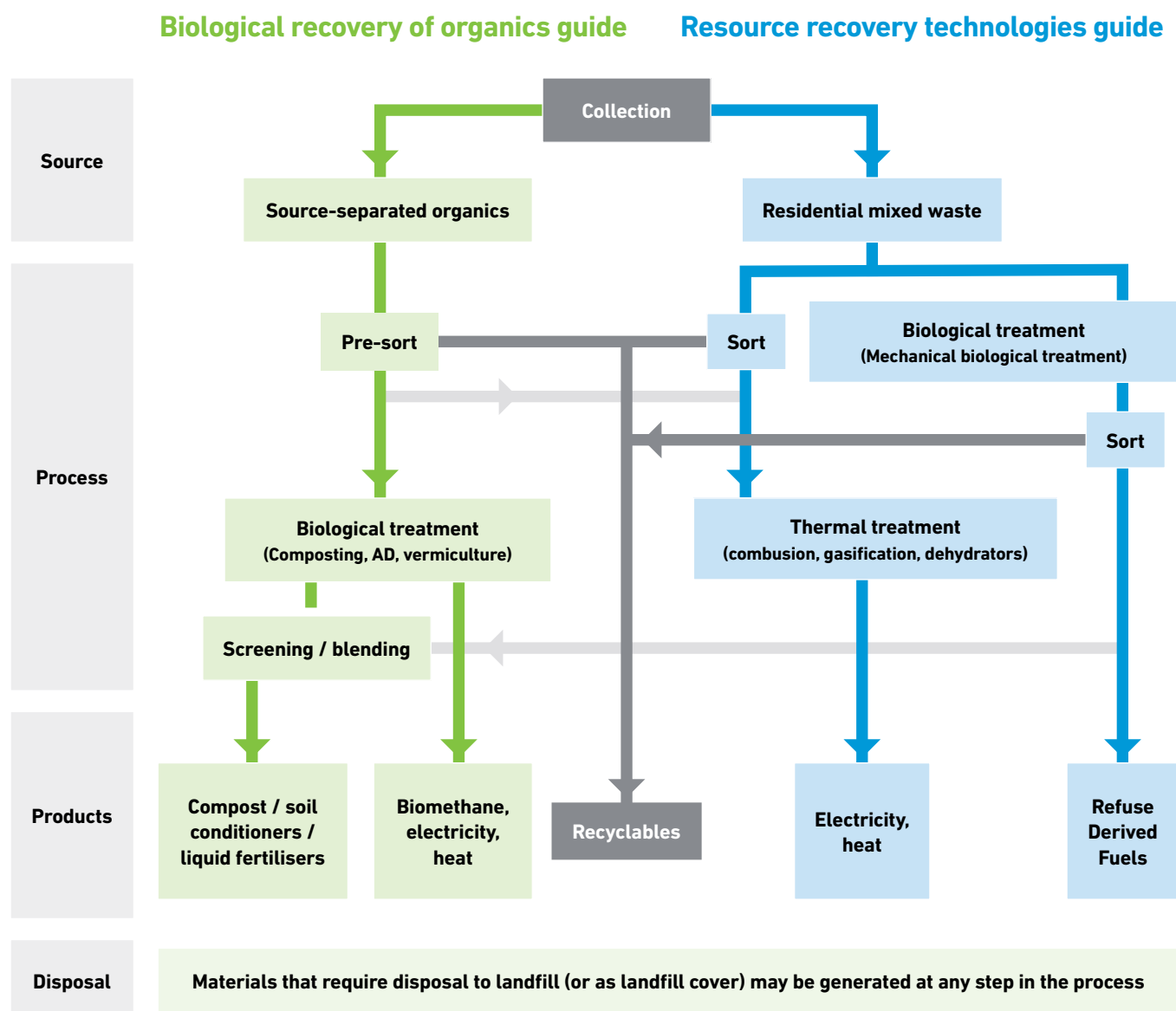
The Guide to Biological Recovery of Organics provides discussion on topics such as:

- › Sources and types of organic waste and their characteristics
- › Controlling the quality of organic waste feedstock
- › Biological processing technologies for organics, and the resulting products and residues
- › Markets for recycled organics (RO) products and bioenergy
- › Delivery of organics recovery solutions including planning and environmental approvals, and operational risk management
- › Best practice performance measures for organics recovery solutions.

The authors of both guides have sought to minimise duplication of information where possible by cross-referencing between the two guides. Figure 1 illustrates the relative scope of each guide in terms of waste and product flows.

For further sources of information and guidance, please refer to Section 7 of this Guide.

FIGURE 1: COMPLEMENTARY SCOPES OF THE BIOLOGICAL RECOVERY OF ORGANICS GUIDE AND TECHNOLOGY GUIDE



2 Waste and Material Streams

This section provides an overview of the different waste materials and streams that are typically feedstocks for resource recovery infrastructure.

2.1 Commingled Recyclables

Aspect	Description
Description	<p>Commingled recyclables (or 'mixed recyclables') are dry recyclables partially separated at source but require further sorting to extract saleable materials.</p> <p>This stream is typically low density and mostly dry, with little or no putrescible organic components (except as incidental or non-target contamination materials) and comprises paper and cardboard, plastic and glass containers, and ferrous and non-ferrous containers collected together. The majority is sourced from municipal kerbside recycling collections but some is also sourced from the commercial sector.</p>
Opportunities	<ul style="list-style-type: none"> ➤ Advancements in sorting technologies: As sorting technologies improve, there is the potential to expand the range of materials that can be collected in commingled recycling streams and sorted and recovered through MRFs, as has been seen in the past with the expanding range of rigid plastics and liquid paperboard products accepted in commingled recycling. Future opportunities include flexible plastics. ➤ Reprocessing market expansion: Future opportunities exist to undertake more reprocessing in Victoria (e.g. see Section 3.5.3 on plastics reprocessing) which will support more sustainable and expanded recovery of the commingled recycling stream locally, helping to avoid dependence on volatile export markets and overseas reprocessors. ➤ Education of waste generators: Ongoing education at the business and household level provides opportunities to capture a higher proportion of recyclable materials through commingled collection services and reduce contamination levels, increasing profitability for Material Recovery Facility (MRF) operators and ultimately leading to greater levels of resource recovery.
Challenges	<ul style="list-style-type: none"> ➤ Collection and processing impacts end product quality: The compaction of low-density commingled recyclables for transport and consequent MRF processing breaks items such as glass, affecting the recovery and end product quality (of both glass and other products such as paper / cardboard). ➤ Contamination of recyclables: Poor separation at businesses and households can lead to contamination of recyclables in the commingled stream. Significant contamination, like the presence of food organics, may lead to material being sent directly to landfill. The management of contamination represents a considerable cost to MRF operators. ➤ Commodity prices and stockpiling: Clean MRFs (see Section 3.2.1) rely on the sale of end products to reprocessors as their main revenue stream. The recovered materials, including paper, plastic, glass and metals, are global commodities and influenced by macro-economic factors. Downturns in the global prices for these materials affect the financial viability of clean MRF businesses, and have led to stockpiles of materials in Victoria. ➤ Managing environmental and community impacts: Excessive stockpiles of materials may be a potential fire hazard, which poses an environmental and health risk to local communities living near MRFs. A heightened level of community concern and angst regarding these facilities could impact the 'social licence' to operate for the resource recovery sector generally. This could make it more challenging for these facilities to operate in future, or for new facilities to obtain approvals. See EPA publication on the Management and storage of combustible recyclable and waste materials⁵ for further information on stockpiles.
Suitable technologies	<p>Commingled recyclables are typically sorted in Clean MRFs (see Section 3.2.1) prior to distribution to reprocessors. There are over 20 Clean MRFs in Victoria of varying scales.</p>
Outputs	<p>A range of recyclable materials are extracted from commingled recyclables in a clean MRF, including recovered paper, cardboard, various plastic polymers, glass and metals. These are sold on to reprocessors, both domestically and overseas for manufacturing into new products with recycled content.</p> <p>The processing of commingled recyclables also results in residual streams which need to be managed. See Section 3.5.4 on options to recover further value from the glass fines fraction.</p>
Market constraints	<ul style="list-style-type: none"> ➤ Local reprocessing capacity: While a significant proportion of recovered materials are reprocessed in Victoria, there is still a large volume that is exported for reprocessing and remanufacturing. This is partly due to a lack of local reprocessing capacity, market constraints on the products and a general lack of manufacturing capacity to absorb the reprocessed materials. ➤ Volatile commodity markets: Volatile commodity markets can result in low commodity values for recovered materials, which has a significant impact on the viability of MRF operations and therefore, the recovery of commingled recyclables. A drop in global commodity prices often results in stockpiling of recovered materials, rather than flow through to the market. This is currently the case for glass fines and some types of plastics.

5 Management and storage of combustible recyclable and waste materials – Guideline, EPA Publication 1667.1, November 2017, <http://www.epa.vic.gov.au/~media/Publications/1667%201.pdf>

2.2 Organics (including timber)

Aspect	Description
Description	<p>Organic wastes are discarded plant or animal matter from domestic or industrial sources. Common examples include food and garden organics, timber and wood waste, which are included in the SWRRIP. Organics also includes some prescribed industrial wastes (PIW) such as fats, oils and greases (FOGs), food and beverage processing wastes, paunch and abattoir wastes, as well as agriculture and forestry organics, and biosolids from wastewater treatment plants (WWTPs).</p> <p>The characteristics of organic waste are a function of the type and source of the organics. In general, high carbon, dry materials include woody garden waste, dry leaves and paper; while high nitrogen, relatively wet materials include grass clippings, food waste, biosolids and manures.</p> <p>Paper and cardboard that is not recyclable, because it is contaminated, low quality or mixed with other materials; may become part of the organics stream. The preference is to recycle paper and cardboard where possible through source separation or as part of the commingled recyclable stream (see 2.1).</p> <p>For further information on the sources and types of organic waste and their characteristics, please refer to the <i>Guide to Biological Recovery of Organics</i> (Sustainability Victoria, 2018).</p>
Opportunities	<p>Increased capture and recovery of food waste: Increased recovery of organics relies on both new approaches to collection as well as appropriate processing technologies. More Victorian councils are introducing kerbside organics services including co-collection of domestic food organics and garden organics (known as FOGO collections). Dedicated organics services for the commercial sector are also increasing.</p> <p>Increased recovery of organics from mixed residuals: As advanced sorting and other processing options come online, there may be opportunities to recover organics from mixed residual waste, particularly where segregation at source is challenging.</p> <p>Energy recovery: Some advanced technologies for processing organics also generate renewable energy in various forms (electricity, heat and fuels), helping to offset rising energy costs and providing additional revenue opportunities. Removing wet, putrescible organics from the residual waste stream also improves opportunities for thermal energy recovery of the remaining residual waste.</p>
Challenges	<p>Limited suitable sites and residential encroachment of processing facilities: There is a limited supply of suitable land for organics processing facilities, which require appropriate and adequate buffers to avoid odour issues and other community impacts. Where planning controls are inadequate, residential encroachment is a threat to many existing facilities, particularly in metropolitan areas.</p> <p>Poor management leading to impacts on the environment, community amenity and public health: Treating/processing organics can generate noxious odours and leachate which, if not well managed, can lead to community complaints and in a 'worst case' scenario, potential regulatory action.</p> <p>Biosecurity risks: Organic wastes have the potential to carry weeds, pests and diseases. Operators and proponents of biological processing facilities should be familiar with their regulatory obligations and consider the biosecurity risks associated with the feedstock that is being collected and transported to their facility for processing. They should also be aware of any particular biosecurity issues specific to the areas where they operate, source feedstock and distribute products. Particular care needs to be taken when transporting feedstock, including food and garden waste, from urban areas to regional processing facilities or between agricultural regions, to ensure biosecurity risks are minimised. Refer to the <i>Guide to Biological Recovery of Organics</i> (Sustainability Victoria, 2018) for further discussion on biosecurity.</p> <p>Contamination of feedstock decreases product quality: Source separated garden organics from municipal sources are typically clean; however, FOGO organics can be prone to higher levels of contamination which is a function of the level of community engagement and education about the new/changed kerbside service. Organics which have been extracted from mixed municipal residual waste are also typically high in contaminants (see Section 3.2.3 on MBT technologies). The resulting products from contaminated feedstocks are of poor quality and consequently, lower value in the market.</p> <p>High cost of processing: Depending on the technology type employed, the net cost of more advanced processing solutions for organics can be high (both realistic capital costs and realistic operating costs).</p> <p>Impact of treated timber on the recovery of clean timber: Untreated timber from construction and demolition (C&D) sources, either separated at source or extracted from mixed C&D waste, is recoverable but only if separated from treated timber which can be challenging.</p>

Aspect	Description
Suitable technologies	<p>Biological processing of organics:</p> <ul style="list-style-type: none"> › Windrow composting, aerated static pile composting, in-vessel composting, vermi-composting (Section 3.3.1) › Anaerobic digestion (Section 3.3.2) <p>Thermal processing of organics:</p> <ul style="list-style-type: none"> › Combustion (Section 3.4.1) › Gasification (Section 3.4.2) › Dehydration, shredding (Section 3.4.3 and 3.5.1 respectively) › Emerging technologies such as pyrolysis, torrefaction and advanced fuel production via fermentation or hydrothermal liquefaction (Section 4) <p>Mechanical processing:</p> <ul style="list-style-type: none"> › Mixed Waste MRF (Section 3.2.2) › Mechanical-biological treatment (incorporates biological processing) (Section 3.2.3) › Mechanical heat treatment (Section 4.1) <p>It is important to match the technology to the risks associated with feedstock types and proposed location. Refer to the <i>Guide to Biological Recovery of Organics</i> 2018, EPA Composting Guidelines (EPA Publication 1588.1, June 2017), and EPA Energy from Waste Guidelines (EPA publication 1559, December 2013).</p>
Outputs	<p>Biological processing of organics:</p> <ul style="list-style-type: none"> › Mulch – a ‘woody’ product that has been chipped/shredded to a given size and typically applied to the soil surface. › Compost, organics fertiliser and other soil conditions – products intended to improve/amend the condition of a soil, typically dug into the soil. › Blended products – such as compost and soil mixes, which provide a broader range of benefits than the individual components, e.g. structure for plant growth (soil) and organic nutrients (compost). › Digestate – comprises the remaining solids and nutrient-rich water from the process. Liquid digestate may be used as liquid fertiliser in agriculture, although it may need to undergo further treatment. The solid digestate will require further stabilisation (for example, through aerobic composting) before being used as a soil conditioner. Both solid and liquid digestate require analysis and quality assurance testing to ensure contaminants such as heavy metals are within acceptable levels. These outputs are PIW and advice should be sort from EPA regarding the regulatory requirements for re-use of these materials. › Biogas (40–60 per cent methane) and biomethane (95 per cent methane) – from AD processes, are useful gases that can be used in energy production. › Electricity and heat – produced from biogas or biomethane conversion. › Ethanol – produced from fermentation, ‘bio-ethanol’ is a liquid fuel. <p>The <i>Australian Standard for Composts, Soil Conditioners and Mulches (AS4454-2012)</i> is a voluntary industry standard for compost, soil conditioner and mulch products that provides a minimum level of quality assurance which certified products must meet. Refer to the <i>Guide to Biological Recovery of Organics 2018</i> for further information on biological processing of organics and the above products.</p> <p>Thermal processing of organics:</p> <ul style="list-style-type: none"> › Electricity and heat › Biofuels – such as ‘bio-ethanol’ › Biochar – a charcoal-like material that can be used as a soil conditioner. Typically produced from woody materials, but also dried biosolids and other organics. There is no accepted general specification for biochar products and it is important that producers take steps to demonstrate the product is fit-for-purpose for its intended use and will not cause adverse impacts to land or water. Producers of biochar are advised to seek EPA guidance on appropriate applications and specifications for use of these materials. <p>Mechanical processing:</p> <ul style="list-style-type: none"> › RDF – a broad term referring to solid fuels produced from highly calorific waste materials that have typically been processed to reduce moisture, inert and hazardous content. › Mulch, animal bedding, particleboard (from waste timber)

Aspect	Description
Market constraints	<p>Recycled organics (RO) products:</p> <ul style="list-style-type: none"> ➤ Poor quality products undermine the market: The sale of unpasteurised and/or contaminated products such as mulch and compost has reduced confidence in the market to buy recycled organics (RO) products as a whole, further undermining the sale of good quality products. Agriculture remains a large potential market but many users are concerned about poor quality products and unsure if the products will deliver results for their particular need/application. ➤ Costly transport distances restrict rural markets: Agricultural markets for RO products have been largely limited due to transport costs from the point of product manufacture (metropolitan fringe areas) to agricultural areas (regional) and willingness to pay by farmers. <p>Energy and other products:</p> <ul style="list-style-type: none"> ➤ Difficulty accessing the market: Energy products such as electricity and heat are best used either on-site or by a neighbouring user. Finding reliable, stable users in close proximity to the site of generation is challenging. While electricity can be exported to the grid, low and unpredictable wholesale power prices and high costs to connect to the grid limit the viability of this option. ➤ Limited product application: Domestic markets for products such as biochar and renewable gas remain undeveloped and largely untested.

2.3 Tyres and rubber

Aspect	Description
Description	<p>Discarded tyres are a complex, interwoven mix of raw materials including around one-half rubber, one-fifth steel wire and one-fifth carbon black, with minor proportions of textiles and other additives and chemicals compounds⁶. Passenger tyres typically contain synthetic rubber, whereas truck and agricultural vehicle tyres contain higher proportions of natural rubber.</p> <p>Other sources of discarded rubber include conveyor belts, which are mostly made up of synthetic rubber, often with nylon or steel reinforcement.</p>
Opportunities	<ul style="list-style-type: none"> ➤ Product stewardship supporting increased recovery: The industry-run Tyre Stewardship Australia (TSA) supports scheme participants across the supply chain in recovery of end-of-life tyres and funds research and development into recycled tyre products uses and end-markets. ➤ New uses for tyre-derived products: Research and development into uses for tyre-derived products, such as rubberised road products like asphalt and spray seal and emerging markets such as mining explosives, support greater uptake by government and industry. Stronger end markets support increased resource recovery by improving the overall business case for recycling. ➤ Tyre-derived fuel (TDF) is cost-competitive when global oil prices are high: The export market for tyre-derived fuel (TDF) can be a significant outlet for Australian tyres. Consumption of TDF may provide an opportunity in future when global oil prices are high, allowing TDF to compete with fossil fuels.
Challenges	<ul style="list-style-type: none"> ➤ Stockpiling of tyres and community impacts: Stockpiling of tyres has been a controversial topic for many years, with a number of legacy stockpiles around Victoria, particularly in regional areas. Communities living near these stockpiles have been particularly affected by the constant threat of fire and associated health and amenity impacts. ➤ Processing cost and limited markets: Recovery of tyres is limited by the cost of processing the complex mix of materials that makes up tyres and the limited markets for recycled products. Whilst crumb rubber is a valuable product, its manufacturing generally incurs high capital and processing costs which can be difficult to recover in the value of the products. Tyre recyclers have found it particularly difficult in recent years with low global oil prices causing international demand for TDF to decline. Domestic demand for TDF is limited due to few facilities that could use the fuel (e.g. cement kilns, large-scale industrial boilers). ➤ Commercialisation time: Lag-time between early-stage research and new product development: The tyre industry, through groups such as TSA, is working to develop local markets for a range of tyre-derived products that could consume a larger volume of recycled product (e.g. bituminous spray seal additives, tyre crumb-based explosives) but these efforts will take time to have a significant impact. ➤ Emerging technology untested in Australia: A number of pyrolysis technologies are being developed in Australia and overseas, and approaching commercial deployment but are still limited in their commercial track record and present a number of risks. Tyre pyrolysis technologies currently in use in South East Asia are generally considered unsuitable for the Australian context with regard to emissions controls and ability to comply with environmental regulations.
Suitable technologies	<p>Traditional tyre reprocessing to produce rubber crumb, scrap metal and waste fibres involves shredding and sorting technologies and then specialised machinery to convert the rubber crumb into a recycled granule (2-15mm), buffings (<2mm) and crumb rubber (less than 1mm).</p> <p>Emerging thermal technologies may provide further opportunities to recover fuel and energy from tyres in Australia. Steel can also be recovered and potentially carbon black.</p> <p>Thermal treatment technologies that can be used to recover energy from tyres are:</p> <ul style="list-style-type: none"> ➤ Pyrolysis (see Section 4.2) ➤ Gasification (see Section 3.4.2) ➤ Combustion (see Section 3.4.1)

Aspect	Description
Outputs	<p>Products made from shredding/processing tyres:</p> <p>Rubber crumb is produced in various size fractions for different applications, including:</p> <ul style="list-style-type: none"> › Crumb rubber (less than 1mm) used for tile adhesives, bituminous spray seal and asphalt › Buffings (less than 2mm) used for playground surfaces and artificial turf › Granule (2 to 15mm) used for equestrian arenas, mulch, walkways › Tyre-derived fuel (typically 50mm – 80mm) used as a fuel in cement kilns and industrial boilers in overseas markets <p>Traditional markets for crumb rubber, buffings and granule are limited (e.g. rubber flooring, soft-fall playground surfaces, tile adhesives). New markets such as asphalt additives, rubberised explosives and uses of tyre-derived aggregate (TDA) in civil engineering are being developed and expanded in Australia.</p> <p>Other products made from recycled rubber include:</p> <ul style="list-style-type: none"> › Marine non-slip surfaces, athletics tracks, playground and sporting surfaces › Explosives › Vibration dampening, for example beneath rail tracks › Brake pads › Building insulation › Civil engineering applications such as tyre reinforced earthen embankments and retaining walls <p>Products derived from thermal processing of tyres:</p> <ul style="list-style-type: none"> › Synthetic crude oil which can be refined to various fuels, oils and solvents › Carbon char or carbon black (subject to product quality standard) › Syngas for energy production › Electricity, heat (if combusted or gasified) › Recovered steel for recycling
Market constraints	<p>Existing markets are saturated: The 2015-16 National market development strategy for used tyres⁶ notes that use of crumb rubber in binders, glues and adhesives remains the major domestic market for tyre-derived products; however, these markets are largely saturated with only limited opportunity to expand from current levels.</p> <p>New markets require further R&D and specifications: The national strategy highlights a number of new local markets which could absorb significant volumes of tyre-derived products, such as crumb rubber in road construction (both in road spray seals and asphalt, rubberised explosives and the use of tyre-derived aggregate in civil construction; however, further R&D and nationally consistent specifications are needed to fully realise these applications and allow the market to more rapidly develop, supported by procurement practices focused toward recycled products and materials.</p> <p>Certain markets are untested in Australia: Markets for products of tyre pyrolysis are largely untested in Australia due to lack of operating commercial plants. Ability to comply with fuel and other product standards (e.g. carbon black), and the high cost of production, remain a significant challenge.</p>

⁶ Based on 2015-16 data in the National market development strategy for used tyres, Randell Environmental Consulting, 2017 (currently unpublished)

2.4 Plastics

Aspects	Description
Description	<p>Discarded plastics encompasses both flexible and rigid plastics:</p> <ul style="list-style-type: none"> ➤ Flexible – packaging film, plastic bags, shrink wrap, builder’s film, agricultural films such as bale wrap. The majority of flexible plastics are made of low density polyethylene (LDPE), linear low-density polyethylene (LLDPE) or high density polyethylene (HDPE). ➤ Rigid – bottles, containers, toys and building products such as pipes. The most common rigid plastics are made of polyethylene terephthalate (PET), high density polyethylene (HDPE), poly-vinyl chloride (PVC), and polypropylene (PP). <p>The major plastic polymer types are identified by a Plastics Identification Code (PIC) number from 1 to 7.</p>
Opportunities	<p>High value commodity: As plastic is derived from fossil fuels and effectively does not breakdown in the environment, recycling provides significant life-cycle benefits. Clean recovered plastics are a relatively high value commodity.</p> <p>Ease of collection and processing for rigid plastics: Rigid plastics are generally easier to collect and process and so have higher rates of recycling.</p> <p>Opportunities for increased collection and local reprocessing of plastic film: As collection of flexible plastics increases from households and businesses, there will be more opportunities for local reprocessing of this stream and diversion from landfill. A number of metropolitan Melbourne councils are trialling the collection of flexible plastic packaging within kerbside collection systems.</p> <p>Product stewardship supports increased recovery: For PVC in particular, there is a voluntary industry-run product stewardship scheme by The Vinyl Council of Australia, that supports recovery and recycling of PVC.</p>
Challenges	<ul style="list-style-type: none"> ➤ Lack of collection systems and processing for flexible plastics: For the flexible plastics that are recovered, the majority are recovered from industrial sources and sent overseas for processing. Very little post-consumer domestic material is currently recovered. Flexible plastics are generally recyclable but more challenging to commercially collect and reprocess given their low density. In conventional kerbside recycling systems, film plastics are considered a contaminant that causes blockages in equipment and affects product quality. ➤ Variation in types of rigid plastics accepted at MRFs: The types of plastics that are accepted in commingled recycling systems and at Clean MRFs varies, and therefore, the recovery potential varies in different areas. Furthermore, these plastics generally need to be separated into resin types for remanufacturing into new products. Given the large number of plastic products and packages, the separation of plastics can be challenging. ➤ Cost of processing: Many plastics contain dyes, fillers and additives, which are difficult to remove in the recycling process and may affect product quality. Furthermore, composite products such as plastic film/metal foil composites are difficult to recycle because it is virtually impossible to separate the composite materials. ➤ Degradation and reduced quality: Most flexible plastics are thermoplastics⁷ which means that the polymer structure is degraded by reprocessing. This means that the materials are often reprocessed into products of lower value than the original product. ➤ New packaging types have reduced recyclability: The trend away from rigid packaging by manufacturers of products such as detergents and sauces towards lighter weight flexible pouches and sachets has reduced the recyclability of the packaging.

⁷ A thermoplastic is a plastic material that becomes pliable or mouldable above a specific temperature and solidifies upon cooling.

Aspects	Description
Suitable technologies	<p>Traditional plastic recycling varies by type, but generally involves sorting by plastic resin type and then melting and extruding into pellets than can be re-manufactured into new products (see Section 3.5.3).</p> <p>For plastics that cannot be viably recycled (e.g. low grade or contaminated mixed plastics), thermal technologies may also be suitable to exact energy and/or produce fuels and oils:</p> <ul style="list-style-type: none"> › Pyrolysis (see Section 4.2) › Gasification (see Section 3.4.2) › Combustion (see Section 3.4.1) <p>Alternatively, plastics can be converted into RDF products for use in cement kilns or other thermal plants. Clean, well-sorted plastics are a high value product and should preferably be recycled where it is practical and viable to continue their use as a valuable resource, but thermal technologies which generate energy or produce a source of energy may be best for mixed residual waste with a high proportion of plastics that cannot be feasibly separated out.</p>
Outputs	<ul style="list-style-type: none"> › Flexible – A range of products including bollards, fence posts, speed humps and street furniture, as a substitute to using virgin plastic or timber. For example, Melbourne-based Replas currently recycles flexible plastics, mostly sourced from supermarkets through plastic bag take-back bins, into man-hole lids (for utility companies) and street furniture. › Rigid – Rigid plastics are sorted, cleaned and shredded to form granules, which can be used to make a range of products including bottles, wheelie bins, plastic pipe, outdoor furniture and textiles. To make textiles, the granules are melted, extruded and spun into polyester yarn. <p>The international standard <i>ISO 15270:2008 Plastics – Guidelines for the recovery and recycling of plastics waste</i> should be observed in producing the above products from plastic waste.</p>
Market constraints	<ul style="list-style-type: none"> › Low global oil prices reduce the value of recycled plastics: The main constraint on plastic recycling is the impact of global oil prices, which is a key ingredient to manufacturing virgin plastics. The recent sustained low oil prices reduces the value of recycled plastics in export markets and makes it cheaper to manufacture new virgin polymers, compared to recycled polymers. Victorian plastic recyclers rely heavily on export markets with the majority of material destined for China. › Contamination of feedstock decreases product value: The quality of end products made from recycled plastics is directly related to the quality of inputs/feedstock. The level of contamination in many source feedstocks further restricts the export market. There have been increased constraints placed on plastics imported into China in recent years. This has impacted the local and national recycling markets, forcing additional sorting and processing, or stockpiling of material that is low value and not cost effective to process further. › Entry of 'bio-plastics' into the market: 'Bio-plastics' produced from renewable materials such as plant biomass have begun to enter the plastics recycling stream. Many of these are not recyclable by conventional methods and considered contamination which can affect the quality of the recycled plastic stream and its saleability. › Market preference for clear plastics: Clear plastics are preferred in the recycled materials market. The variety of colours of rigid plastic constrain the recycling of some plastics.

2.5 E-waste

Aspect	Description
Description	<p>'E-waste' describes waste electrical or electronic equipment, or anything with a power cord or battery at the end of its useful life. It includes a range of items used and discarded at work and at home. These items contain a range of materials, from precious metals to ceramics, glass and polymers (plastics).</p> <p>Currently, whitegoods (e.g. fridges, cookers, etc.) are generally managed through scrap metal dealers, while end-of-life TVs and computers are collected through the National Television and Computer Recycling Scheme (a product stewardship scheme).</p> <p>However, small e-waste items not included in the National Television and Computer Recycling Scheme (e.g. electronic toys, torches, hair care and beauty products, vacuum cleaners, heaters, etc.) are generally not recycled and are disposed to landfill.</p>
Opportunities	<ul style="list-style-type: none"> ➤ Recovery of valuable components: As consumption of electrical and electronic goods increases and the lifespan of these goods decreases, the generation of e-waste is growing up to three times faster than general municipal waste in Australia. This is creating an opportunity to recover significant volumes of e-waste and extract valuable components, particularly metals including rare earth metals. ➤ New policy settings support increased recovery: The Victorian Government is committed to banning the landfilling of e-waste from 2018, which will likely drive additional recovery, particularly of smaller appliances such as toasters and hair dryers.
Challenges	<ul style="list-style-type: none"> ➤ Environmental and occupational risk / Social licence to operate: Processing large volumes of e-waste by hand requires substantial labour and the risk of being exposed to potentially toxic compounds, while mechanical processing requires shredding of e-waste into small or even fine particles (less than 5 to 10 mm). Workplaces need to ensure environmental, health and safety measures are adequate in preventing workplace accidents and reducing exposure to toxics and airborne fines. There is a possibility that unless managed well, e-waste recovery may not gain the 'social licence' to operate from the community. Any sight that processes greater than 500 tpa of e-waste requires a licence from EPA. ➤ Current processing capacity and cost of technology: As the Victorian government implements a landfill ban for e-waste, the processing capacity of industry will need to increase in order to handle the increase in volumes and types of e-waste. Mechanical technologies are becoming more common but the best technology, with the highest environmental and OHS safeguards, will come at the highest cost. ➤ Lack of collection systems: At present, collection systems for e-waste are limited to select drop-off points and it is not always easy for consumers to know where/how to dispose of e-waste, resulting in e-waste ending up in the municipal residual waste bin or 'stockpiled' in the home. Furthermore, some collection points do not have adequate systems in place to manage the environmental and human health risks from the more hazardous types of e-waste, such as cathode ray tube screens and computers.
Suitable technologies	<p>E-waste is often dismantled by hand as it is difficult to have machinery that can adapt to the wide range of e-waste types. The recycling process generally involves:</p> <ul style="list-style-type: none"> ➤ Removal of hazardous components (batteries, mercury lamps, etc.) ➤ Either manual dismantling or mechanical processing (e.g. shredding, crushing followed by sorting techniques) to liberate and separate target materials and homogenise the streams ➤ End processing of the separated streams through physical, chemical and thermal processes, to refine products for reprocessing or prepare residues for appropriate disposal. <p>The use of pyrolysis (Section 4.2) is an emerging option being developed for dismantling e-waste into its constituent compounds for separation and recovery.</p>
Outputs	<p>Individual components (recovered by manual processing), or flakes or small particles of plastic, ceramics, glass and various metals (recovered by mechanical processing).</p> <p>The steel, copper and aluminium are often smelted in Australia, as well as some plastics, while other plastics may be exported for reprocessing overseas. Other components that may be exported for reprocessing include batteries from which cadmium, lithium and cobalt can be recovered.</p> <p>These can then be remanufactured into new products.</p>
Market constraints	<ul style="list-style-type: none"> ➤ Poor sorting/processing undermines product quality: Markets for recycled materials from e-waste can be constrained by poor quality recycled materials if the sorting/processing process is not adequate. ➤ Volatile commodity markets: As global commodities, recycled materials from e-waste can decrease in value when the commodity price falls, which can make virgin materials cheaper and more attractive to industry, impacting the viability of e-waste recycling operations

2.6 Glass Fines

Aspects	Description
Description	Glass fines are small pieces of glass, typically <50mm, which are the heavy undersize stream from the screening of commingled recyclables in a MRF. As such, the stream also contains a range of other waste materials including ceramics, stoneware and Pyrex fines, and small pieces of plastics, metals and paper. In raw form, the contamination may represent up to 30 per cent of the glass fines stream depending on the Clean MRF process.
Opportunities	<ul style="list-style-type: none"> › Government support for increased recovery: The Victorian Government has identified glass fines as a priority material in its Victorian Market Development Strategy for Recovered Resources⁸. › Production of glass sand and other aggregate products: There are opportunities to extract the glass (through mechanical sorting) and crush it to produce glass sand and other aggregate products. This solution is being implemented at a number of locations across Australia. There are also a number of other solutions are being investigated currently within Victoria.
Challenges	<ul style="list-style-type: none"> › Low value of glass fines: In raw form from the MRF, glass fines (<50mm) are unsuitable for use in glass manufacturing due to contamination. It is technically possible to mechanically process glass fines through a beneficiation process which recovers the glass for remanufacturing, this option is not always commercially viable as glass manufacturers can generally satisfy their demand for recovered glass from uncontaminated glass cullet (>50mm) with little incentive to invest in more advanced and costly recovery of glass from fines. › High cost of further processing: Glass beneficiation and extracting and crushing the glass into glass sand and other products are both net cost processes – they require a gate fee to process the glass fines because the value of the recovered products is insufficient to cover processing costs. In Victoria, glass fines currently represent a negative value stream with limited market outlets, resulting in high rates of landfilling and stockpiling. In 2015, SV estimated that there is some 300,000 tonnes of glass stockpiled at sites across Melbourne⁹.
Suitable technologies	<ul style="list-style-type: none"> › Glass fines beneficiation (Section 3.5.4) › The other solution, which is being implemented at a number of locations across Australia, is to extract the glass (again through mechanical sorting) and crush it to produce glass sand and other aggregate products.
Outputs	<p>Glass fines can be recycled back into glass manufacturing following a beneficiation process, or converted into recovered sand and aggregates for use in various applications including:</p> <ul style="list-style-type: none"> › asphalt ('glassphalt') › sand/abrasive grit blasting › construction, piping and road aggregates › concrete aggregate › sports turf/drainage › brickmaking additives › glass wool insulation › filler powder for resins, paints, glues › water filtration media <p>Glass fines can also be used as an alternate day cover for landfills, which is a particularly low value use.</p>
Market constraints	<ul style="list-style-type: none"> › Reduced manufacturing demand for recovered glass: Glass manufacturing in Australia is in decline due to competition from imported products and other packaging types, which impacts demand for glass cullet recovered from fines. › Slow uptake of recovered glass sand and aggregates: For glass sand products, there is a reluctance by civil contractors (including councils) to use recovered glass sand and aggregates in applications such as pipe bedding or asphalt mixes, despite its technical performance being as good as virgin sand. Demand in civil applications is likely to be inconsistent, following construction cycles and large civil infrastructure projects. › Competing material prices: Virgin quarried sand is still relatively abundant and cheap so it is difficult for recovered glass sand to compete on price with virgin and other recovered aggregate products. › New markets are yet to fully develop: Other more advanced applications for glass sands such as water filtration media or sand blasting media, exist and are being further developed, but currently consume small quantities of glass.

⁸ <http://www.sustainability.vic.gov.au/our-priorities/statewide-waste-planning/2015-2020-priorities/victorian-market-development-strategy-for-recovered-resources>

⁹ Victoria's Waste & Resource Recovery Infrastructure Investment Prospectus, October 2015

2.7 Concrete and Brick

Aspect	Description
Description	<p>Concrete and brick are dense, inert, solid materials. Concrete is made of cement, aggregates (e.g. sand, gravel, or recycled material) and water, and may include steel reinforcing. There are various types of bricks made from combinations of clay with sand, and lime or concrete materials.</p> <p>Concrete and brick are common materials used in building construction and therefore make up a significant proportion of waste generated by demolition activities.</p> <p>Bricks are more commonly recovered from domestic demolition sources, whereas concrete is commonly recovered from commercial and civil demolition sources.</p>
Opportunities	<ul style="list-style-type: none"> ➤ Relative ease and low cost of processing: Concrete and bricks are highly recycled due to the relative ease and low cost of reprocessing and significant demand for aggregate products for construction and infrastructure projects. ➤ Metropolitan opportunities: A shortage of virgin quarry material in close proximity to the Melbourne area is favouring the use of recycled content products. The close proximity of C&D reprocessors in Melbourne also reduces transport costs compared with virgin quarry sourced materials from further afield. ➤ Regional processing opportunities: There are opportunities to provide increase recovery of concrete and brick in regional areas of Victoria, but scale is a significant factor in justifying investment in the crushing and screening equipment. One solution is to jointly procure or hire mobile equipment to undertake periodic crushing and sorting as needed. ➤ Source separated loads provide high quality outputs: Unlike other priority waste material streams (such as glass, discussed above in Section 2.7), the reprocessing industry is able to encourage masonry materials to be separated at the source (or at intermediate facilities) by using pricing mechanisms such as gate fees, which are lower for source separated loads. Source separated loads enable simpler, cheaper and more effective processing and higher quality recycled products to be produced. ➤ Product specifications boosting confidence in recycled products: The market for recycled masonry products is beginning to emerge more rapidly as new applications, supported by product specifications, become more widely accepted and implemented.
Challenges	<ul style="list-style-type: none"> ➤ Mismatched supply and demand: It can be a challenge to manage supply and demand, due to mismatches in the timing of activity in the supply (construction and demolition) and demand (e.g. roads and infrastructure projects) sides of the market. Stockpiling of concrete and brick helps to even out fluctuations in supply and demand, within regulatory and site licence constraints. ➤ Changing building technology and construction methods: The viability of recycling C&D materials could potentially be affected by changes in building technology and construction methods, such as the use of expanded polystyrene 'waffle pods' in slab construction which make it harder for the concrete to be recovered using current technology. Stronger binding agents in brick construction make whole brick recovery more difficult and increases the proportion of broken bricks and the difficulty of cleaning bricks for re-use.
Suitable technologies	<p>It is often possible to source separate most brick and concrete during demolition to facilitate recovery. Otherwise, the materials can also be extracted from mixed C&D waste in a C&D MRF (see Section 3.2.2). It is noted that concrete and brick are typically processed together as there is little benefit in separating them once mixed.</p> <p>Following the C&D MRF processing, concrete and brick is crushed and screened to produce a secondary aggregate (see Section 3.5 reprocessing technologies).</p>
Outputs	<p>Crushed concrete can be reused as an aggregate within new concrete, and recovered concrete and brick aggregates can be used in structural fill, road base, paths, backfill and drainage applications. Aggregate products are screened to produce a variety of size fractions for different applications.</p> <p>Whole clean bricks can be reused intact in housing and construction.</p>

Aspect	Description
Market constraints	<ul style="list-style-type: none"> › Perceptions of product quality: The market for recycled masonry products functions well, but it can be constrained by customer perceptions of product quality. Anecdotal evidence suggests there may be some reluctance to use recycled product for higher performance applications where traditional “proven” products are available. Evidence (case studies) and user experiences supporting the application of recycled products is gradually growing in the market place. › Competing material prices: Recovered aggregates need to compete on price with virgin materials or be cheaper to overcome product quality perceptions in the market. › Contractual specifications for ‘natural’ products: Some construction specifications state the use of ‘natural’ products. This means that civil contracting companies undertaking these works are limited in their ability to substitute ‘natural’ products with recycled products. › Costly transport distances restrict regional markets: Cost of transport (i.e. proximity of source material to end use) will continue to be a governing factor in the economic viability of recycled vs virgin aggregate products. Whilst major C&D waste reprocessing infrastructure has been established in metropolitan Melbourne, similar operations are generally lacking in regional areas of Victoria.

2.8 Mixed Residuals

Aspect	Description
Description	<p>Mixed residual wastes are materials that cannot be viably recovered via existing systems or have not been captured by existing recycling systems. This includes the garbage collected from households, businesses and industry, as well as the waste material from reprocessing activities that cannot be recovered or is considered contamination.</p> <p>Mixed residuals typically comprise a broad mix of materials, which depending on the source, may include:</p> <ul style="list-style-type: none"> › food and garden organics › wood waste › plastics › paper and cardboard › ferrous and non-ferrous metals › textiles and leather › glass › rubber › nappies and sanitary items › electronic goods and other composite products › masonry materials, sand and soil › hazardous materials inadvertently placed in the bin such as batteries and chemicals, or part of a composite product.
Opportunities	<ul style="list-style-type: none"> › Advanced sorting technologies: There are numerous approaches to sort mixed residual streams to extract materials which can be recycled or used for energy recovery. › Waste to energy: The high calorific value of the organics and plastics within mixed residual waste provide an opportunity to recover that energy in a usable form, as feedstock for refuse-derived fuels (RDF) or energy recovery plants. Under the waste hierarchy, this option is preferable over landfilling, once all viable recycling opportunities have been applied. Genuine residual waste is suitable for waste to energy, and the potential tonnages available in Victoria is sizeable (over a million tonnes annually). Residual waste is a waste stream that would benefit from advanced technological solutions including waste to energy. › Government support for increased recovery: Recovering value from mixed residuals is a key priority of the Victorian Government as set out in the SWRRIP. The plan supports increased resource recovery at landfill sites and collaborative procurements of advanced residual waste treatment solutions by councils. › Household collection systems and volumes: There is no need to alter existing household kerbside collection systems for mixed residuals to support recovery solutions and there are significant volumes generated across the state, with approximately 28 per cent of residual materials currently being landfilled derived from household collections.

Aspect	Description
Challenges	<ul style="list-style-type: none"> ➤ Low cost of landfill: In many cases, landfills provide a cheaper option for managing mixed residuals than many resource recovery options which are typically advanced technologies and thereby costly to construct and operate. Waste material streams tend to flow to the lowest cost pathway. ➤ Securing large volumes of feedstock: Challenges remain in securing the required feedstock volumes under long term contracts to support investment in advanced waste technologies for mixed residual waste. ➤ Potential impacts on the environment, community amenity and public health: Mixed residuals include putrescible materials which can generate noxious odours if not well managed and can lead to community complaints and in a 'worst case' scenario, potential regulatory action. ➤ Contamination and sorting mixed streams: Separating mixed waste streams is technically challenging and often results in low quality and contaminated materials. Advanced technologies provide an option to achieve this but come at higher cost and have their limitations. Contamination is a significant constraint and there is a greater risk of unknown contaminants being present. ➤ Slow uptake of advanced technologies: Overall, progress in implementing advanced technologies, particularly thermal treatment solutions, for mixed residuals in Australia has been slow, despite such solutions being commonplace in other parts of the developed world. There is some nervousness within local government and industry surrounding the technical and commercial risks of advanced technologies, partly fuelled by high profile failures of the past.
Suitable technologies	<p>At present, mixed residual waste is mostly landfilled in Victoria, but there are technologies, both proven and emerging, which can capture additional resources and energy from this waste stream. Advanced sorting technology may be installed at landfill sites to allow pre-sorting of waste on site so that only the genuine residual waste is landfilled.</p> <p>Mechanical biological treatment (MBT) (Section 3.2.3) combines mechanical sorting and biological treatment methods, and allows recovery of the significant organic fraction in putrescible mixed residual waste streams.</p> <p>Mechanical processing of residual waste via a "Mixed Waste MRF" (Section 3.2.2) can lead to separation of various recyclable material streams (e.g. plastics, metals, masonry materials). Mixed Waste MRFs have been commonly adopted for the recovery of materials from residual household and C&I waste.</p> <p>Thermal treatment technologies can also be applied, either directly to mixed residual waste, or to an RDF derived from mixed residual waste, including:</p> <ul style="list-style-type: none"> ➤ Combustion (Section 3.4.1) ➤ Gasification (Section 3.4.2) <p>Other emerging technologies including plasma gasification and pyrolysis (Chapter 4).</p>
Outputs	<p>Recyclable materials, which have not been captured by source segregation systems, may be extracted from mixed residuals through advanced mechanical sorting approaches (see Section 3.2). This depends on the source and nature of the stream – dry streams with limited putrescibles such as C&D waste or dry commercial waste, are easier to sort in this way.</p> <p>Recycled organics (RO) products can be recovered from mixed putrescible residuals via MBT solutions, for use as soil conditioner. However, the quality is lower and the contamination significantly higher, than RO products produced from source segregated organics and these products are unlikely to meet specifications required for agricultural land use. Producers of mixed putrescible residues from MBTs are advised to seek EPA guidance on appropriate applications and specifications for use of these materials.</p> <p>Energy products including electricity, heat and gas fuels, as well as manufacture of RDF which can be transported off site and used to produce energy elsewhere (e.g. at cement kilns, large industrial boilers).</p>

Aspect	Description
Market constraints	<ul style="list-style-type: none"> Difficulty accessing the energy market: Most energy markets are volatile and it can be difficult to predict and rely on revenue from energy products, which can impact the viability and bankability of a project. Some markets such as the National Electricity Market provide a secure energy outlet but may not provide adequate value to make a project viable and private or direct supply outlets may prove more attractive. Achieving long-term security in energy outlets (e.g. through power purchase agreements) is challenging, particularly for smaller scale projects. Markets for waste derived fuels and gas products are largely untested in Australia and generally not as well supported through government incentives and market interventions (as renewable electricity markets, for example). Limited product application: There are limited market opportunities for RDF in Victoria due to a lack of existing thermal processors that could utilise this fuel (for example, cement kilns). Similarly, there are limited markets for residual ash from thermal processing of mixed residual waste. Internationally, ash has been used in road base and similar applications. Highly contaminated ash may need to be disposed as prescribed waste which adds to overall project costs. Poor quality, low value of recovered materials: The quality of recyclables (e.g. plastics) recovered from mixed waste is low, which may limit markets and outlets, particularly in the face of competition from cleaner streams. Similarly, RO products recovered from mixed waste typically have limited market outlets (mostly mine and landfill rehabilitation), given the higher contamination levels, customer perceptions and competition from clean stream products.

3 Current Resource Recovery Technologies

The discussion on resource recovery technologies in this Guide is broadly divided by those technologies which are currently in use at commercial scale and considered to be proven and established, versus those which are still in varying stages of development and commercialisation with a limited commercial track record, and considered to be emerging technologies. This chapter covers the current, established technologies while chapter 4 covers the technologies considered to be emerging.

The distinction between established and emerging technologies is not always clear cut. Some of the technologies that are classed as emerging and discussed in Chapter 4 have a track record in recovering particular material types or within particular industrial niches (these situations are noted where appropriate). Some of the technologies discussed in this chapter are technically proven, but commercially challenged. There are many examples of technologies where a particular version or application, or specific proprietary system, is commercially proven whereas the majority of the technologies in that category are not proven and therefore that category in general is considered emerging.

Technologies which are considered established and proven will typically have multiple commercial scale facilities, usually from more than one provider, that have been in regular operation for a significant period of time (years). Technologies which are commercially established overseas but have not yet been implemented in Victoria or Australia, are still considered in this current resource recovery technologies section.

The classification of a technology as 'emerging' in this Guide is not intended to suggest that it should be avoided but rather that there may be additional risks and considerations, or questions to be asked of technology proponents. Innovation in waste processing technologies is to be encouraged but all users of, and investors in, resource recovery technologies need to be properly informed about the commercial track record, risks and limitations associated with a given technology. This Guide is not intended to provide an exhaustive discussion on these issues, but rather to highlight common risks and issues, and prompt further investigation where appropriate.

Resource recovery technologies and solutions discussed in this Guide have been broadly classified as follows:

- › **Sorting solutions**, whose predominant purpose is to sort a mixed waste stream into component materials for recovery, using mostly mechanical sorting techniques, such as clean and dirty MRFs, MBT and mechanical heat treatment (MHT) technologies
- › **Biological treatment solutions**, for recovery of resources from organic wastes, including aerobic composting and anaerobic digestion technologies
- › **Thermal treatment solutions**, where the predominant conversion process is thermal and energy recovery is usually the main objective, including gasification, pyrolysis and combustion technologies, but also thermal dehydration of organics
- › **Reprocessing technologies**, which are predominantly mechanical but may involve biological or thermal elements, and are focused on adding value to an already separated material to prepare it for sale and/or re-manufacturing.

Table 2 below illustrates the rating scheme that has been applied to each technology to indicate its track record on the waste streams identified as relevant.

TABLE 3: RATING SCHEME FOR RESOURCE RECOVERY TECHNOLOGIES

Track Record	Definition
Well Established	Tens or more facilities with a long track record of operating commercially
Established at Commercial scale	Multiple facilities operating commercially, over a significant period of time (several years)
Limited Track Record	Multiple facilities operating at commercial scale but mixed success / limited current operations
Very Limited Track Record	Very few commercial scale plants, mixed commercial success, existing plants may be mostly demonstration or pilot plants, with very limited full scale operational experience
Not Established	No known commercial plants / poor track record of operation

3.1 Technologies overview

Each technology is best suited to processing a range of different waste feedstocks and generating various products. The matrix below (Table 4) provides an overview of these factors to guide readers to the most relevant sections of this Guide. Further detail on key technical parameters is provided in the following sections and Chapter 4 (emerging technologies).

TABLE 4: SUMMARY OF KEY RESOURCE RECOVERY TECHNOLOGIES, THEIR MATURITY, SUITABLE FEEDSTOCKS AND RESULTING PRODUCTS

Technology	Feedstocks	Products / outputs	Maturity	Section
Sorting processes				
Clean Materials Recovery Facility (MRF)	Mixed / commingled recyclables (municipal and commercial)	<ul style="list-style-type: none"> ➤ Separated recyclable materials: paper, cardboard, plastics, glass, steel and aluminium ➤ Glass fines for potential further processing ➤ Light residuals – potential RDF ➤ Residuals to landfill 	Proven, well established in Victoria and internationally	3.2.1
Dirty Materials Recovery Facility (MRF)	Mixed residual waste (C&D, municipal and commercial)	<ul style="list-style-type: none"> ➤ Separated recyclable materials including paper, cardboard, plastics, glass, steel, aluminium, masonry products, soil, timber ➤ RDF ➤ Residuals to landfill 	Well established for C&D and dry C&I, less so for municipal waste	3.2.2
Mechanical-Biological Treatment (MBT)	Mixed putrescible residual waste (mostly municipal, but also commercial), other organics	<ul style="list-style-type: none"> ➤ Low grade soil improver / compost ➤ Recyclable materials including rigid plastics, steel and aluminium ➤ RDF ➤ Residuals to landfill (up to 40-50 per cent without RDF) 	Proven, well established in Australia and internationally	3.2.3
Mechanical Heat Treatment (MHT)	Mixed residual wastes (municipal and commercial)	<ul style="list-style-type: none"> ➤ Organic rich fibre – low grade soil improver, fuel ➤ RDF from inorganic fraction – to thermal process ➤ Recyclables (low grade) 	Limited track record - one facility in Australia but otherwise limited examples operating commercially	4.1
E-waste recycling	Electronic and electrical wastes	<ul style="list-style-type: none"> ➤ Separated plastics and metals for reprocessing ➤ Hazardous residues for disposal ➤ Dust and wastewater residues from emission control systems 	Established with several operating facilities, but evolving technologies and feedstocks	3.2.4
Biological treatment solutions				
Open windrow composting	Garden organics, stabilised biosolids, manure	<ul style="list-style-type: none"> ➤ Compost, mulch ➤ Residuals 	Proven, well established across Victoria and Australia	3.3.1.1
Aerated static pile composting	Garden & food organics, biosolids, manure	<ul style="list-style-type: none"> ➤ Compost, mulch ➤ Residuals 	Proven, well established across Australia	3.3.1.2
In-vessel composting	Garden & food organics, food processing waste, industrial organics, liquid organics, odourous wastes	<ul style="list-style-type: none"> ➤ Compost, mulch ➤ Residuals 	Proven, well established in Victoria and internationally	3.3.1.3

Technology	Feedstocks	Products / outputs	Maturity	Section
Vermicomposting	Food organics, soft garden waste, pre-composted or digested material	<ul style="list-style-type: none"> › Castings › Worms › Liquid fertiliser › Residuals 	Proven technology, but limited successful commercial plants	3.3.1.4
Anaerobic digestion	Food organics, commercial organics, biosolids, manures, food and beverage processing waste, liquid organics Garden organics, crop residues (dry AD only)	<ul style="list-style-type: none"> › Biogas / biomethane, CNG, electricity, heat › Digestate (compost) › Residuals 	Proven, well established internationally, with increasing adoption in Australia	3.3.2
Thermal treatment solutions				
Combustion	Mixed residual waste, RDF, waste timber, agricultural residues	<ul style="list-style-type: none"> › Electricity, heat › Bottom ash – recovered aggregate / fill › Fly ash – for disposal or recovery › Recycled metals (from bottom ash) 	Well established and proven internationally. No plants in Australia processing mixed waste but there are small plants for single-stream biomass wastes.	3.4.1
Gasification	Mixed residual waste, RDF, waste timber, plastics, agricultural residues	<ul style="list-style-type: none"> › Electricity, heat › Syngas – into chemicals, fuels, gas › Bottom ash – recovered aggregate / fill › Fly ash – for disposal or recovery › Recycled metals (from bottom ash) 	Multiple commercial references, much less than combustion, mostly close-coupled syngas combustion configurations. More advanced production of clean syngas is yet to be commercialised	3.4.2
Pyrolysis	Tyres, plastics, dry biomass, RDF	<ul style="list-style-type: none"> › Liquid oil, fuels, solvents › Syngas - electricity, heat › Char – biochar, carbon black › Recyclables – mostly metals (e.g. from tyres) › Gas clean-up residues (hazardous) 	Limited – a number of tyre technologies are close to commercialisation in Australia but limited operations history Pyrolysis of other waste streams is challenging with varying degrees of success	4.2
Plasma gasification	Mixed residual waste, RDF, wood, hazardous wastes	<ul style="list-style-type: none"> › Syngas – clean, carbon monoxide + hydrogen, can be used for electricity, heat, fuels, chemicals › Slag – aggregate product › Metals › Gas clean-up residues (hazardous) 	Not yet proven in commercial operation on mixed waste streams. Notable large scale failures overseas.	4.3
Torrefaction	Waste wood, some organics and forestry or agricultural residues	<ul style="list-style-type: none"> › Charcoal solid fuel 	Limited commercial scale plants in operation internationally	4.4

Technology	Feedstocks	Products / outputs	Maturity	Section
Dehydrators	Food organics from commercial catering, other wet organics	<ul style="list-style-type: none"> › Dried organics powder › Condensed wastewater 	Multiple commercial plants in operation, but only in small scale, niche applications	3.4.3
Advanced fuel production				
Fermentation	Bagasse, crop residues, forestry residues, food processing waste, waste wood, paper & cardboard	<ul style="list-style-type: none"> › Ethanol › Stillage (compost) 	Limited commercial scale plants in operation internationally	4.5.1
Gas-to-liquids processes	As for gasification and plasma gasification: Mixed residual waste, RDF, waste timber, plastics	<ul style="list-style-type: none"> › Liquid fuels (various) › Bottom ash – recovered aggregate / fill › Fly ash – for disposal or recovery › Recyclables extracted in pre-processing 	Limited commercial scale plants in operation internationally	4.5.2
Hydrothermal Liquefaction	Biosolids, food processing wastes, slurries and manures, ground woody biomass	<ul style="list-style-type: none"> › Bio-crude › Refined liquid fuels › Residuals / ash 	No known commercial plants, pilot plants only	4.5.3
Reprocessing solutions				
Timber Shredding	Source segregated timber or timber extracted by a dirty MRF (excluding treated, painted or glued timber)	<ul style="list-style-type: none"> › Mulch › Biomass fuel › Animal bedding › Feedstock to particleboard manufacturing 	Well established across Victoria and Australia	3.5.1
Mechanical recovery of rubber	Separated end-of-life tyres, conveyor rubber	<ul style="list-style-type: none"> › Tile adhesive additive › Spray seal bitumen additive › Rubber flooring and mat products › Playground soft-fall surfaces › Sports facility surfaces › Moulded products › Inorganic mulch 	Well established across Victoria and Australia	3.5.2
Plastics reprocessing	Separated plastics including flexible plastics and EPS	<ul style="list-style-type: none"> › Cleaned and pelletised polymer feedstocks › Final products including outdoor furniture, bollards, fence posts, decking boards and manhole pit lids 	Well established technologies but limited to small scale applications in Victoria	3.5.3
Glass fines beneficiation	Glass fines stream from a clean MRF	<ul style="list-style-type: none"> › Crushed, sorted glass cullet; or › Glass sand of various size fractions for use in construction and other applications 	Proven technologies across a small number of commercial facilities in Australia	3.5.4
Concrete & brick recycling	Source segregated concrete and brick (and other masonry products) or extracted via a dirty MRF from mixed C&D	<ul style="list-style-type: none"> › Recovered aggregate for civil / construction applications 	Well established across Victoria and Australia	3.5.5

3.2 Sorting solutions

Sorting solutions in this context include processes which are primarily designed to physically separate mixed waste streams into component materials, either for reuse or sale to reprocessors; or for further recovery via biological or thermal methods (discussed below). Sorting solutions vary in their scale and degree of sophistication depending on the quality of the feedstock (e.g. contaminant levels) and quality requirements for the products.

Sorting systems for mixed waste streams can be broadly categorised under the following technology types:

- › Clean materials recovery facilities (clean MRFs)
- › Dirty materials recovery facilities (dirty MRFs)
- › Mechanical biological treatment (MBT)
- › Mechanical heat treatment (MHT)

Clean MRFs and dirty MRFs are pure mechanical sorting systems, generally with no conversion or modification of the component materials once they are separated. MBT is a group of technologies that combine mechanical sorting with biological treatment of the organic fraction, and have been included here given the primary objective is to sort mixed waste for subsequent recovery.

Mechanical heat treatment technologies are primarily designed to separate out the organic fraction for subsequent processing, using a combination of mechanical and thermal processes. MHT technologies are discussed as an emerging technology in Section 4.1 as, while there are some successful projects, they have generally not attained the technical and commercial track records to be considered a proven technology.

3.2.1 Clean MRF

A clean materials recovery facility (MRF) is designed to further sort dry recyclables which have been partially segregated, such as a kerbside commingled stream, into materials suitable for sale onto reprocessors. Clean MRFs typically receive source-separated commingled recyclables from domestic kerbside collections and commercial recycling collections. They may also receive source separated dry recyclables from resource recovery centres and drop off facilities.

MRFs utilise a variety of mechanical separation techniques. Most modern MRFs are highly automated but still include some element of manual sorting; either to remove unwanted materials (plastic bags, other contaminants, hazardous items) or to pick out higher value materials not easily separated by the machinery.

The mechanical sorting equipment used in a MRF is often a function of the scale of the plant (larger plants can justify investing in more advanced equipment) and the relative value of the end products (e.g. value of mixed plastics versus separated polymers). MRFs are usually flexible in that they may utilise additional shifts to either extend the capacity of the facility or to 'polish' grades of recyclables when the market value can justify the additional costs associated (e.g. separating 'mixed papers' into newspapers and magazine fractions).

Common equipment in a typical MRF includes:

- › Feed hoppers and conveyors which provide a constant metered feed to the process
- › Manual picking stations which present the materials on a conveyor for picking in a safe manner
- › Various types of screens to sort materials based on particle size (e.g. trommel screen) or shape (e.g. star screens which separate 2D flat paper and cardboard from 3D containers)
- › Ballistic separators and wind-sifters which sort heavy materials (glass, metal, rigid plastic) from lightweight materials (paper, plastic film)
- › Magnets to capture ferromagnetic metals
- › Eddy current separators to capture non-ferrous metals (mostly aluminium)
- › Optical sorters to separate plastics by polymer type and/or colour, or glass by colour
- › Glass breaker to prepare sorted glass into cullet for transport
- › Balers to pack materials into dense bales for transport

Further detail on equipment types and options is presented in Figure 2. Some MRFs are specifically designed to sort and consolidate recyclables from the commercial sector, which may present differently to domestic commingled recyclables – for example, they may receive a large proportion of source separated cardboard.

Outputs and residues

Materials accepted at a clean MRF will consist mainly of commingled dry recyclable materials; mostly glass, metals, paper, cardboard and rigid plastic. These materials, once sorted, will be sold onto reprocessors which may be domestic or overseas.

A small number of MRFs in Australia accept plastic film, but this is currently constrained by lack of markets for the material and ability of the process to handle it. This may change over time and flexible plastics are a priority material for ongoing market development activities in Victoria¹⁰.

Clean MRFs rely on the sale of recovered materials to reprocessors as the major revenue stream, more so than gate fees. Therefore it is important to establish that long term markets are available for the products, and to account for fluctuations in future commodity prices. These are global commodities, often sold into export markets, so will be influenced by macro-economic factors.

MRFs also produce a residual stream which comprises the contaminants and undesirable materials removed during processing, as well as fine recyclable materials (small pieces of glass, plastic and bottle tops) that have fallen through the screens. These residuals are generally disposed to landfill. The proportion of residuals (relative to inputs) is a function of both the MRF process (technology choice) and the level of contamination in the feedstock (efficiency of source separation at the origin of the recyclables), which in turn is impacted by the sorting behaviour of the waste generators.

In some cases, a heavy fines stream will be produced which contains most of the broken glass fines as well as small pieces of plastic and metal. This can be sent for further reprocessing to recover the glass and other materials (see discussion on glass fines processing in 3.5.4). This is dependent on there being a market for the recovered glass fines.

The light residual fraction from a MRF, if kept separate from the heavy fines, will include plastic film and small pieces of paper and cardboard. This stream has potential for use as a refuse derived fuel, subject to outlets being available.

10 www.sustainability.vic.gov.au/our-priorities/statewide-waste-planning/2015-2020-priorities/victorian-market-development-strategy-for-recovered-resources

Track Record

Clean MRF technology is well established and commonly used across Australia and internationally, mainly to support kerbside recycling programs. There are numerous reference plants at various scales and degrees of sophistication. There are also numerous reputable suppliers of MRF equipment and whole plants.

With so many different types of equipment to choose from, it is important that the right equipment is chosen for the required purpose and duty. The sorting equipment used in MRFs is also constantly evolving and improving. For example, the use of optical sorters in MRFs has grown significantly over recent years, allowing a greater degree of sorting of materials into higher value commodities.

Current technology developments include robotic sorters which combine optical vision systems (such as near infrared) with artificial intelligence that can identify items and direct a robot arm to pick targeted items, whilst constantly 'learning' and improving performance over time. For example, American company Bulk Handling Systems has developed a system designed to work with existing optical sorting technology but provide quality control sorting, such as picking contaminants from a stream of PET plastics, thus replacing a manual picker. Other systems are in development. Robotic sorting of recyclables generally is in the early stages of commercial deployment and still largely unproven in terms of performance and commercial viability.

It is important that all MRF equipment is used for the purpose for which it is designed and proven.

Visy Recycling Materials Recycling Facility (MRF), Heidelberg (VIC)



The Visy Recycling Heidelberg MRF is a sorting facility for dry recyclables. The commingled recyclables are deposited into the hopper by a front end loader which feeds the material across a series of 60 conveyor belts, transporting it through the separation process. This involves firstly, removing materials of no commercial value through manual sorting, including items such as plastic bags, clothing, and garden waste, which are disposed to landfill. The material then moves through three trommel screens to separate paper, cardboard and glass fines; an over-band magnet to separate steel; air classifier to separate low density, lightweight plastics, aluminium and liquid paper cardboard; a fourth trommel screen to separate undersized aluminium from the plastics and liquid paper cardboard; eddy current separator to separate remaining aluminium from the plastics; plastic perforator to reduce volume of plastics and; a fifth trommel screen to sift glass fines from whole glass.

Cleanaway Perth MRF (Super MRF), South Guildford (WA)



Cleanaway has opened a high-tech MRF, costing \$20 million in 2017, with the capacity to process up to 250,000 tonnes of recyclable material per annum or 50 tonnes of material per hour. The MRF is described as the most advanced commingled recovery system in the country with state of the art optical sorting technology capable of separating recyclable materials and delivering diversion rates of up to 97 per cent. The MRF is capable of recycling household and commercial and industrial recyclables.

The facility has the capability to recover eight different material streams, including newspaper, mixed paper, cardboard, glass, aluminium, steel, HDPE plastic and, PET plastic. Eight optical sorters use light rays to detect targeted products. Glass crushing and clean up technology is also part of the facility, to remove all light contaminants and produce recycled glass that can be immediately available for civil construction or reuse without further processing at a beneficiation plant. The Perth MRF also has mechanical bag breakers to split bags automatically and extract recyclables.

Challenges and benefits

Managing contaminants (non-target materials) is an ongoing challenge for MRF operators, and one which needs a coordinated effort of stakeholders along the feedstock supply chain (councils, collectors, residents and businesses). Some materials such as film plastic can cause blockages and operational problems for the equipment, while high levels of putrescible waste can contaminate otherwise recyclable materials and reduce their value or render them as reject waste.

The capacity of a MRF is typically defined in terms of tonnes that can be processed per hour, such that annual capacity is then a function of the operating hours of the process. As a purely mechanical process, MRFs can be switched on or off easily. Subject to any planning constraints on working hours, it is possible to increase or decrease the overall throughput of a MRF by adjusting the working hours of the plant (within limits), for example by adding shifts.

As sorting technology has become more advanced and automated, small MRFs have tended to be less viable and larger MRFs are being developed which can take advantage of economies of scale and invest in new technologies.

A clean MRF is typically a relatively low energy user. Depending on the level of separation employed, including the level of automation and number of processes involved, it should be expected to have a parasitic load of 10-25 kWh/t of feedstock.

Summary

A summary of key aspects of clean MRFs is presented in Table 5 and a generic process flow is presented in Figure 2.

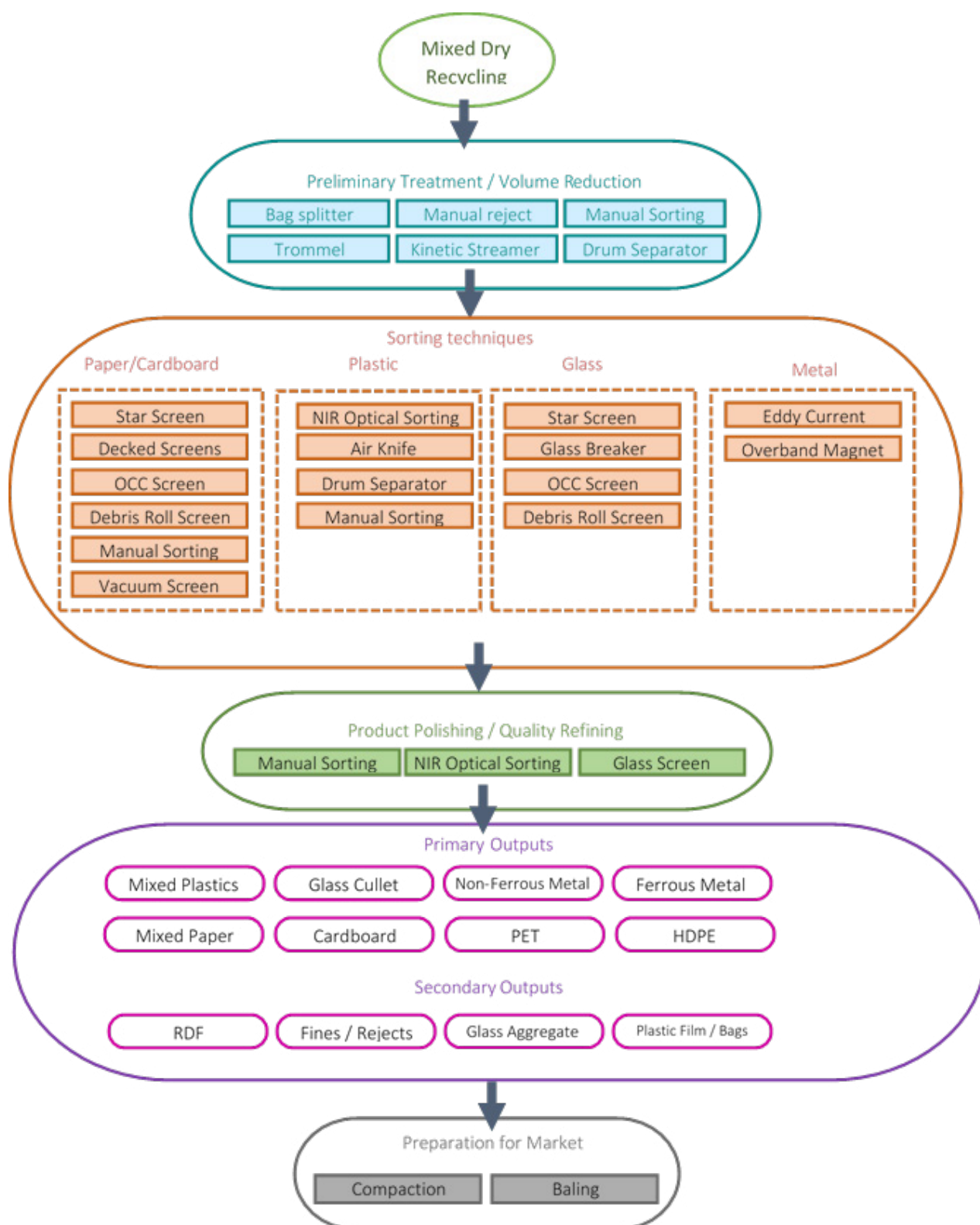
TABLE 5 SUMMARY OF ASPECTS FOR CLEAN MRF TECHNOLOGIES

Technology Type	CLEAN MRF
Commercial track record	Well established - 21 MRFs in Victoria at different scales ¹¹ ; dozens of plants across Australia
Waste feedstocks	Mixed / commingled recyclables (municipal and commercial)
Typical capacity range	20,000-200,000 tpa
Indicative capital cost range ¹²	\$20M
Operational cost factors	Recyclate revenue (fluctuating), maintenance costs associated with materials handling, reject disposal costs
Indicative land-take	0.1-0.4m ² / tonne
Factors for scaling	The hourly capacity of individual mechanical equipment is main parameter; some flexibility in annual capacity by adjusting working hours (within limits); planning limitations may constrain working hours; recyclate storage may be a constraint (physical and regulatory limits).
Products / outputs	<ul style="list-style-type: none"> › Separated recyclable materials including paper, cardboard, plastics, glass, steel and aluminium › Glass fines for potential further processing › Light residuals – potential RDF › Residuals to landfill
Key issues and main risks	<ul style="list-style-type: none"> › Volatile markets for products linked to global commodity and oil prices › Heavy reliance on export markets for reprocessing of paper and plastics › Economies of scale, favouring larger facilities › Low gate fees, emphasising product pricing risks › Contamination management including plastic film, putrescibles, hazardous waste › Stockpiling of products for future sale › Safety issues around manual sorting
Questions to ask	<ul style="list-style-type: none"> › Recovery performance – overall and by material, to be demonstrated › Quality of sorted materials including contamination rates › Management of glass and glass fines › Operating throughput flexibility
Reference plant examples	<ul style="list-style-type: none"> › Visy MRF, Heidelberg › Polytrade MRF, Campbellfield › SKM MRF, South Geelong › Tambo Waste MRF, Lakes Entrance

11 SWRRIP Amendment Consultation Draft, July 2017, <http://www.sustainability.vic.gov.au/our-priorities/statewide-waste-planning/2015-2020-priorities/statewide-waste-and-resource-recovery-infrastructure-plan>

12 Indicative capital cost in 2017 for a 100,000 tpa capacity facility

FIGURE 2 CLEAN MRF PROCESS FLOW



3.2.2 Mixed Waste MRF

A mixed waste materials recovery facility (Mixed Waste MRF) is designed to process mixed residual waste which has not been subjected to source separation. It is often called a 'Dirty MRF' on account of the feedstock being likely to contain a much higher proportion of contaminants compared with a clean MRF.

Like a Clean MRF, it uses various combinations of mechanical separation equipment with some manual picking to extract recyclable materials and other resource streams such as refuse derived fuel (RDF) as discussed below.

The term Mixed Waste MRF covers a broad range of technologies and applications. Facilities that process mixed construction and demolition (C&D) waste can be categorised in this group, which are common in Victoria and across Australia, with varying degrees of sophistication. Mixed Waste MRFs that process non-putrescible commercial and industrial waste are less common but gaining interest as a means to improve recovery of this stream without additional source segregation.

There are no existing stand-alone Mixed Waste MRFs for putrescible mixed waste (municipal or commercial) in Australia. It is significantly more challenging to separate quality recyclables from putrescible waste and manual picking of these materials presents additional health and safety concerns. The production of RDF from putrescible waste is possible but more challenging (than RDF produced from dry waste) and the product will be of lower quality, from a contamination and energy content perspective. There are mechanical-biological treatment (MBT) plants in Australia that effectively combine a mixed waste MRF for putrescible waste with biological processing of the organic fraction – this technology is discussed in 3.2.3 below.

At the basic level, a mixed waste MRF can be a relatively simple sorting and recovery operation with a heavy reliance on manual picking to extract recyclables from a mixed waste stream. A basic system might include a slow-speed shredder or bag opener to prepare and improve handling of the material; a trommel screen to remove fines; an over-band magnet to extract ferrous metals; and a manual picking platform with multiple picking stations to target other recyclables. Manual picking provides a high degree of flexibility to target different materials according to the incoming feedstock and product market conditions.

Depending on the feedstock composition, more advanced automated systems may incorporate various types of screens; ballistic separators and wind-sifters; eddy current separators and possibly optical sorters.

Outputs and residues

Target materials for a mixed waste MRF are typically those which are high in value and/or have strong markets or are potentially usable as a fuel to avoid disposal costs. For plants processing C&D waste including skip bin waste, recovered materials include soil fines; concrete, brick and masonry (which are reprocessed into secondary aggregates – see Section 3.5.5); metals; timber and plastic. Recovery rates of up to 75 per cent to 85 per cent are generally possible with more advanced processes but more manual sorting approaches will be less (with soil and masonry making up the bulk of recovered materials by weight).

For mixed waste MRFs that process commercial waste, these will tend to target dry, non-putrescible loads which are high in recyclable content. Typical target products include paper, cardboard, plastics, metals and timber packaging and offcuts.

Mixed waste MRFs processing municipal waste are likely to target high value materials such as metals and rigid plastics, resulting in relatively low recycling rates, the main driver often being diversion from disposal through segregation of an RDF (as in MBT facilities).

Any recyclables extracted from mixed waste, particularly waste with a putrescible content, will be lower quality and more contaminated than those sorted in a clean MRF. Consideration needs to be given as to outlets for these materials and likely prices received, particularly in light of competition from cleaner streams.

Refuse Derived Fuel (RDF)

Mixed waste feedstocks from various sources can be processed in a mixed waste MRF to produce a refuse derived fuel (RDF). RDF is a general and broad-ranging term that can be applied to any solid fuel derived through the processing of waste materials. It typically contains the combustible fractions of waste including timber, plastic, paper and cardboard.

In processing mixed waste to produce an RDF, the aim is to:

- Reduce hazardous contaminants or undesirable components
- Remove non-combustible (inert) and wet material thereby increasing the calorific value of the fuel
- Homogenise the fuel product in terms of particle size and composition
- Potentially to densify the product to reduce transport costs to the end destination

There are no mandatory quality standards that define RDF. In Europe, standards have been developed to differentiate higher quality products, which are termed Solid Recovered Fuels (SRF). The standards are voluntary but provide customers with confidence in the product quality. In Australia, the term Process Engineered Fuel (PEF) has emerged for higher quality RDF products which are suitable for use in applications where there are more sensitive feedstock requirements such as cement kilns. There is no specific standard for PEF quality and it is generally determined by the customer, based on their process characteristics.

ResourceCo operates a mixed waste MRF in Adelaide processing both C&D and dry commercial waste to recover recyclables and produce PEF for use in the adjacent cement kiln. The company has also announced plans for a similar facility in Sydney.

RDF outlets in Australia are very limited at present and particularly in Victoria, since the closure of the state's only cement kiln at Warrn Ponds. Using RDF in cement kilns is a good solution as the cement product absorbs the ash and many of the pollutants from combustion. Hence most cement kilns can partially substitute their existing coal or natural gas consumption with RDF, with only relatively minor plant modifications. Quality of the fuel is key however, with strict requirements that are generally specific to each cement kiln, to avoid adverse impacts on cement quality.

With few cement kilns left in Australia, there is growing interest in producing RDF (or PEF) for export to cement kilns in South East Asia where there are hundreds of cement kilns and where local waste characteristics and market conditions make it unviable to produce their own RDF in significant volumes. This is a market outlet for Australian RDF that is likely to grow over coming years.

Otherwise, it is technically challenging to use RDF directly in other existing thermal plants such as coal fired power stations or industrial furnaces. Furnace characteristics and requirements for significant upgrades to air pollution control systems tend to make it unattractive.

The other major outlet for RDF is dedicated thermal waste treatment plants of the types discussed in Section 3.4, of which there are none yet operational in Australia. In this case, the mixed waste MRF can either be integrated with the thermal plant, or be a separate facility such that one or more mixed waste MRFs in urban / industrial areas can feed RDF to a more remote thermal plant.

RDF is most commonly produced from dry commercial residual waste and the combustible fractions of C&D waste. It is possible to produce RDF from putrescible residual waste but this would usually be done via a MBT process where the organic fraction is bio-dried to increase its energy value. This is a relatively common approach in Europe (see 3.2.3 below).

ResourceCo RDF Plant, Adelaide (SA)

ResourceCo operates a mixed waste MRF in Adelaide (Wingfield) as a joint venture with Suez, processing both C&D residuals and dry commercial waste to recover recyclables and produce process engineered fuel (PEF) for use in the adjacent cement kiln, operated by Adelaide Brighton Cement.

Dry calorific materials such as mixed plastics, timber and textiles are recovered in the PEF stream while soil and masonry products are recycled. The plant processes approximately 150,000 tonnes of raw material annually which produces around 85,000 tonnes of PEF. The plant has capacity to increase throughput to 350,000 tpa subject to PEF outlets.

For the cement kiln, the PEF replaces around 20 per cent of natural gas consumption.

ResourceCo has also announced plans for a similar PEF facility in Sydney and another Australian city (yet to be announced) and received funding from the Clean Energy Finance Corporation towards these two projects.

Track record

Mixed waste MRF solutions are widely used to recover materials from C&D waste and there are several examples of these types of processes in Victoria. Sorting processes for C&D waste are becoming more advanced and automated, driven by rising landfill costs and increasing demand for quality recovered materials.

Mixed waste MRFs processing mixed commercial or domestic residual waste are less common. Nevertheless, there is potential for mixed waste MRFs to be deployed, perhaps at landfill sites as a pre-treatment to landfill, to recover higher value materials such as metals and hard plastics, although the net diversion will be small.

There are facilities processing dry commercial waste in Sydney and Adelaide, recovering recyclables and producing RDF. This application is likely to grow with a number of projects planned in Sydney and growing interest in export of RDF to cement kilns in Asia.

The technology used in mixed waste MRFs is generally well established and proven. Current developments in this field include robotic sorting systems, to improve efficiency and reduce both labour costs and safety risks associated with manual picking. As for the systems being developed for clean MRFs, there are robotic sorting systems being developed for sorting C&D waste such as that from Finnish supplier, ZenRobotics (see case study). Artificial intelligence is a key component allowing the system to improve its performance over time. This is an area which is likely to see significant growth over coming years as other systems are developed and applied to other waste streams, and commercial viability improves.

Sunshine Groupe C&D MRF– Brooklyn, Melbourne

In early 2017, the Sunshine Groupe in Melbourne installed a robotic sorting system at their C&D recycling and disposal site in Brooklyn as part of a new mixed C&D waste MRF development.

The MRF will process up to 120,000 tonnes per annum of dry commercial and C&D waste. It will be subject to conventional primary sorting process to separate recoverable streams and then the robotic process will be used as a secondary process to sort pure material types for sales. The system from Zenrobotics can sort around 6000 objects from the belt per hour, equating to approximately 7–8 tonnes per hour.

The MRF is expected to recover approximately 50 per cent of the waste stream initially, rising to 70 per cent – 80 per cent over time. There is no data around the actual technical and commercial performance of the facility to date.

Challenges and benefits

The main challenge for mixed waste MRFs is recovering products of reasonable quality and securing market outlets for those products. For facilities processing C&D waste, these markets are generally well established. For recyclables extracted from other mixed streams, quality is typically lower and market opportunities constrained.

For RDF, current domestic market outlets are very limited and export markets are still in early stages of development.

A mixed waste MRF is typically a relatively low energy user. Depending on the level of separation employed, including the level of automation and number of processes involved, it should be expected to have a parasitic load of 25-35 kWh/t of feedstock.

Summary

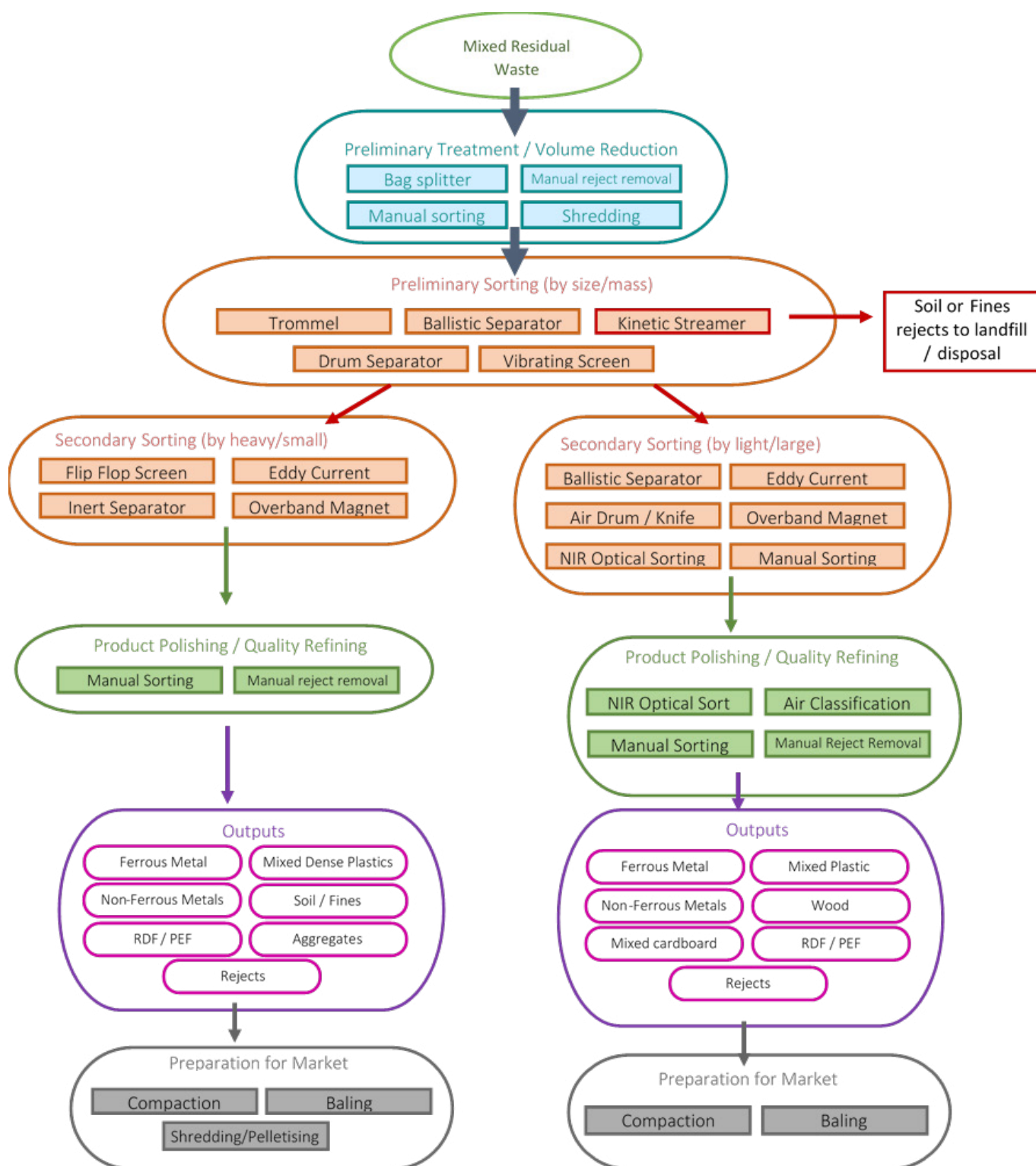
A summary of key aspects of mixed waste MRFs is presented in Table 6 and a generic process flow is presented in Figure 3.

TABLE 6 SUMMARY OF ASPECTS FOR DIRTY MRF TECHNOLOGIES

Technology Type	MIXED WASTE MRF
Commercial track record	Well established with several facilities processing C&D waste across Victoria at different scales. Internationally established in processing dry C&I waste. Less track record in processing municipal waste.
Waste feedstocks	Mixed residual waste (C&D, municipal and commercial)
Typical capacity range	50,000-200,000 tpa
Indicative capital cost range ¹³	\$25M
Operational cost factors	Recyclate revenue and impact of higher contamination, maintenance costs associated with materials handling, reject disposal costs, RDF offtake costs, odour control for facilities processing putrescible wastes.
Indicative land-take	0.15 – 0.35m ² / tonne
Factors for scaling	The hourly capacity of individual mechanical equipment is main parameter; some flexibility in annual capacity by adjusting working hours (within limits); planning limitations may constrain working hours; recyclate storage may be a constraint (physical and regulatory limits).
Products / outputs	<ul style="list-style-type: none"> › Separated recyclable materials including paper, cardboard, plastics, glass, steel, aluminium, masonry products, soil, timber › RDF › Residuals to landfill
Key issues and main risks	<ul style="list-style-type: none"> › Volatile markets for products linked to global commodity prices › Local markets for RDF › Economies of scale, favouring larger facilities › Contamination management including plastic film, putrescibles, hazardous waste › Stockpiling of products for future sale › Fire hazard of stockpiling › Safety issues around manual sorting
Questions to ask	<ul style="list-style-type: none"> › Recovery performance › Quality of sorted materials including contamination rates › Operating throughput flexibility
Reference plant examples	<ul style="list-style-type: none"> › Sunshine Groupe C&D MRF, Brooklyn › Alex Fraser C&D MRF, Brooklyn › ResourceCo Fuel plant, Adelaide

13 Indicative capital cost in 2017 for a 100,000 tpa capacity facility

FIGURE 3 MIXED WASTE MRF PROCESS FLOW



3.2.3 Mechanical biological treatment (MBT)

Mechanical Biological Treatment (MBT) is primarily used for treating mixed putrescible waste streams with a relatively high proportion of organics (mostly municipal). It can allow the recovery of the organic fraction of mixed residual waste without implementing source separation collection systems.

MBT is a group of technologies that combine:

- Mechanical processing to recover recyclables and extract an organics-rich fraction
- Biological processing of the organic fraction to produce a low grade soil improver and/or recover energy through anaerobic digestion.

The mechanical sorting part of the process is effectively a mixed waste MRF, employing a blend of processes including typically a shredder or bag opener, trommel screen, manual picking station, magnets, eddy current separators and wind-sifters. After the initial shredding or bag opening stage, most of the putrescible organics and fibre (paper and cardboard) will be small particles which are separated in the trommel as the undersize stream (typically less than 80mm). The oversize stream contains most of the inorganic materials which is subject to picking and extraction processes to capture recyclables.

One variant of the process is rotary drum digesters which are used as the first stage in a number of Australian MBT plants. Unprocessed, unshredded mixed waste is loaded into the digesters where it is constantly turned over a period of around 3 days. The organic material in the waste undergoes rapid decomposition while the mechanical agitation of constant rotation helps to break down the organics and fibre content to small particles. The drum process is followed by screening to separate the organic fines from the larger materials. Again, the oversize stream is subject to picking and extraction of recyclables.

The organic-rich fines are subjected to either an enclosed aerobic composting process (see 3.3.1) or anaerobic digestion process (see 3.3.2). This generally produces a low-grade soil improver and in the case of AD, biogas which can be used as fuel for energy. The soil improver or low grade compost is subject to further refining to remove glass, metals and plastic contamination. Many plants process it through a hammer mill or similar unit to crush the glass fines down to unrecognisable sand particles. Advice should be sort from EPA regarding the regulatory requirements for re-use of these materials.

Outputs and residues

The existing Australian facilities all use aerobic stabilisation of the organics to produce a soil improver which is used in rehabilitation of mine sites or in broad-acre agriculture. The product typically contains elevated levels of physical contaminants (mostly glass and plastic) and chemical contaminants (e.g. heavy metals), particularly compared with compost produced from source separated organics. In some states, strict environmental and quality standards are set which determine how and for what purpose it can be used. Lead contamination from batteries in the waste stream has been a particular challenge for some Australian plants. Advice should be sort from EPA regarding the regulatory requirements for re-use of these materials.

Outlets for MBT compost are limited, as they are generally unsuitable for application to agricultural land and would be restricted to mine and landfill rehabilitation. This is a significant constraint on further deployment of the technology. Without any existing MBT facilities in Victoria, the regulations around use of MBT compost are yet to be tested.

In Europe, regulations on the use of MBT compost are particularly stringent and most MBT plants there are now producing RDF as the main output, for use in thermal treatment plants. In those plants, the aerobic stabilisation process is operated as a bio-drying system, where the natural heat of composting combined with constant aeration, reduces the moisture content of the organics fraction. As markets and outlets for RDF develop, as discussed in 3.2.2, it is possible that future MBT projects in Australia will follow this trend.

The recyclables extracted by MBT plants are typically limited to high value materials including metals and rigid plastics and typically account for less than 5 per cent of the throughput. The quality and value of recyclables is low due to high contamination.

The overall recovery performance of an MBT plant that does not produce RDF is typically in the range 50–65 per cent (assuming an outlet exists for the low value compost), resulting in a significant residual stream that needs to be landfilled. The recovery performance is largely a function of the scale and sophistication of the plant (larger plants tend to invest in more advanced processing equipment) and also the organic content of the incoming waste. For councils that have effective organics kerbside collections, the recovery rate of MBT would be much reduced.

With RDF production, total diversion performance of MBT can be increased to 80–90 per cent.

Track record

MBT is well established internationally. It was originally developed in Germany as a pre-treatment to landfill, in response to a ban on the landfilling of putrescible waste and there are now over 300 MBT plants are operating across Europe. There are a number of MBT plants in Australia, particularly NSW and Western Australia, plus one in north Queensland. There are no MBT facilities in Victoria at this time.

They have typically been deployed where there is a significant shortage of putrescible landfill capacity and landfilling costs are high. Most of the existing plants are now working well but have not been without their challenges and flaws in the past. Many of the plants have suffered technical challenges resulting in extended shutdowns; odour problems; and/or poor recovery performance. This can be partly attributed to the lack of design and operational experience of the proponents of the early plants, but this capability has improved significantly over the last the decade in Australia.

Global Renewables UR-3R Facility, Eastern Creek, Sydney (NSW)



The Eastern Creek UR-3R Facility was established in 2004 and is now the largest MBT plant in the Southern Hemisphere. It employs 80 people and has a 25 year contract to process 220,000 tonnes of mixed household waste per annum. The plant has expanded over the years from its original processing capacity of 175,000 tpa.

The UR-3R Facility utilises an MBT process which consists of mechanical and hand sorting, intensive enclosed composting, maturation and refining. The plant originally included energy recovery from the organic-rich fraction through anaerobic digestion using a percolation technology. Although the AD part of the process worked, it was not financially viable to operate and was eventually decommissioned. The MBT plant continued to operate with just the composting process for organics.

It has gradually improved its performance over time and is now running well, with one of the highest diversion rates of any Australian MBT plant.

In 2009, the proponent was successful in legal action against its customer (Waste Service NSW) arguing that the waste stream being supplied was no longer in line with their original contractual arrangements, resulting in a renegotiation of the contract. This highlights the importance of understanding the waste stream composition and how it might change over time, for the duration of a long-term contract.

Challenges and benefits

MBT processes are primarily employed to stabilise and recover the organic fraction of mixed waste without having to rely on or invest in, source segregation systems. As more councils implement kerbside organics collections and move towards including food organics in those services, the benefits of MBT as an organics diversion measure are diminished.

As noted in the case study above, the key challenge for MBT is finding viable and secure markets for the main outputs, whether that is soil improver and/or RDF. Use of MBT compost is likely to be tightly controlled in Victoria and limited to niche applications.

The biological processing stage of an MBT plant tends to be highly odorous, requiring effective enclosure and treatment of process air through a biofilter, and possibly acid scrubbers for extreme odour loads. Most of the Australian MBT plants have suffered from odour control issues to differing extents.

There has been particular challenges with the application of anaerobic digestion to the organics fraction and this part of the process has often failed due to the sensitivity of AD processes to chemical and physical contaminants. This is generally consistent with international experience.

MBT technologies have a relatively high energy consumption in the range 50-80 kWh/t of total feedstock. This will depend on the level of pre-sorting, automation involved, and method of composting or digestion employed. For anaerobic digestion MBT facilities there is a typical gross energy generation of 150-160 kWh/t total input feedstock when using a CHP (cogeneration) engine to generate electricity.

Summary

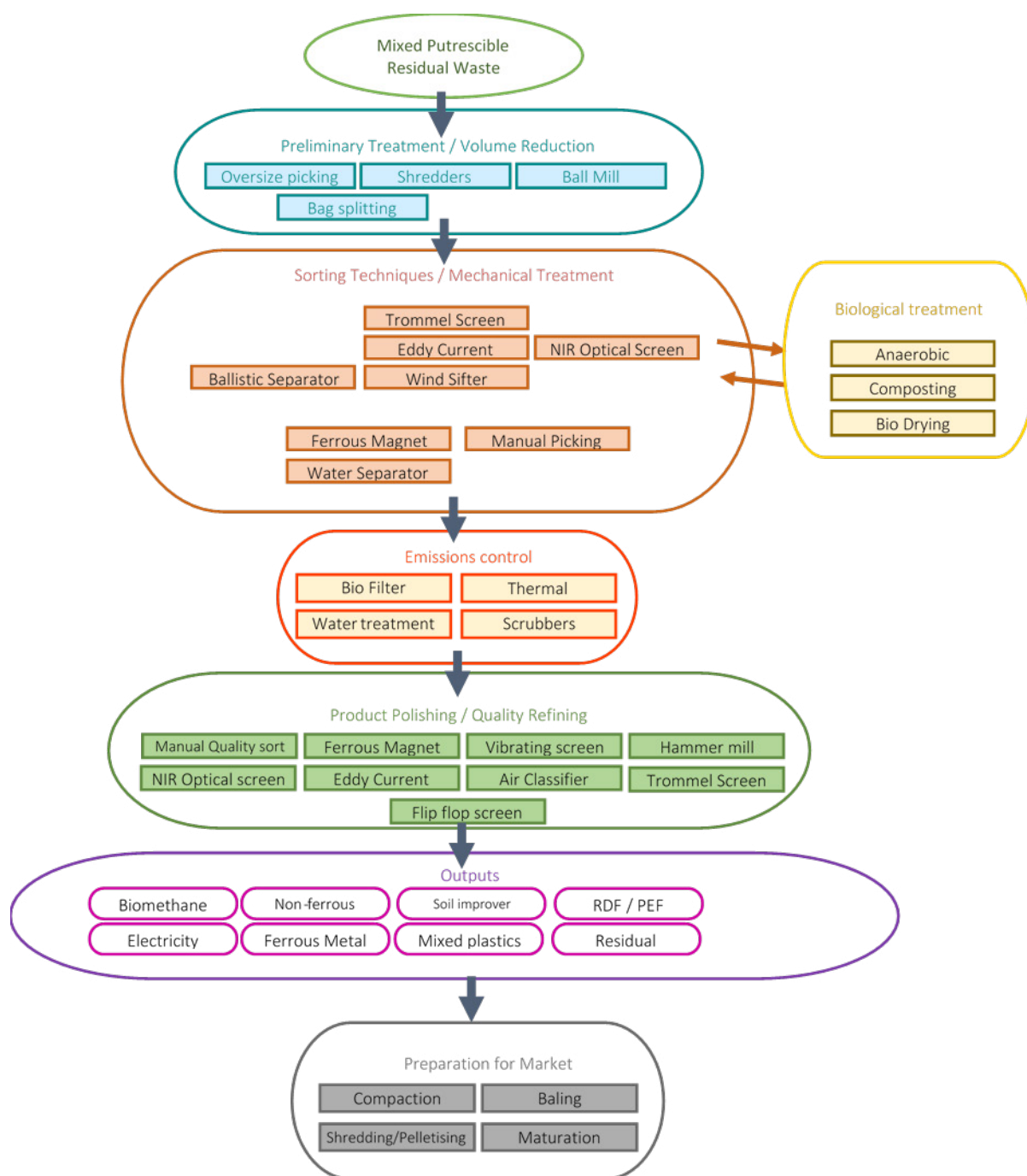
A summary of key aspects of MBT technologies is presented in Table 7 and a generic process flow is presented in Figure 4.

TABLE 7 SUMMARY OF ASPECTS FOR MBT TECHNOLOGIES

Technology Type	MECHANICAL BIOLOGICAL TREATMENT
Commercial track record	Well established - Nine operating commercial facilities in Australia and over 300 in Europe
Waste feedstocks	Mixed putrescible residual waste (mostly municipal, but also commercial), other organics
Typical capacity range	50,000-250,000 tpa
Indicative capital cost range ¹⁴	\$50M
Operational cost factors	Residual disposal costs, compost / RDF offtake costs, maintenance costs, odour control systems
Indicative land-take	0.2 – 0.5m ² / tonne
Factors for scaling	The capacity of the biological processing phase is usually the limiting factor on overall capacity but may have some flexibility, the mechanical processing phase typically has more flexibility by adjusting working hours.
Products / outputs	<ul style="list-style-type: none"> › Low grade soil improver / compost › Recyclable materials including rigid plastics, steel and aluminium › RDF › Residuals to landfill (up to 50 per cent)
Key issues and main risks	<ul style="list-style-type: none"> › Tight restrictions and limited outlets for compost product due to higher risk of contaminants › Declining organics content in residual waste / incorrect predictions of waste composition › Undeveloped / limited markets for RDF › Low or negative revenue from compost / RDF › Economies of scale, favouring larger facilities › Odour control › Particular risks with use of AD for organics
Questions to ask	<ul style="list-style-type: none"> › Experience of design, construction, operations team › Recovery performance and impact of changes in input waste quality › Quality of recovered materials including contamination and markets › Operating throughput flexibility
Reference plant examples	<ul style="list-style-type: none"> › Global Renewables UR3R Plant, Eastern Creek Sydney › Suez Neerabup MBT plant, Perth › Veolia MBT plant, Woodlawn, NSW

14 Indicative capital cost in 2017 for a 100,000 tpa capacity facility

FIGURE 4 MBT PROCESS FLOW



3.2.4 E-waste recycling

'E-waste' describes waste electrical or electronic equipment, or anything with a power cord or battery at the end of its useful life. Items of e-waste such as whitegoods (e.g. fridges, cookers, etc.) which are predominantly metal, are generally recycled through the scrap metal sector; whereas the National Television and Computer Recycling Scheme (NTCRS) is designed to provide an effective process for the management of end of life TVs and computers.

AS 5377

Australian standard (AS 5377) for *Collection, storage, transport and treatment of end-of-life electrical and electronic equipment* outlines the minimum requirements for the safe and environmentally sound collection and management of e-waste. It is designed to support re-use and recovery of e-waste, reduce the proportion of e-waste landfilled and protect worker health and the environment. Since July 2016, service providers processing e-waste collected through the National Television and Computer Recycling Scheme need to be certified to AS5377. This only currently applies to those participating in the NTCRS but additional product stewardship schemes for other e-waste materials can be expected in the future.

Small e-waste items not included in the National Television and Computer Recycling Scheme (e.g. electronic toys, torches, hair care and beauty products, vacuum cleaners, heaters, etc.) are generally not recycled and are disposed to landfill either as residual waste collected through kerbside bins, or as drop-off materials at transfer stations.

E-wastes contain a range of materials, from precious metals to ceramics and polymers. Some of these materials are valuable, while some have hazardous components. Due to the complexity of materials that make up e-waste, they can be extremely difficult to recycle. Therefore, there are two main objectives of e-waste recycling processes: to obtain materials, and; to detoxify.

The processes used for dismantling of e-wastes and recovering value are described below.

Step 1: Toxic Component Removal: This is an essential step, primarily for e-wastes containing hazardous substances (i.e. batteries, mercury lamps etc). Their removal ensures that dispersion and contamination of the streams that are desired for recovery are not lost in undesirable streams.

Step 2: Pre-processing: This applies physical techniques to liberate and upgrade desirable materials into relatively homogenous streams, which are used as inputs for end-processing.

Two basic approaches used here:

- Manual separation
- Mechanical separation

The processes can be mechanical or manual. Mechanically, the objects are reduced in size by shredding and crushing, then sorted. Through mechanical separation processes, crushing the e-waste items breaks the material bonds between the composites and laminates and weakens the adhesive forces that hold the different types of particles together. The plastics, metals and other materials are liberated from each other. The composites of plastic and metals are fragmented into flakes and small particles, which can then be separated according to their densities.

Manually, the wastes are dismantled by trained personnel into their component parts. Manual separation results in lower material recovery rates as compared to mechanical separation. Manual sorting and dismantling is the simplest and most direct pre-processing technique.

This also results in unaltered size of materials for reuse, making sorting easier and improving the components reusability. Mechanical and manual approaches are often combined.

Step 3: End processing: This is the final stage of refining and detoxifying the various outputs that have been liberated from the separation stage. The processes can include physical, chemical and thermal processes, which reduce the impurities and prepare them for appropriate disposal. Given the broad range of materials that form e-waste, diverse and separate treatment processes are needed.

Physical separation techniques used can include:

- Air or water sink float separation for separating metals from plastics
- Optical sensor separation for separating different plastics
- X-ray sensor separation for separating glass from lead glass
- Magnetic separation for separating ferrous metals from other metals
- Eddy current separation for separating non-ferrous metals

While the liberated materials may be similar to those recovered from other waste streams, the feed material is complex and they are presented in a variety of forms. Therefore, sequences of technical processes are needed.

For example, to recover the various metals in circuit boards, furnaces or smelters are needed, as well as a sequence of hydrometallurgical and electrometallurgical processes, to further recover metals.

Additionally, gas cleaning systems are needed to prevent the release of VOCs, dioxins other toxic gases into the atmosphere. Substandard processes that are commonly seen in this industry include: acid stripping, de-soldering of chips and shredding and low temperature plastic melting.

Therefore, a typical end-processing system may involve:

- Multiple eddy current separators to extract nonferrous metals like copper and aluminium. The remaining inert materials are sent to a second separator for further recovery. There are advanced options, which can pick up materials that are not captured through eddy current separators, such as x-ray imagery devices which provide high resolution imagery of the material and enable sorting based on the relative brightness of the images. The higher the atomic density of the material the darker the image.
- Plastics found in e-waste are also sorted through increasingly advanced technology options, through density separation techniques, where granulates flow through different liquids, causing some plastics to float and others to sink. However, it is noted that flame retardants and other additives that are used on plastics in e-waste that make them resistant and durable, make them difficult to recycle, and potentially hazardous to environment and human health.
- Non-metallics will generally be separated from the metallics. Certain non-metallics can be recycled into products. Only a limited amount of metallics will be put through a smelting or direct chemical process due to the danger of harmful fumes being potentially released into the atmosphere.
- Hydrometallurgical refining (used in refineries through smelting of materials such as Printed Circuit Boards (PCBs)) and chemical extraction processes are used to remove the desired materials.
- Environmental pollutant controls for waste dust, water and fumes need to be incorporated as part of the solution. This can involve investments in industrial dust collectors, waste water treatment plants and scrubber systems.
- Slag that might be generated during the smelting process generally needs to be landfilled. Wastewater is typically a spent chemical solution, which is treated with dissolved solids removed and water treated to trade waste requirements. Sludges that are produced are generally dried and sent to landfill.

E-Cycle Division (Formerly PGM Refiners), Dandenong (VIC)



Subject to further acquisition, Toxfree acquired PGM Refiners in early 2016 including the e-waste recycling facility in Dandenong. The facility is located in a major industrial hub, with a large footprint for storage and accepting product and has the capacity to process 1000 tonnes of e-waste a month. The facility takes and processes e-waste from the National Television Computer Regulatory Scheme (NTCRS) co-regulatory arrangement, TechCollect, other specialist e-waste collectors, and landfills and transfer stations.

The incoming material first passes through the site's weighbridge and then employees undertake a primary manual sort to divide the stream into categories such as CRT units, flat panel displays, printers, and IT peripherals, with batteries and ink cartridges removed. The sorted e-waste then goes through a custom-built semi-automated processing line, with recovers resources through a combination of crushing, density separation, magnetic separation and x-ray sorting. The facility has a recovery rate of 90 per cent, reclaiming circuit boards, plastics, scrap, funnel and panel glass. Once the materials are separated and bagged, local and international manufacturers buy most of the product, while a small amount is sold on to downstream recyclers for further processing.

This site also employs the Swiss-made BluBox technology, an integrated plant for recycling mixed lamps and LCD flat panel screens (including those in TVs, monitors, laptops, tablets and smart phones) that contain mercury. The process involves dry treatment and has an in-built mechanical crushing system; it operates under negative pressure to extract mercury vapour and contaminated phosphor, while outputting valuable products. The technology can process one tonne of flat panel displays per hour, or 2,100 tonnes per annum.

Outputs and residues

Most of the materials that are liberated from e-waste are not exclusive and form streams that would be captured in normal household or industrial streams (i.e. metals, plastics, glass). Therefore, some of these facilities, may be processing different materials (not just e-waste), to capture economies of scale.

However, there are some e-wastes that are unique, such as circuit boards and CRT glass, which need to be dealt with separately through specialised reprocessing processes.

There are emerging trends in the application of technology for separating e-wastes. The use of pyrolysis (described in Section 4.2) is emerging as a technology option for dismantling e-waste into its constituent streams.

Track record

E-waste recycling as an industry is relatively new and constantly evolving to keep track of the changing nature of the waste materials being recycled. That said, the component processes and technologies are mostly established and proven. There are a number of e-waste recycling facilities in Victoria and across Australia using a range of different approaches and processes.

Challenges and benefits

Manual pre-processing of large volumes of e-waste requires substantial labour and the risk of being exposed to potentially toxic compounds. Therefore, environmental, health and safety measures are critical in preventing workplace accidents and reducing exposure to toxic compounds.

Dismantling small items is easier than dismantling large appliances, due to the difficulty of physically dealing with these objects on a working table.

Not all materials can be completely detached during shredding, particularly if they are composited materials or attached with permanent joiners, such as glue or lead soldering. Therefore, to avoid the undesirable effects of these, e-waste should be shredded into small and even fine particles where possible (to sizes below 5 to 10 mm), under the right conditions to reduce environmental and occupational risk of fines (dust) being distributed unintentionally.

Summary

A summary of key aspects of e-waste processing technologies is presented in Table 8.

TABLE 8 SUMMARY OF ASPECTS FOR E-WASTE PROCESSING

Technology Type	E-WASTE RECYCLING
Commercial track record	Several commercial facilities in operation but an evolving sector and technologies, adapting to new e-waste streams. Component technologies are generally established but new ones being developed.
Waste feedstocks	Electronic and electrical wastes
Typical capacity range	10,000-15,000 tpa
Indicative capital cost range	No data
Operational cost factors	Labour for manual sorting / dismantling, residual / wastewater disposal costs, power consumption, emissions controls
Indicative land-take	No data
Factors for scaling	Generally scalable component technologies, ability to vary throughput by varying operating shifts / hours. Storage of feedstock and products likely to be a constraint on most sites.
Products / outputs	<ul style="list-style-type: none"> › Separated plastics and metals for reprocessing › Hazardous residues for disposal › Dust and wastewater residues from emission control systems
Key issues and main risks	<ul style="list-style-type: none"> › Safety impacts of manual sorting and hazardous components › Catering for wide range and evolving e-waste feedstock › Separating composite materials
Questions to ask	<ul style="list-style-type: none"> › Diversity of e-waste items that can be processed › Expected recovery performance › Impact of changes in feedstock mix over time › Health and safety protection and hazard reduction measures › Quality of recovered materials including contamination and markets › Operating throughput flexibility
Reference plant examples	<ul style="list-style-type: none"> › MRI, Campbellfield › TES-AMM, Clayton › Sims metals – e-waste recovery branch, Mount Waverley › Outlook community e-waste recovery operation, Darebin

3.3 Biological treatment solutions

Biological treatment technologies are primarily used to recover value from organic wastes of various types, including source segregated waste streams (as discussed in Section 2.3); or an organic fraction that has been extracted from mixed residual waste through a sorting process (for example, MBT).

In nature, organic matter is decomposed by a wide range of bacteria, fungi and other micro-organisms as well as worms and insects, to produce humus which is returned to the soil, contributing to natural carbon and nutrient cycles. Biological processing of organics involves harnessing natural decomposition processes in a controlled environment to convert organic materials into useful and valuable products.

Decomposition can either take place in aerobic conditions (oxygen / air is present) or anaerobic conditions (no air present). In aerobic conditions, the degradable carbon in the organic matter is oxidised to carbon dioxide gas, with heat released in the process. Under anaerobic conditions, a different set of micro-organisms converts the carbon in the organic matter into a mixture of methane and carbon dioxide gases. Alternatively, if yeast is present, fermentation can occur where sugars in the organic matter are converted to alcohol and/or acids.

Biological waste treatment processes seek to facilitate this decomposition in a controlled environment with optimised conditions of temperature, moisture, aeration / oxygen levels and nutrient balance. In this way, it occurs more rapidly and consistently, providing a predictable process to convert organic waste into valuable products. In the case of anaerobic processes, the methane and carbon dioxide (biogas) is also harvested and used for its energy value.

The information presented below focuses on biological processing technologies and their characteristics. Please refer to the *Guide to Biological Recovery of Organics* (Sustainability Victoria, 2018) for more detailed information on feedstocks, products, markets, quality control and best practice approaches to developing organics recovery projects.

3.3.1 Aerobic Processing

The most common technology for processing organic waste is composting in its various forms. Composting is an aerobic process where organic waste is converted into a compost product which can be used as a soil conditioner in various markets.

At a commercial level, the principal types of composting processes employed are:

- › Windrow composting
- › Aerated static pile composting
- › In-vessel composting
- › Vermicomposting

These processes are discussed in more detail below. There are other variants and specific proprietary technologies which may differ in some characteristics. This Guide primarily focuses on commercial scale operations – there are small scale enclosed composting systems which can be employed by a business or in a precinct setting, or on-farm composting systems, which are not explicitly discussed below but share common traits with larger scale systems.

Smaller scale operations, particularly those processing food waste can also take advantage of de-hydration technologies which are not a biological process (the predominant conversion mechanism is thermal) and are discussed in Section 3.4.3).

Composting is generally a flexible and robust process that works well with a range of both source separated organics and organics separated from mixed waste. However, careful control by an experienced operator is required to minimise the processing time, avoid unwanted emissions (particularly odour) and produce a high quality saleable product. The following common steps typically apply:

The various forms of composting differ in the way that the feedstock is mixed, aerated and contained; within the core composting process. However, in most processes, the pre- and post-processing steps are very similar, regardless of the primary composting process employed.

- **Pre-processing** – feedstock is subjected to visual inspection and picking of physical contaminants, then shredded or ground and screened to reduce particle size and homogenise the material. Feedstocks are blended to balance moisture and nutrient content.
- **Maturation** – after the primary composting process (discussed below), the compost is usually cured or matured by storing in large windrows or piles for several weeks or months until it is fully stabilised (no longer decomposing).
- **Post-processing** – the matured compost is usually screened to produce two or three size fractions to suit market requirements, and may be subjected to further contaminant removal (e.g. wind-sifting to remove plastic film). The fine fraction compost may be used in soil and top-dress blends, and a coarser fraction that is used as mulch. There may also be an oversize fraction of un-composted woody material which is either disposed or returned for re-processing.

Outputs and residues

The main products from composting of organics, common to all variants of the technology, are:

- Mulches – larger woody particles applied to soil surface to conserve moisture
- Soil conditioners including various grades of compost products and organic fertilisers, applied to soil to add nutrients and carbon and improve soil health
- Blended products (e.g. soil mixes, potting mix, top dressing) which combine compost with inert soils and sand, to suit a range of specific applications

The Australian Standard for Composts, Soil Conditioners and Mulches (AS4454-2012) sets out measures to ensure a minimum level of quality assurance requirements for producers of recovered organics in Australia. AS4454-2012 sets out requirements for the processing of organics, particularly around achieving pasteurisation of pathogens and weeds; and managing contamination levels. It is a voluntary standard, primarily focused on assuring the quality of organic products¹⁵ and mixtures of organic products that have been produced through composting and pasteurising techniques, as discussed below.

AS4454-2012 categorises products of composting according to:

- Particle size – fine soil conditioner, fine mulch or coarse mulch
- Maturity / pasteurisation - mature compost, composted product, pasteurised product

The value of the compost product is a function of a number of factors, including:

- The quality of the product and its suitability for use in higher value operations such as horticultural potting mixes as opposed to low value options such as broad acre spreading.
- The local demand for the compost product compared with the cost of transporting the compost to end users.
- The operational cost of refining the raw compost product to meet end users' needs and/or Australian Standard AS4454.

3.3.1.1 Open windrow composting

Open windrow, or turned windrow composting is the most common and simple form of organics recovery which is often used to treat garden waste at commercial scale. The prepared feedstock is formed into long uniform prism-shaped 'piles' of material known as windrows, on a large open outdoor pad. The windrows at commercial processing sites are typically up to 2-3m high and 5-7m wide at the base.

The windrows are then left for typically 8-12 weeks to compost which is a function of the feedstock mix, turning frequency and local climate. Aeration in this case is passive – the air flows through the voids in the material, so it is important that the particles are not too small, wet or compacted. Aeration is also provided through occasional mixing and turning. For small scale operations, turning may be undertaken by a front end loader or tractor drawn turning machine. Larger facilities are likely to use a specialised self-propelled compost turning machine which drives along the windrow lifting and mixing the compost, and reforming the windrow behind it.

Track record

Open windrow composting is a well-established and understood technology with multiple commercial reference facilities across Victoria and Australia. It is the primary method of processing garden organics and other commercial, industrial and agricultural organics.

Please refer to the *Guide to Biological Recovery of Organics* (Sustainability Victoria, 2018) for case studies, including open windrow composting.

Challenges and benefits

Being an open process there is an increased risk of odour release, which is heightened whenever composting material is being moved (e.g. during initial forming of the windrow or during turning operations). As such, any operating sites must have adequate buffers in place around the site to prevent community and environmental impacts.

EPA Compost Guidelines¹⁶ indicate open windrowing is generally not suitable for processing more odorous waste streams, including domestic and commercial food waste. It is also more difficult to control vermin and to ensure the material is evenly subjected to sustained high temperatures that are required for pasteurisation. The EPA guidelines provide information on a number of topics including appropriate buffer (separation) distances, odour control, leachate management and stormwater control.

Windrow composting is a low cost method of processing organics and can be established with relatively low capital investment, including at small scales. It does require a large land footprint to accommodate the windrows and can be labour intensive.

Windrow composting has an extremely low electricity demand associated with water management and site facilities. A typical facility will use under 1kWh/t of feedstock material¹⁷ but consumption of diesel for mobile plant will be significant.

Summary

A summary of key aspects of windrow composting technologies is presented in Table 9 and a generic process flow is presented in Figure 5.

15 AS4454 does not apply to organic fertilisers such as blood and bone or liquid organic wastes, liquid seaweed products, non-organic mulches (e.g. gravel), non-organic soils and soil conditioners (e.g. gypsum and sand), non compostable materials (e.g. plastics) and materials variously described as 'compost starters' and 'activators'.

16 EPA Guidance Publication 1588.1, <http://www.epa.vic.gov.au/our-work/publications/publication/2017/june/1588-1>

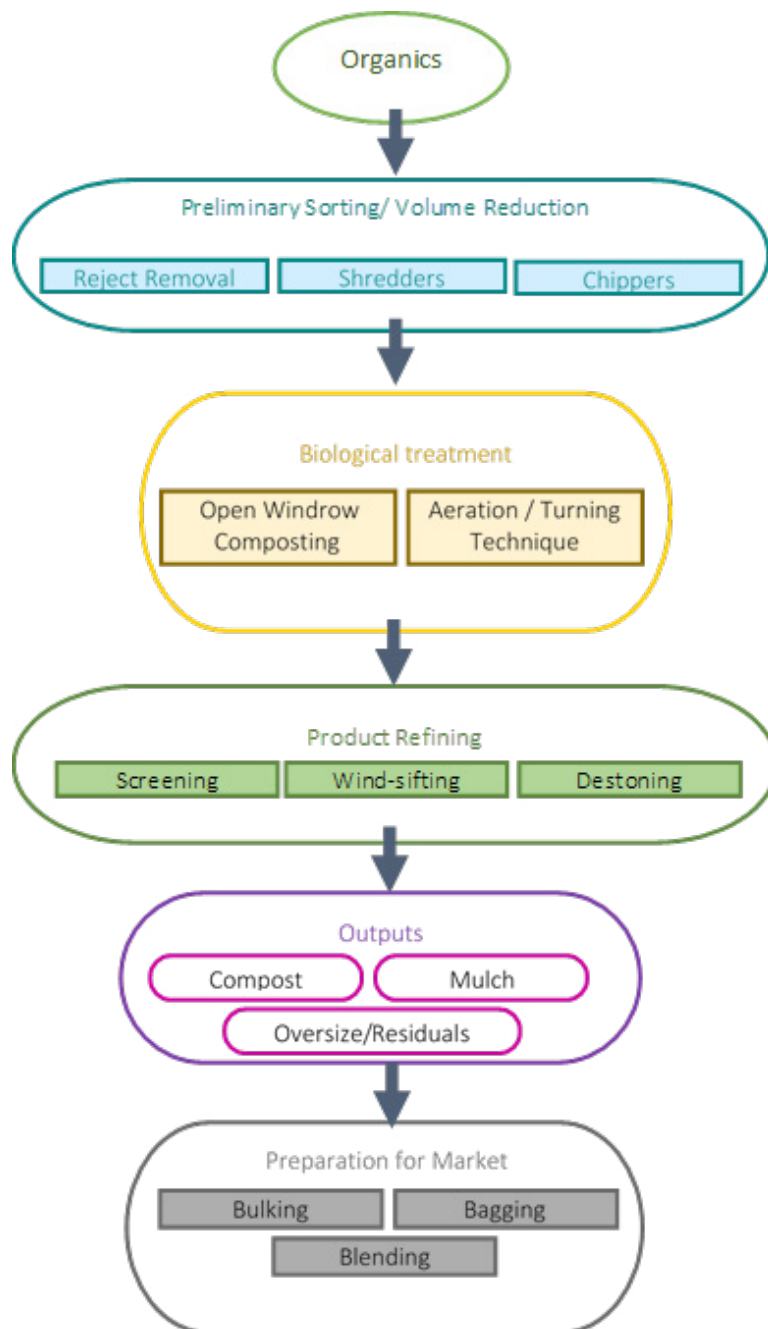
17 This is because the turning operation is undertaken by a dedicated diesel fuelled vehicle, and electricity use on site is usually for office / ancillaries only.

TABLE 9 SUMMARY OF ASPECTS FOR WINDROW COMPOSTING TECHNOLOGIES

Technology Type	OPEN WINDROW COMPOSTING
Commercial track record	Well established - hundreds of operating facilities across Australia of varying scales
Waste feedstocks	Source segregated organics, particularly garden organics, some commercial organics, agricultural and forestry residues, biosolids. Generally not suitable for food waste and other odorous / vermin attracting materials.
Typical capacity range	2,000-50,000 tpa
Indicative capital cost range ¹⁸	\$3M
Operational cost factors	Fuel and maintenance for mobile plant, labour, compost refining / offtake costs
Indicative land-take	0.7 – 0.8m ² / tonne
Factors for scaling	Process requires a large land area for composting and maturation windrows, so capacity is usually limited by available site area.
Products / outputs	<ul style="list-style-type: none"> › Compost / soil conditioner › Mulch › Blended soil products
Key issues and main risks	<ul style="list-style-type: none"> › Identifying suitable sites, with buffers, that are close to waste sources and end markets › Secure markets for compost in close proximity › Contamination management and impact on product quality / value › Odour control challenges, particularly during turning and loading activities › Bioaerosol impacts (micro-organisms which may become airborne in fine particles and mist during turning / loading)
Questions to ask	<ul style="list-style-type: none"> › Experience and existing networks for marketing of products › Product quality control procedures and compliance with AS4454 › Contamination management procedures and acceptance limits › Community engagement approach
Reference plant examples	<ul style="list-style-type: none"> › Suez, Epping Organic Resource Recovery Facility › Enviromix, Dingley Village composting facility

18 Indicative capital cost in 2017 for a 30,000 tpa capacity facility

FIGURE 5 WINDROW COMPOSTING PROCESS FLOW



3.3.1.2 Aerated static pile composting

Aerated static pile composting is similar to open windrow except that, rather than regular turning of the windrows, aeration is achieved by applying forced air flow from a blower through the pile, via perforated pipes installed under the windrow. The pipe is either embedded within the underlying pad or laid on top of the pad prior to first placement of the windrow (also called a mobile aerated floor or MAF system). A blower is attached to the pipes and can either be set to blow air out through the windrow (positive pressure) or draw it in (negative pressure). In the case of negative aeration, there is an option to process the odorous air through a bio-filter to control odours.

Sensors in the windrow typically monitor temperature and moisture levels and timers can be used to control and optimise the air flow.

Aerated static pile composting is particularly suited to processing garden waste with minor proportions of other materials. It can also be used to process denser and wetter organics such as biosolids or food processing residues, subject to regulations and licence requirements.

A further variant of this process is covered aerated piles, where a textile cover is applied over the top of the windrow. The cover adds a level of containment which improves the control of the conditions within the windrow. The covers are applied using a custom designed roller attachment to standard material handling plant. They are secured and weighed down once in place.

Proprietary covers for the static windrow piles are designed to allow carbon dioxide to vent out, whilst containing odours and minimising rainfall ingress. Covering the windrows provides some of the advantages of enclosed composting (see below) and may enable the processing of food waste; however, odour issues can still arise during loading and unloading of the windrows.

Track record

Aerated static pile systems are an established and proven technology. A number of council-run and commercial composting operations across Australia have upgraded their operations to integrate static aerated pile composting systems as a means to increase capacity, better control odours and/or improve product quality control.

Please refer to the *Guide to Biological Recovery of Organics* (Sustainability Victoria, 2018) for case studies, including aerated static pile composting.

Challenges and benefits

Regular turning is not required but at least one turning may be necessary as temperatures in the outside layers of the pile may not reach the pasteurisation temperatures.

The ability to control the air supply to the piles can allow for larger piles to be created and/or shortened processing times, increasing the land efficiency of the process. With good automated control of the aeration, the composting process can be more closely controlled than in turned windrows.

The moderate additional capital investment in aeration systems is usually offset by reduced need to turning equipment and reduced footprint of the composting pad. Labour input is usually less without the turning, but energy consumption is higher for the blower.

Summary

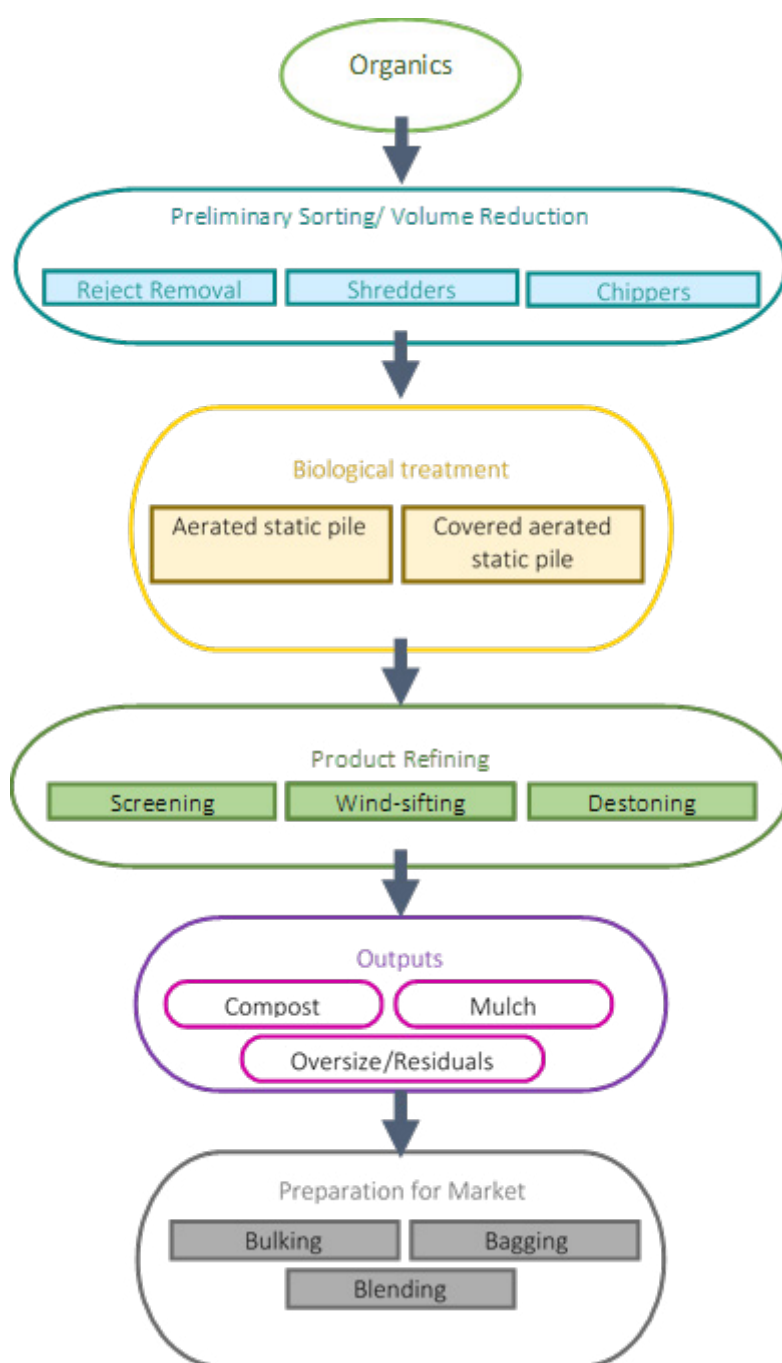
A summary of key aspects of windrow composting technologies is presented in Table 10 and a generic process flow is presented in Figure 6.

TABLE 10 SUMMARY OF ASPECTS FOR WINDROW COMPOSTING TECHNOLOGIES

Technology Type	AERATED STATIC PILE COMPOSTING
Commercial track record	Established – several operating facilities across Australia of varying scales
Waste feedstocks	Source segregated organics, particularly garden organics, commercial organics and biosolids. Potential to process food organics, particularly if covered.
Typical capacity range	2,000-50,000 tpa
Indicative capital cost range ¹⁹	No cover: \$4M Textile cover: \$7M
Operational cost factors	Fuel and maintenance for mobile plant, electricity for aeration, labour, compost refining / offtake costs
Indicative land-take	0.5 – 0.6m ² / tonne
Factors for scaling	Process requires a large land area for composting and maturation windrows, so capacity is usually limited by available site area.
Products / outputs	<ul style="list-style-type: none"> › Compost / soil conditioner › Mulch › Blended soil products
Key issues and main risks	<ul style="list-style-type: none"> › Identifying suitable sites, with buffers, that are close to waste sources and end markets › Secure markets for compost in close proximity › Contamination management and impact on product quality / value › Odour control challenges, particularly during turning and loading activities › Bioaerosol impacts (micro-organisms which may become airborne in fine particles and mist during turning / loading)
Questions to ask	<ul style="list-style-type: none"> › Track record of system with proposed feedstocks › Power consumption and aeration control / optimisation measures › Experience and existing networks for marketing of products › Product quality control procedures and compliance with AS4454 › Contamination management procedures and acceptance limits › Community engagement approach
Reference plant examples	<ul style="list-style-type: none"> › Pinegro products MAF composting facility, Morwell › Lismore Council, MAF composting facility, NSW

19 Indicative capital cost in 2017 for a 30,000 tpa capacity facility

FIGURE 6 AERATED STATIC PILE COMPOSTING PROCESS FLOW



3.3.1.3 In-vessel composting

In-vessel composting (IVC) is a group of more advanced composting systems where the process is fully contained within a vessel or building, and closely controlled to accelerate and optimise the composting process. IVC is particularly suited to more odourous waste streams such as food waste and the organic-rich fraction separated from mixed residual waste as part of a mechanical biological treatment process. These materials can also contain pathogens and therefore are considered higher risk than garden waste materials and needing more containment.

Under the EPA composting guidelines, enclosed composting is likely to be required where the feedstock contains higher risk materials such as food waste, food processing waste, unstabilised biosolids, grease trap waste, fresh manure and liquid organics.

For facilities processing mixed domestic food and garden organics from a kerbside collection, which have sensitive receptors nearby, an in-vessel system is likely to be required.

The containment 'vessel' may come in many forms including:

- › Bays or beds within a building (hall systems)
- › Rectangular tunnels
- › Rotating horizontal drums
- › Plug flow composters
- › Vertical flow silos or towers

Most processes provide optimal and automated monitoring and control of composting conditions by providing:

- › Mechanical agitation
- › Controlled forced aeration
- › Containment of heat to maximise pasteurisation
- › Temperature and moisture monitoring
- › Capture of process air which can then be treated to remove odours

Aeration is provided in a variety of ways:

- › In most tunnel systems, the compost is static and aeration is provided from a blower through a network of perforated pipes in the tunnel floor (either positive or negative)
- › In rotating drum systems, aeration is provided via the constant mixing and turning of the rotating waste
- › In hall systems, a variety of mechanical turning equipment is used including bucket wheels, augers and windrow turning machines.

IVC systems generally can either operate in batch mode (as in tunnel systems) or in continuous processing mode, as in hall composting and rotating drum systems where fresh feedstock is regularly added at one end, and compost removed from the other.

Plug flow and vertical flow systems are usually smaller scale, often suitable for commercial premises, institutions or precinct solutions. Plug flow systems are continuous flow and provide mixing by way of paddles or tynes on a rotating axle within a horizontal cylinder. Vertical silos have no mixing but passive aeration is encouraged by the varying temperature profile within the tower.

Track record

IVC is a well established and proven technology with a small number of plants in Victoria and several more across Australia. It is growing in popularity as more councils move towards kerbside co-collection of food and garden organics, which requires a more advanced processing solution.

Please refer to the *Guide to Biological Recovery of Organics* (Sustainability Victoria, 2018) for case studies, including in-vessel composting.

Challenges and benefits

IVC can be an energy intensive process, predominantly for the power to provide the forced aeration and mechanical turning. Typically, temperatures between 55°C and 65°C are achieved by IVC processes because the heat is contained in the vessel (any more than 65 degrees is harmful to the bacteria involved).

Higher sustained temperatures have the advantage of killing potentially pathogenic organisms in the waste and can also be used to dry material if desired (bio-drying). In Europe, enclosed bio-drying systems are used extensively to dry organic fraction from mixed waste in an MBT facility, such that it can be used to produce an RDF.

IVC is a more intense form of composting but is often used to partially decompose and pasteurise the waste, followed by a secondary open composting and/or maturation phase. Hence the duration of the in-vessel phase will typically be between 10 and 21 days. This reduces the capacity requirement of the more expensive IVC phase but also adds to the overall site footprint requirement when the open windrow phase is included.

Odours are contained and captured by ensuring vessels are sealed and air is continuously extracted to maintain the vessel under negative pressure. The extracted process air is usually treated through a bio-filter and/or scrubbers. The waste is also contained from vermin and protected from weather conditions, including rainfall which might produce excessive leachate. Any leachate that does seep out during the composting process is captured and recirculated back into the compost.

The parasitic load of IVC technologies varies greatly dependent on the technology utilised. Intensive technologies which require forced aeration, mechanical turning and use batch processes will typically be towards the higher end of the scale. A range of 4-16 kWh/t is typical.

Summary

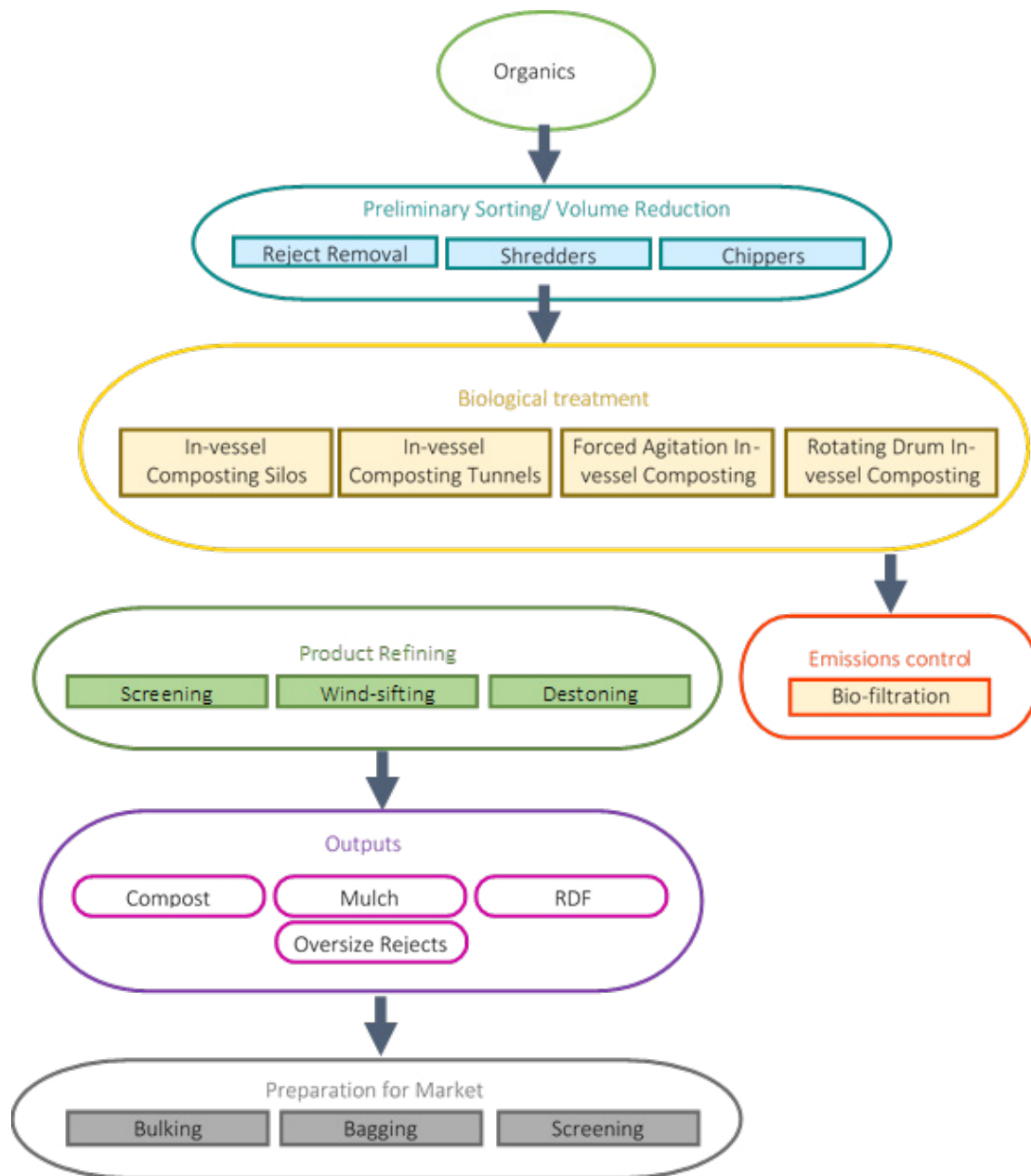
A summary of key aspects of in-vessel composting technologies is presented in Table 11 and a generic process flow is presented in Figure 7.

TABLE 11 SUMMARY OF ASPECTS FOR IN-VESSEL COMPOSTING ACTIVITIES

Technology Type	IN-VESSEL COMPOSTING
Commercial track record	Well established and proven, small number of plants in Victoria, several others elsewhere in Australia (mostly NSW). Hundreds of plants across Europe.
Waste feedstocks	Source segregated organics, particularly food and garden organics, commercial and industrial organics, food processing waste, biosolids. Also organics extracted from mixed waste as part of an MBT process.
Typical capacity range	10,000-100,000 tpa
Indicative capital cost range ²⁰	\$10M
Operational cost factors	Electricity for aeration and turning, maintenance, odour control, compost refining / offtake costs
Indicative land-take	0.4 – 0.7m ² / tonne
Factors for scaling	Capacity of the in-vessel process is the main factor. Some technologies such as tunnels, are modular and expandable.
Products / outputs	<ul style="list-style-type: none"> › Compost / soil conditioner › Mulch › Blended soil products › Stabilised, dried organics into RDF
Key issues and main risks	<ul style="list-style-type: none"> › Secure markets for compost in close proximity › Contamination management and impact on product quality / value › Odour control including effectiveness of biofilters
Questions to ask	<ul style="list-style-type: none"> › Odour control measures › Process control and optimisation measures › Experience and existing networks for marketing of products › Product quality control procedures and compliance with AS4454 › Contamination management procedures and acceptance limits › Community engagement approach
Reference plant examples	<ul style="list-style-type: none"> › Gippsland Water, Soil and Organic Recycling Facility (SORF) at Dutson Downs › Veolia, Bulla Organics Recycling Facility at Bulla › Western Composting, Organics Reprocessing Facility at Shepparton

²⁰ Indicative capital cost in 2017 for a 30,000 tpa capacity facility

FIGURE 7 IN-VESSEL COMPOSTING PROCESS FLOW



3.3.1.4 Vermicomposting

Vermicomposting, or vermiculture, involves the breakdown of organic waste by worms and other microorganisms. It is generally suitable for high moisture, softer organics or materials such as food waste, commercial and industrial organics, manures and biosolids. The worms can be sensitive to chemical contaminants in the feedstock or changes in conditions.

Vermicomposting can be used with other materials such as garden waste, if they have been pre-composted and ground to be more digestible by the worms. Unless the materials have been pasteurised through a composting process, vermicomposting may not destroy weed seeds and other pathogens.

As well as the food source (the organic waste being recovered), the worms need to be provided with bedding material which provides a stable habitat and usually has high absorbency, porosity for air flow and a high carbon to nitrogen ratio to prevent rapid breakdown (e.g. straw, shredded paper and cardboard).

Worms also need adequate but not excessive moisture (more than 50 per cent water content but not saturated); adequate aeration (usually passive but aided by porosity in the feedstock and bedding material); protection from extreme temperatures; and protection from excessive disturbance and movement (worms tend to stop feeding when disturbed).

There are three basic types of vermicomposting systems.

- › Windrows (batch or continuous)
- › Beds or Bins (batch or continuous)
- › Flow-through reactors (continuous)

For batch systems, bedding and feedstock are mixed and shredded as necessary, at the beginning of the process and the worms are added to break down the organic material over a period of weeks or months. In continuous processes, the worms are placed in the bedding material, and feedstock and new bedding are added incrementally on a regular basis. The castings are also harvested on a regular basis.

Track record

The technology of vermi-composting is well established but previous projects have suffered commercially, which likely stems from the high operational costs (labour intensive) and challenges realising the expected value of the products in the market.

There are few commercial facilities in operation presently in Australia, with the recently established Circular Food facility in Somerton a notable exception. There is a small number of operators using the process with a primary focus on producing castings and worms (rather than processing organic waste). An example is Australian Vermiculture based in Mildura, with a facility in South Australia supplying products to farmers.

There were commercial facilities constructed in the late 90's and early 2000's which are thought to be no longer operating, including the Triton facility at Lismore (NSW) processing various domestic food and garden waste, or the Vermitech facility in Redlands (Queensland) processing biosolids.

Please refer to the *Guide to Biological Recovery of Organics* (Sustainability Victoria, 2018) for case studies, including vermicomposting.

Challenges and benefits

In general, the process requires more labour, space and time for decomposition and harvesting of the worms, than other biological processes. It is more sensitive to environmental conditions than composting including temperature and acidic feedstocks.

As such, its uptake on a commercial scale has been limited and usually only at relatively small scales. This suggests that as a commercial organics recovery solution, it is difficult to make vermicomposting viable and competitive with other organics recovery processes.

Pasteurisation of the feedstock through elevated temperatures does not occur, and while there is evidence that the worms can reduce pathogens (through the digestive process), it is difficult to guarantee sanitisation of organics without a separate, upfront pasteurisation process.

Outputs and residues

The worm castings, also called vermi-compost, are generally superior in quality and soil benefits to that of conventionally produced compost. They can be used without further stabilisation however may be pelletised to improve handling.

Excess worms can be harvested and are a valuable protein source for fish and animal feeds.

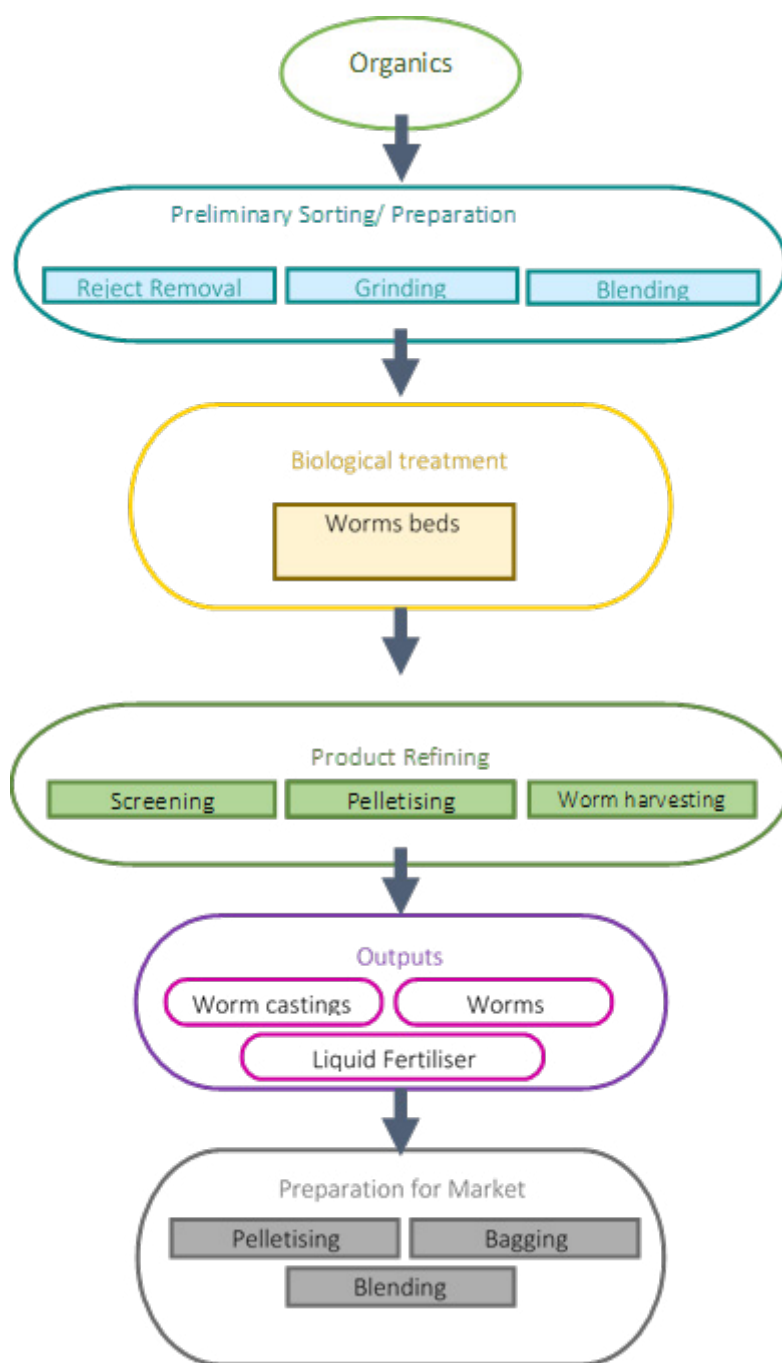
Summary

A summary of key aspects of vermicomposting is presented in Table 12 and an outline process flow diagram presented in Figure 8.

TABLE 12 SUMMARY OF ASPECTS FOR VERMICOMPOSTING

Technology Type	VERMI-COMPOSTING
Commercial track record	Proven as a technology but commercially challenging as a viable commercial-scale organics recovery solution. Limited existing commercial plants, mostly small scale and niche. Mixed success of historic projects.
Waste feedstocks	Source segregated putrescible organics, particularly food organics, manure, food processing waste, biosolids. Also pre-composted or digested organics.
Typical capacity range	100 – 5,000 tpa
Indicative capital cost range	No data, due to lack of commercial references
Operational cost factors	Electricity for aeration and turning, maintenance, odour control, compost refining / offtake costs
Indicative land-take	1.0 – 2.0m ² / tonne
Factors for scaling	Capacity of the worm beds is the main factor which are generally modular and expandable
Products / outputs	<ul style="list-style-type: none">› Worm castings / vermi-compost soil conditioner› Liquid fertilisers (worm casting tea)› Worms – protein, animal feed
Key issues and main risks	<ul style="list-style-type: none">› Labour intensive process› Small scale / high land-take› Protection from extreme temperatures / weather› Markets that realise the full value of the product› Feedstock limitations› Lack of high temperature pasteurisation
Questions to ask	<ul style="list-style-type: none">› Feedstock acceptance limitations› Security of product markets and values› Pasteurisation of pathogens
Reference plant examples	<ul style="list-style-type: none">› Circular Food, Somerton

FIGURE 8 VERMI-COMPOSTING PROCESS FLOW



3.3.2 Anaerobic processes

Anaerobic decomposition processes occur in the absence of oxygen, which in the case of anaerobic digestion (AD), leads to the production of methane-rich biogas. Fermentation is another anaerobic process, which is an emerging technology in terms of application to organic wastes, but results in the production of ethanol (see 4.5).

3.3.2.1 Anaerobic Digestion

It involves a complex system of different microbe groups, which must be carefully controlled to produce an optimal output of biogas.

AD can be applied to a wide range of organics including food and garden organics, biosolids, manures and a variety of commercial, industrial and agricultural solid and liquid residues.

All AD processes are enclosed and sealed to exclude air and contain the biogas, using specifically designed digester vessels. They can operate under two distinct temperature ranges: mesophilic conditions (20–45°C) and thermophilic conditions (50–65°C) and can comprise either single or multiple process stages.

There are two principal approaches to the digestion of organic wastes:

- **Wet AD processes** – are most common and typically used to treat materials which are in, or can be made into, a liquid or slurry phase (ie, pumpable), usually with a solids content of no more than around 15 per cent.
- **Dry AD processes** – are used to treat materials which are solid, stackable and with solids content of more than 20 per cent that is not easily soluble.

The existing AD systems in Australia and most of the systems globally are wet systems. Dry systems are usually applied where the feedstock includes garden waste or other materials that are insoluble or difficult to macerate (e.g. woody crop residues).

Please refer to the *Guide to Biological Recovery of Organics* (Sustainability Victoria, 2018) for more detailed information on Wet and Dry AD, including feedstocks, outputs, markets, quality control and best practice approaches to developing organics recovery projects.

Outputs and residues

Like composting, AD still results in an organic residue (called digestate) which has value as a soil conditioner product. The digestate output comprises the remaining solids and nutrient-rich water from the process.

The solid digestate will require further stabilisation (for example, through aerobic composting) before being used as a soil conditioner. Both solid and liquid digestate will require analysis and quality assurance testing to ensure contaminants such as heavy metals are within acceptable levels.

Most wet and some dry AD processes produce liquid digestate which may be used as liquid fertiliser in agriculture, although it may need to undergo further treatment. The solid digestate will require further stabilisation (for example, through aerobic composting) before being used as a soil conditioner. Both solid and liquid digestate require analysis and quality assurance testing to ensure contaminants such as heavy metals are within acceptable levels. These outputs are PIW and advice should be sought from EPA regarding the regulatory requirements for re-use of these materials.

The volume of digestate produced from AD can be significant and it is important to consider the testing regime, quality requirements, outlets and markets for this material. The business case for a project must account for the costs associated with managing digestate (stabilisation, transport, handling and application).

The biogas is typically 50–60 per cent methane with minor trace elements and carbon dioxide making up the balance. The biogas production rate depends on the feedstock and process efficiency, but garden organics typically produces around 90 m³ biogas per tonne of feedstock, compared with food organics at around 120m³/t and grease-trap waste at around 800m³/t.

It is conventionally used to fuel an on-site gas engine generator to produce electricity, for either internal use or export to the grid. This technology is well proven and low risk, with various generators on the market that are specifically designed to run on biogas.

A recent and growing trend is to upgrade biogas through a refinement process which removes the carbon dioxide and contaminants, to produce a near pure methane gas known as biomethane, which is equivalent to natural gas. Biomethane can be compressed and used as vehicle fuel (akin to compressed or liquefied natural gas) or injected into the natural gas distribution grid as a renewable substitute for fossil natural gas²¹. The technology to refine and compress biogas is readily available, usually as compact modular plants.

Anaerobic digesters are net exporters of energy and will typically have a low parasitic load which utilises some of the generated heat and electricity. When producing electricity from biogas, a combined heat and power (CHP) generator is typically 30–35 per cent efficient and will generate in the order of 170–360 kWh/t of feedstock. The production of biogas, and therefore power, is closely linked to the feedstock characteristics and the effectiveness of the digestion process. Larger plants will benefit from utilising larger and more efficient engines. The thermal (heat) output will typically be in the range 900–1200 kWh/t feedstock.

Track record

Wet anaerobic digestion is an established technology in Australia for treating sewage sludge from municipal wastewater treatment plants, some wet agricultural wastes and food and beverage processing residues (e.g. brewery waste). It has also been used to process commercial food waste and food processing wastes at dedicated facilities such as EarthPower in Sydney, Richgro in Perth and more recently, Yarra Valley Water's facility digesting commercial food waste.

Anaerobic digestion is common internationally (particularly Europe and UK) as a treatment technology for food and/or garden waste, which may be blended with other streams including biosolids and manure.

Dry AD is yet to be implemented in Australia but is more common in parts of Europe and growing in North America, mostly for the processing of co-collected kerbside food and garden organics.

The technology for conversion of biogas to biomethane is proven and this option is becoming increasingly common in Europe and North America where biogas is injected into gas mains or used to heavy vehicle fleets (particularly waste collection trucks), buses and other commercial light and heavy vehicles. It is yet to be implemented in Australia but could be attractive in some cases given rising gas and fuel prices.

Please refer to the *Guide to Biological Recovery of Organics* (Sustainability Victoria, 2018) for case studies, including dry and wet AD.

21 There may be the need to apply additives (for odour or to raise calorific value if required), prior to injection into the gas grid.

Challenges and benefits

The benefit of AD over aerobic processing is the opportunity to extract energy during the process. Biogas production also leads to a diverse range of energy product options including electricity, heat, gas and vehicle fuels. This comes with additional cost and process complexity, which needs to be balanced against the potential revenues from energy sales.

AD processes can be more sensitive to feedstock and environmental changes, compared with composting. The process needs to be carefully monitored and controlled, and care taken not to introduce feedstocks that could be toxic to the biology, or impact the potential usability of the outputs.

Summary

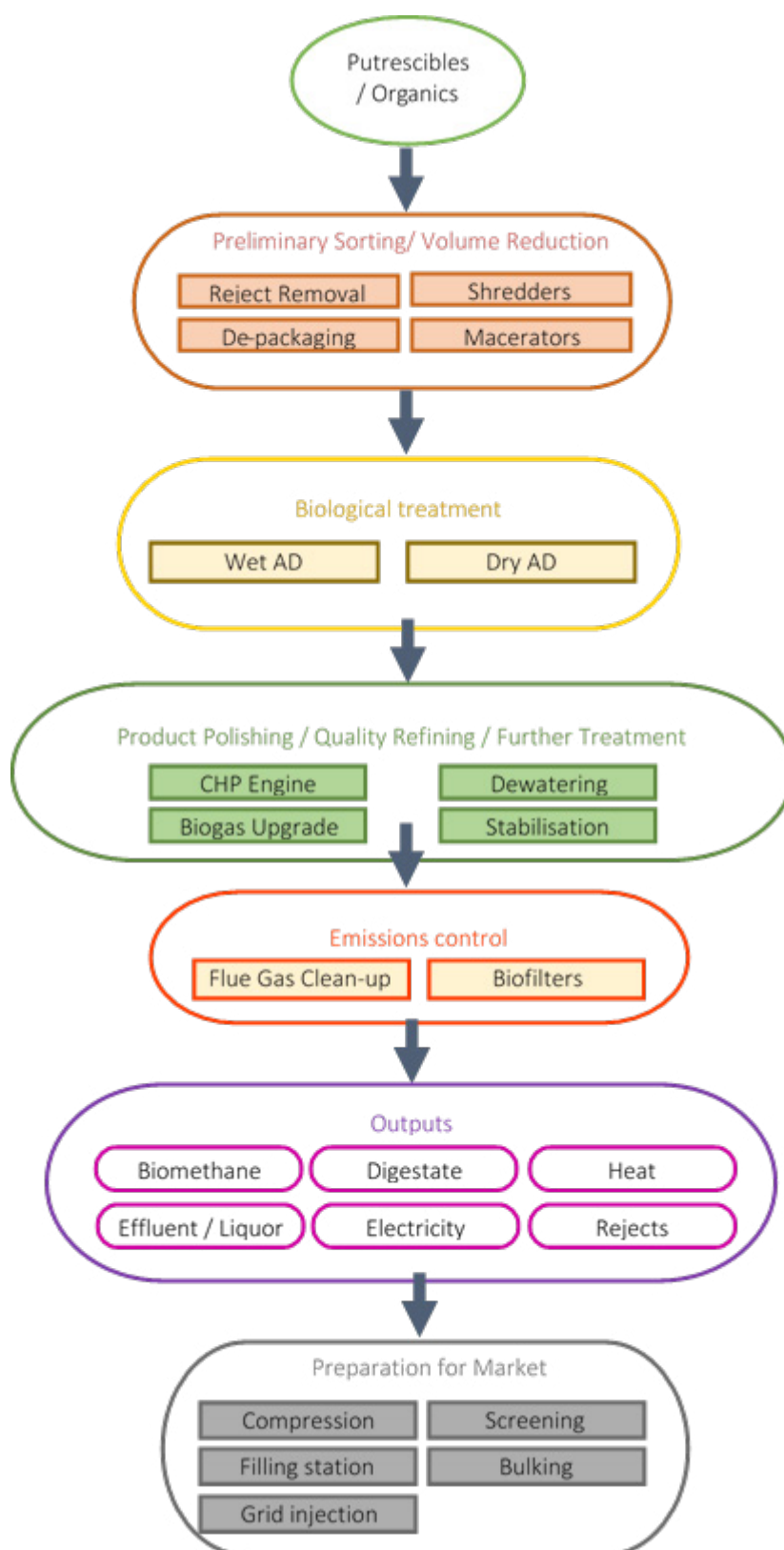
A summary of key aspects of anaerobic digestion technologies is presented in Table 13 and a generic process flow is presented in Figure 9.

TABLE 13 SUMMARY OF ASPECTS FOR ANAEROBIC DIGESTION TECHNOLOGIES

Technology Type	ANAEROBIC DIGESTION
Commercial track record	Well established and proven internationally. Small number of plants using wet AD technology in Australia. Dry AD has some presence in Europe.
Waste feedstocks	Source segregated putrescible organics, particularly food and garden organics, manure, food processing waste, biosolids.
Typical capacity range	10,000 - 80,000 tpa
Indicative capital cost range ²²	\$12M
Operational cost factors	Maintenance, odour control, digestate stabilisation / offtake costs
Indicative land-take	0.4 – 0.7m ² / tpa capacity
Factors for scaling	Limited flexibility to operate outside design range. Capacity of the digesters is the main factor, which are modular in some systems.
Products / outputs	<ul style="list-style-type: none"> › Biogas or biomethane › Electricity, heat › Stabilised digestate (compost) › Liquid digestate (fertiliser) in controlled circumstances
Key issues and main risks	<ul style="list-style-type: none"> › Quality of the digestate › Secure markets for digestate in close proximity when digestate is of adequate quality › Contamination management and impact on process equipment › Biogas / biomethane quality and compliance with standards › Monitoring, controlling and optimising for biogas production › Odour control
Questions to ask	<ul style="list-style-type: none"> › Odour control measures › Process control and optimisation measures › Experience and existing networks for marketing of products › Product quality control procedures and compliance with standards › Contamination management procedures and acceptance limits › Community engagement approach
Reference plant examples	<ul style="list-style-type: none"> › Yarra Valley Water ReWaste facility, Wollert › EarthPower AD plant, Sydney › Richgro AD facility, Perth

22 Indicative capital cost in 2017 for a 30,000 tpa capacity facility

FIGURE 9 ANAEROBIC DIGESTION PROCESS FLOW



3.4 Thermal treatment solutions

Thermal treatment technologies have potential to recover energy from the carbon-based materials present in single stream wastes such as tyres, plastics, timber, and organics; refuse derived fuels or mixed residual waste streams.

Combustion processes have been widely deployed for processing waste materials across the globe and have the strongest technical and commercial track record of all residual waste treatment technologies. Waste combustion facilities with energy recovery are often interchangeable referred to as energy-from-waste (EfW), waste-to-energy (WtE) or energy recovery facilities (ERF)²³.

The term 'mass-burn' combustion relates to plants which are designed to process mixed residual waste with little or no pre-processing. This is the most common approach in existing EfW facilities globally and is appropriate where there are efficient upstream separation and recycling systems (i.e. source segregation of recyclables and organics). Other technologies are specifically designed to treat a pre-processed, highly calorific RDF (see Section 3.2.2).

Modern combustion energy-from-waste (EfW) facilities in Europe, North America and Asia, are a far cry from the municipal incinerators (destructors) that were formerly operated across Victoria at locations including Geelong, Essendon, Prahran and others. Nevertheless, there is a lingering community perception associated with waste combustion that will need to be addressed as of the community engagement approach for any thermal treatment project.

Firstly, modern systems are very efficient at converting energy in the waste feedstock into usable electricity and heat, as opposed to historic waste incinerators that were purely a disposal solution and had no energy recovery. Large modern EfW plants can convert 25–30 per cent (or in some cases reportedly in excess of 30 per cent) of the energy in the waste into electricity.

Modern technologies include advanced air pollution control systems that have been shown to effectively minimise and control emissions of noxious and toxic compounds including dioxins, furans, acid gases, nitrogen oxides and particulates. Dioxins and similar compounds were historically a major concern for any waste combustion activities but the formation and management of these compounds is now much better understood and modern plants are able to minimise dioxin production to negligible levels through a combination of controlling chlorine inputs; close control of the combustion process; high temperature destruction; and air pollution control technologies.

The Western Australian Government commissioned an investigation into the environmental and health impacts of EfW facilities in 2013²⁴. It reviewed various relevant studies and found there was little convincing evidence of heightened risk of health impacts from modern EfW facilities that are well operated in compliance with regulations. The UK Government's Health Protection Agency also reviewed research on potential links between emissions from EfW plants and effects on health, finding that modern, well-managed plants make only a small contribution to local air pollutants and any impacts on health are likely to be very small and not detectable²⁵.

Aside from combustion, there are a number of newer thermal technologies that have been developed over recent decades to process waste feedstocks. These are collectively termed advanced thermal treatment (ATT) technologies, which includes various forms of gasification, pyrolysis and plasma gasification.

Of these technologies, only some forms of gasification have attained a sufficient technical and commercial track record to be considered as proven technologies. Gasification involves converting feedstock materials into an energy-rich gas stream called syngas (discussed in more detail below). There are a number of commercial plants which directly combust this syngas without refinement, in a boiler to generate steam and, like most combustion EfW plants, produce electricity via a steam turbine. This version of gasification, which may be termed close-coupled gasification, is relatively proven with commercial plants operating across Europe and in Asia (particularly Japan and Korea).

Other gasification technologies that aim to produce a clean, refined syngas stream which can be a substitute for natural gas; used to produce hydrogen, chemicals or liquid fuels; or to generate power through a gas engine generator or gas turbine, are less commercially proven and considered emerging technologies. However, given that some forms of gasification are commercially proven, it has been included in this chapter.

Pyrolysis and plasma gasification have also not yet reached commercial proven status in terms of recovering value from mixed waste streams and are thus considered in Section 4 as emerging technologies.

Modern thermal EfW facilities are in effect small to medium sized power stations that are able to recover renewable energy²⁶ from residual waste that would otherwise be sent to landfill. Modern EfW facilities are required to comply with stringent emission controls to protect human health and the environment.

EfW plants can be deployed as part of an integrated waste and resource recovery solution. In Europe EfW has been coupled with recycling schemes to achieve resource recovery and landfill diversion rates in excess of 75 per cent. There has been concern that investing in large scale EfW plants could undermine efforts to maximise recycling but this should not be a problem, provided plants are appropriately scaled for the current and future expected volume of true residual waste.

Current waste gasification and combustion facilities can recover energy from waste as:

- Electricity
- Heat in the form of high or low pressure steam for industrial processes
- A combination of these forms in a combined heat and power (CHP) or tri-generation configuration (power, heating and cooling)

23 Energy from waste is also be used to describe gasification, pyrolysis and anaerobic digestion technologies which recover gas, heat or electricity from processing a waste derived feedstock.

24 <http://www.epa.wa.gov.au/sites/default/files/Publications/WSP%20Waste%20to%20Energy%20Technical%20Report%20Stage%20Three.pdf>

25 UK DEFRA, Energy from Waste - A guide to the debate, February 2013

26 The proportion of the energy produced that is considered 'renewable' is a function of the composition of the feedstock and relative energy contributions of organic components, as determined by the Clean Energy Regulator Guidelines <http://www.cleanenergyregulator.gov.au/DocumentAssets/Documents/guidelines-determining-renewable-components-waste-electricity-generation-0312.pdf>

3.4.1 Combustion

Combustion involves burning of waste in an excess supply of air in a purpose-designed furnace. The heat energy is usually recovered through the use of a water tube boiler and heat exchangers to generate steam (in a similar way to that used in a coal-fired power station). The steam is then fed into a steam turbine to generate electricity; and/or supplied to local heating/cooling customers for use in industrial processes.

Three principal types of combustion technology have been developed to recover energy from residual waste:

- Moving grates – the most common approach, where waste is fed along a mechanical bed that passes through the combustion chamber. To maximise 'burn out' of the waste, moving grates incorporate some form of mechanical agitation mechanism, which may take the form of rollers, reverse-acting grates, or reciprocating grates.
- Rotary kilns – where waste is fed into a horizontal drum furnace down an incline that rotates or oscillates, mixing the waste to facilitate 'burn out'.
- Fluidised beds – where shredded waste or RDF is fed on to a bed of hot suspended particles (usually sand) which is 'fluidised' by up-flowing air to assist the mixing and rapid heating of the waste.

Typically, combustion EfW plants dealing with unprocessed municipal waste can manage incoming waste with a net calorific value between 8.5 and 10.5MJ/kg, although each facility will have its own design parameters. Good mixing in the waste bunkers helps to deal with variations in waste composition.

Through combustion, the waste is converted into carbon dioxide and water vapour, with a wide variety of trace gases and ash residue. Modern combustion plants are required to hold the combustion gases to a temperature of at least 850°C for at least two seconds, which helps to ensure full combustion and destruction of noxious organic compounds such as dioxins. Any non-combustible materials (e.g. metals, glass) remain as a solid, known as Bottom Ash, which contains a small amount of residual carbon (typically less than 3 per cent).

Waste combustion plants incorporate extensive monitoring systems throughout the combustion, energy recovery and gas clean-up stages that allow almost instantaneous adjustment of the process to ensure efficient operation of the plant and compliance with emission requirements.

All modern, waste combustion plants have extensive gas clean up or air pollution control (APC) systems that remove the acid gases, particulates and heavy metals from the flue gases before they are discharged to the atmosphere. The generation of dioxins and furans is avoided through careful control of combustion conditions but any trace amounts can be captured in the APC system. Fine particulates in the exhaust gas are filtered out (called fly ash) resulting in a small residue stream which is usually classified as hazardous waste (prescribed industrial waste).

Isseane EfW Plant, Paris France

The Isseane waste combustion plant is located in the heart of Paris on the banks of the Seine and has been designed to meet best practice local emissions limits. It has a capacity of 460,000 tpa and feedstock is sourced from urban areas within 10km of the plant.

The €580 million facility was built by French waste disposal authority SYCTOM. The combustion plant is operated by TSI consortium, which is lead by French renewable energy firm TIRU Groupe.

Two thirds of the facility is constructed underground to minimise visual impact and it has a green roof and wooden cladding, with small chimneys.

Combustion gases are treated to remove 99 per cent of particulate emissions and other pollutants. Bottom ash is taken away on barges for re-use in aggregates, while recovered metal is recycled and fly ash is sent for hazardous waste disposal.

The plant can generate up to 52MW electricity via a steam turbine and provides district heating for nearby buildings including the Musée d'Orsay.

Outputs and residues

The main output of waste combustion is electricity which can be fed into the national grid or used directly by a nearby industrial user. Heat, in the form of steam can also be supplied to local heating/cooling customers for use in industrial processes.

Bottom ash can be processed (for removal of metals and stabilisation) to produce an inert material that can be recycled as road-base and fill material. This process is generally screening or blending the bottom ash with other material. Otherwise it needs to be disposed to landfill – in some cases, bottom ash may qualify for disposal to inert landfill but in others, a higher standard landfill may be required or some form of stabilisation / treatment prior to disposal. New technologies are also emerging to recover EfW fly ash as aggregates and other products, but otherwise it will need to be disposed to an appropriate hazardous landfill.

Track record

Waste combustion is a common and proven residual waste treatment process in numerous countries across the world, with a substantial concentration of plants in Europe, North America and Asia. It is an established technology that can be used to treat a variety of waste streams. It usually requires minimal pre-treatment of the waste, such as the removal of unsuitable or oversized materials and the process is relatively robust to changes in waste composition. With the exception of fluidised bed systems, most technologies can handle the majority of municipal type wastes without any processing²⁷.

Moving grate systems are by far the most common technology and account for the majority of EfW plants globally. Rotary kilns are more likely to be deployed for smaller scale plants (see below). Fluidised bed combustion systems generally require a pre-treated RDF feedstock to remove heavy components to ensure that it fluidises properly on the bed. The only two fluidised bed plants developed in the UK have had performance issues, due largely to inadequate feedstock preparation leading to problems with fluidisation of the waste in the furnace.

Challenges and benefits

It is important to ensure that combustion plants align with government objectives and direction of increased resource recovery, and avoiding perverse outcomes. There is notable community and environmentalist group concerns around outcomes of combustion facilities, in regards to both health and environmental impacts, and also its potential to cannibalise higher order recovery.

Combustion plants that process mixed waste are advanced technologies that require a substantial capital investment, particularly in the air pollution control systems. At the same time, steam turbine generators improve in efficiency as the scale increases. Large plants also tend to incorporate more advanced heat recovery systems which boost the overall efficiency of the process.

As such, mixed waste combustion plants tend to be large scale in order to bring unit processing costs down to a competitive level. Most modern projects have a capacity of over 100,000 tonnes per annum and while modern plants exist that are smaller than this (see below), it is generally considered they will have a high unit processing cost and lower energy recovery efficiency. The majority of new plants are in the range 250,000 – 400,000 tonnes per annum. The largest plants in the world process in excess of 1 million tonnes per annum, across multiple parallel processing lines.

The parasitic load of combustion EfW plant is typically in the order of 9–17 per cent of energy production when producing electricity only. The net export of electricity is likely to be in the range of 500–800 kWh/t feedstock, rising to around 1000 kWh/t if combusted as a high calorific value RDF. If heat is exported the thermal output will be greater, however this depends on the availability of suitable heat outlets and the desired mix of heat and electricity.

Battlefield EfW Plant, Veolia, Shropshire UK



The facility was completed in 2015 and can process up to 90,000 tonnes a year of residual waste, generating 8MW which is enough electricity to power about 10,000 homes. The project was delivered under a 27-year contract with Shropshire County Council. The plant is aiming to divert 95 per cent of inputs from landfill and most ash will be recycled as a construction material.

The project created around 180 jobs during construction and 24 permanent operational jobs.

Small Scale Waste Combustion

There are however, plants which operate at less than 100,000 tonnes per annum, including some recently constructed, and the viability of those plants is a function of local circumstances. In the UK, there are a number of plants in this smaller scale range which have been constructed recently, including:

- Exeter (UK) EfW plant – 60,000 tonnes per annum, operated by Viridor for Devon County Council, operational since 2014
- Battlefield (UK) EfW plant – 90,000 tonnes per annum, operated by Veolia for Shropshire County Council, operational since 2015
- Peterborough (UK) EfW plant – 85,000 tonnes per annum, operated by Viridor for Peterborough City Council, operational since 2015

Small scale EfW plants have a number of advantages over larger plants:

- It is easier to secure the required feedstock, particularly if it can be sourced from one local government or as part of a collective contract with a group of councils rather than individually from multiple councils, and if there is reduced need to rely on commercial waste inputs
- It enables localised processing of waste (close to the source of generation), reducing the need to transfer waste long distances
- Localised job creation (particularly in regional communities)
- Community perceptions may be more favourable, as emissions and impacts will be less and there will be less concern around importing waste from other municipalities or areas, although some degree of opposition can still be expected
- Suitably sized facilities reduce the risk of future over-capacity, which may raise concerns about undermining of future recycling efforts.

²⁷ Fluidised Bed combustion systems which require a pre-treated feedstock with a maximum particle size of ~150mm and removal of large inert materials such as metals, glass, stones.

Data collected from UK EfW plants across a range of scales indicates a clear relationship between plant scale and gate fees. Small plants around 70,000 tonnes per annum capacity have gate fees around £130-140 (GBP) per tonne, while larger modern plants of 250,000 tonnes per annum are closer to £80 per tonne²⁸.

One way to overcome the reduced efficiency of steam turbine systems at smaller scales and improve the overall viability of a small scale EfW project, is to also utilise the heat from the process. There are several smaller plants in Scandinavia which burn waste to supply heat for district heating and while there is limited demand for that sort of use in Australia, there may be situations where an industrial process requires a constant supply of heat (in the form of steam) that could be supplied by a small scale waste combustion plant.

Alternatively, it may be possible to co-locate a smaller EfW plant next to an existing coal-fired power station and use the heat / steam from the EfW plant to boost the performance of the existing, larger steam turbine, as has been proposed in one project in NSW (see discussion below).

In addition to mixed waste feedstocks, combustion plants can be designed to process source separated or single-stream wastes, usually at smaller scales. There are numerous reference plants around the world processing:

- Dried biosolids
- Waste wood, forestry residues, woody green waste
- Chicken litter
- Straw and crop residues

There are several plants in Australia burning biomass wastes including bagasse from sugar cane processing as well as sawdust, wood processing residues and crop residues. For these cleaner, single stream feedstocks, the combustion and air pollution control systems can be somewhat simplified meaning that they can be viable at smaller scales. Most of the existing plants in Australia are attached to a processing plant receiving direct heat and power outputs (e.g. sugar mill, saw mills, grain processing plants). In some cases, the steam turbine may be replaced with an alternative generation technology such as Organic Rankine Cycle (ORC) generators which can be more efficient at smaller scale or with lower quality steam.

Co-firing options

The use of waste as a fuel in existing power generation facilities provides an opportunity to use existing infrastructure and significantly reduce the capital outlay required.

The production of RDF for use in cement kilns has been successfully implemented around the world and is gaining interest elsewhere in Australia, but cement manufacture is declining in Australia and no longer occurring in Victoria.

Co-firing of RDF or waste fuels in coal-fired power plants or other industrial furnaces is significantly more challenging as it would likely require an upgrade of the air pollution control systems and could present issues with controlling the combustion process or with internal corrosion in plants not designed to take waste fuels.

The other option is to co-locate an EfW furnace next to an existing power plant or industrial facility and feed steam into the existing plant. A feasibility study into a project of this nature was recently announced in NSW²⁹ whereby a new furnace would process the RDF and supply steam to the adjacent existing power plant, which will boost the output of the existing steam turbines. This concept significantly reduces the capital and operating cost compared with a standalone EfW plant, making use of existing power generation infrastructure.

Summary

A summary of key aspects of mass combustion technologies is presented in Table 14 and a generic process flow is presented in Figure 10.

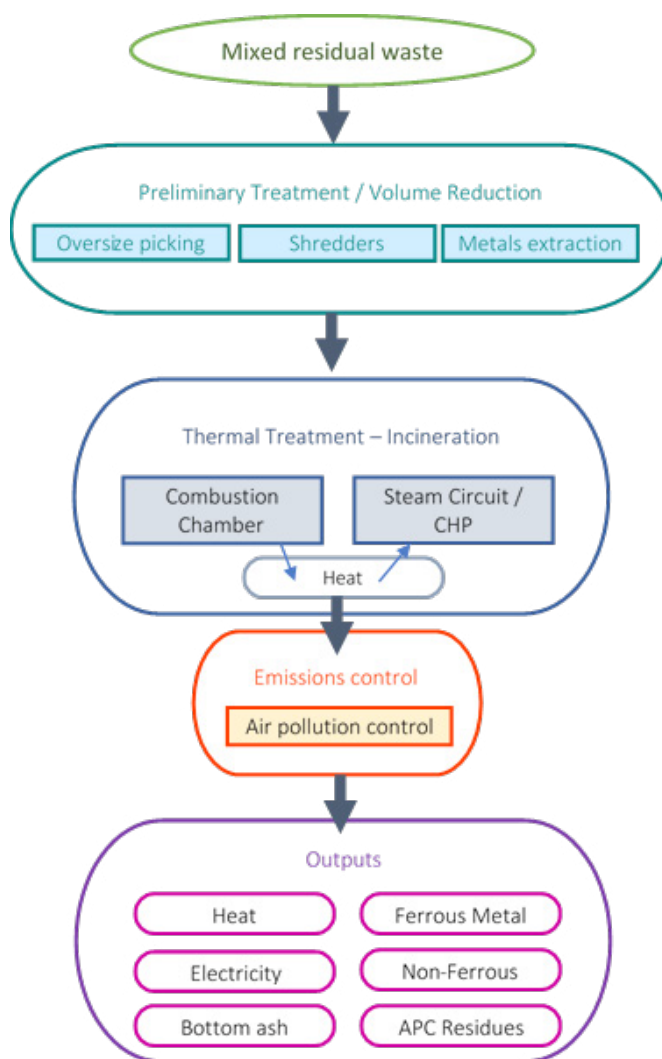
28 <http://task36.ieabioenergy.com/wp-content/uploads/2016/06/IEA-Bioenergy-Small-scale-EfW-Final.pdf>

29 EnergyAustralia commenced a planning and feasibility study in 2017 into a project that would see a new EfW furnace built at its Mt Piper coal-fired power station at Lithgow to burn 100,000 tpa RDF sourced from Sydney, with steam fed into the existing plant: <https://www.energyaustralia.com.au/sites/default/files/2017-02/Energy%20Recovery%20Factsheet.pdf>

TABLE 14 SUMMARY OF ASPECTS FOR MASS COMBUSTION TECHNOLOGIES

Technology Type	COMBUSTION
Commercial track record	Well established and proven internationally. No plants in Australia processing mixed waste but there are small plants for single-stream biomass wastes.
Waste feedstocks	Mixed residual waste, RDF, waste timber, agricultural residues
Typical capacity range	50,000 – 400,000 tpa (largest plants are 1 million+ tpa)
Indicative capital cost range ³⁰	\$65M
Operational cost factors	Maintenance, labour, ash residue management / disposal, value of energy outputs, air pollution control consumables
Indicative land-take	0.15 – 0.25m ² / tonne
Factors for scaling	Capacity is determined by the thermal capacity of the main furnace – i.e. if feedstock calorific value decreases, throughput can increase (and vice versa). Potential for additional processing lines to be added to increase capacity. Much less efficient and cost effective at small scales (less than 100,000tpa).
Products / outputs	<ul style="list-style-type: none"> › Electricity, heat › Bottom ash – recovered aggregate / fill › Fly ash – for disposal or recovery › Recycled metals (from bottom ash)
Key issues and main risks	<ul style="list-style-type: none"> › Optimising capacity for future needs › Community perceptions of EfW and opposition › Planning approvals risks and timeframes › Energy offtake market volatility
Questions to ask	<ul style="list-style-type: none"> › Track record and reference plants in similar applications › Energy recovery efficiency › Flexibility to waste input changes (minimum tonnages, composition change, calorific value envelope) › Process control and optimisation measures › Residue management approaches › Community engagement approach › Experience gaining planning approvals
Reference plant examples	<ul style="list-style-type: none"> › TIRU Groupe, Isseane EfW plant, Paris, France › Veolia, Portsmouth ERF, Hampshire, UK › Viridor, Exeter EfW plant, UK › Veolia, Battlefield ERF plant, Shrewsbury, UK

FIGURE 10 MASS COMBUSTION PROCESS FLOW³¹



30 Indicative capital cost in 2017 for a 100,000 tpa capacity facility

31 This includes the sort of pre-treatment technology that would largely only be applicable to Fluidised Bed Systems

3.4.2 Gasification

In the past, gasification of coal was used extensively to produce 'town gas' in many cities around the world, prior to the exploitation of natural gas reserves. So the technology is not new, but its application to waste and biomass streams has really been in focus over the last two decades.

Whereas combustion occurs with an excess of oxygen to ensure complete oxidation of the carbonaceous materials, gasification occurs in a limited oxygen environment so that the waste is effectively partially oxidised or combusted. The partial oxidation provides sufficient heat to drive the process and make it self-sufficient. The result is generation of a combustible gas stream (syngas) which is mostly a mix of carbon dioxide and hydrogen but may also contain other hydrocarbon gases.

The processes have been commercially used for the treatment of mixed residual and other solid waste streams. The track record of commercial plants treating municipal derived wastes is still limited compared to waste combustion, but there are large scale plants using gasification close-coupled with steam boiler / turbine configurations in operation in Europe, North America and Japan. There are also commercial plants that process single-stream feedstocks such as waste wood.

A number of existing commercial waste gasification technologies are not significantly different to established combustion technologies. The main furnace may use some form of moving grate or fluidised bed that is adapted for a restricted air flow and then the resulting syngas will be combusted in a second chamber with the addition of more air. There are also plants using fluidised bed technologies, mostly in Japan and Korea.

There is little to distinguish this approach from conventional combustion, although it does provide an opportunity to better control the final combustion stage because it is entirely gas phase. Hence the overall inflow of air can be reduced, which improves the overall efficiency and reduces costs associated with the clean-up of flue gases. The temperature in the secondary combustion chamber can also be higher and many Japanese plants employ a high temperature zone (up to 1250°C) to melt the ash to form a vitrified slag that can be recycled as an aggregate. Power generation is usually still through a boiler and steam turbine.

Outputs and residues

The main product of most existing gasification plants is electricity and/or heat. The proven technologies described above, where the gasifier chamber is directly linked to a secondary combustion furnace and the syngas is combusted immediately, are generally not capable of producing a clean syngas.

Technologies that can produce a clean syngas stream are in development but have generally proven more challenging to operate reliably and there are few that have been proven at commercial scale for an extended period. Until those technologies are fully developed and proven, the true potential benefits of waste gasification will not be realised. Such benefits include the generation of power via more efficient internal combustion gas engine generators, gas turbines or fuel cells; substitution of natural gas with syngas; or the production of liquid fuels and chemicals.

Like combustion, gasification also produces ash outputs – a bottom ash and fly ash stream, which can potentially be recovered as aggregate and fill materials but may require landfill disposal at an appropriate landfill facility.

Track Record

There are number of fluidised bed gasification technologies in use in Japan and Korea which have been designed to melt the ash to address specific landfill shortage issues in those countries. While these technologies are commercially proven, their energy output is generally low and their application outside of Japan and Korea has been limited.

Technologies that use a moving grate furnace, close-coupled with a steam turbine include the Energos technology which was deployed in around a dozen facilities in Europe with several more plants under construction in the UK, before the company was put into liquidation in 2016. In the US, Covanta has developed a similar approach by modifying its proven grate combustion technology. Some of these technologies can receive raw mixed waste with little or no preparation.

There are also smaller scale plants using gasification technology which, at the time of writing, were in advanced stages of construction including Suez' Shepparton EfW plant in Surrey (55,000 tonnes per annum) and AmeyCespa's Milton Keynes project (90,000 tonnes per annum).

More advanced gasification technologies, that do not rely on steam turbine generators or that only produce heat, can potentially be deployed at small scales via modular units and there are a number of technologies in development to address this market. Many technologies have been tested and demonstrated but not yet commercially proven, running on waste feedstocks reliably for an extended period. There are significant challenges in cleaning up the syngas to a suitable quality and in controlling the process when running on heterogeneous waste feedstocks.

The most advanced commercial gasification plant internationally, which does produce a clean syngas stream but still employs a steam turbine generator, is the Lahti Energy gasification plant in Finland (see case study).

Lahti Energy gasification plant in Finland

The plant processes 250,000 tpa of high quality solid recovered fuel (SRF), mostly from commercial waste (mostly plastic, wood and paper) which is shredded to less than 60mm and dried to moisture content below 20–30 per cent. It uses two Circulating Fluidised Bed (CFB) reactors operating at a temperature of 900°C. The hot gases rise to the top of the gasifier and then into a cooling system where the gas is cooled and cleaned as the temperature falls to 400°C and impurities fall out as ash. As such, it is one of the few commercial plants to employ syngas cleaning.

The resulting syngas is then burned in the boiler, producing high pressure steam which is directed to the turbine, providing efficient electricity generation as well as heat output. The plant produces 50 MW electric output and around 90 MW heat output to a district heating network (supplied to apartment blocks and industry).

There are a number of examples of gasification plants in Australia using homogenous material streams, such as City Circle Demolitions in Brooklyn, Melbourne³². However there has been only one attempt at waste gasification in Australia for mixed wastes to date (although new projects have been approved in Western Australia). The Solid Waste and Energy Recycling Facility (SWERF) project was constructed in Wollongong, NSW and commissioned in 2000. It was based around a steam reforming gasifier technology from a US company (Brightstar Synfuels) using mixed municipal waste which was pre-treated through an autoclave process. The syngas was to be used for power generation via modular gas engine-generator sets. The plant never worked as expected and was finally decommissioned in 2004, resulting in significant financial losses for the owners.

The key lesson from that failed project is around the risks of rushing to deploy new and emerging technologies and up-scaling them, before they have been adequately tested and proven at smaller scales.

Challenges and benefits

Gasification potentially offers benefits such as improved overall energy recovery efficiency, compared with combustion, due to reduced air inputs. It is also often deployed at smaller scales than combustion but will still suffer the same efficiency limitations where the power is generated via a steam turbine.

The real benefits of gasification for mixed wastes are yet to be realised at commercial scale – these include ability to produce a diverse range of products (natural gas substitutes, liquid fuels and chemicals) or be coupled with more efficient power generation technologies (internal combustion gas engine generators, gas turbines or fuel cells).

Many of the more advanced gasification technologies deployed have experienced issues with reliability and performance. Gasification reactions can produce a range of hydrocarbons including heavy tars, which can prove difficult to manage, causing fouling and blockages.

Gasification technologies have a parasitic load in the order of 15 per cent of electricity generated when operated using a steam cycle energy recovery system. There is limited operation evidence of energy production when other generator types. The net export of electricity is likely to be in the range of 600-800 kWh/t feedstock.

Summary

A summary of key aspects of gasification technologies is presented in Table 15 and a generic process flow is presented in Figure 11.

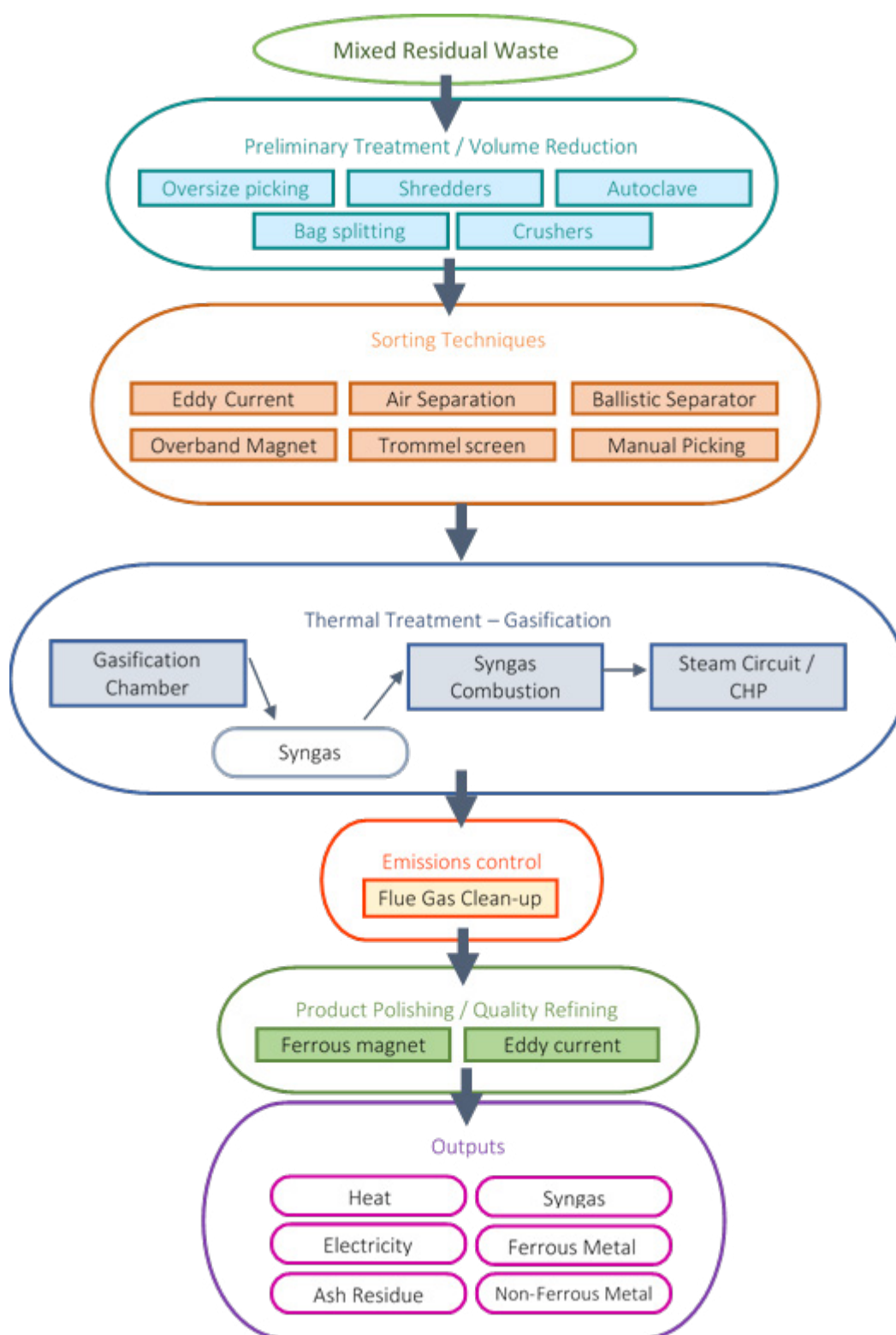
TABLE 15 SUMMARY OF ASPECTS FOR GASIFICATION TECHNOLOGIES³³

Technology Type	GASIFICATION
Commercial track record	Multiple commercial references, much less than combustion, mostly close-coupled combustion configurations. More advanced production of clean syngas is yet to be fully commercialised. No plants in Australia but one failed historic project in NSW.
Waste feedstocks	Mixed residual waste, RDF, waste timber, plastics, agricultural residues
Typical capacity range	50,000 – 250,000 tpa
Indicative capital cost range ³³	\$80M
Operational cost factors	Maintenance, labour, management of unwanted by-products (e.g. tars), ash residue management / disposal, value of energy outputs, air pollution control consumables
Indicative land-take	0.12 – 0.2m ² / tonne
Factors for scaling	Capacity is determined by the thermal capacity of the main reactor. Most facilities are smaller scale (less than 100,000tpa). Emerging technologies are based on modular systems with high degree of capacity flexibility.
Products / outputs	<ul style="list-style-type: none"> › Electricity, heat › Syngas – into chemicals, fuels, gas › Bottom ash – recovered aggregate / fill › Fly ash – for disposal or recovery › Recycled metals (from bottom ash)
Key issues and main risks	<ul style="list-style-type: none"> › Proven reliable application at commercial scale › Process availability / downtime › Syngas clean-up effectiveness › Emissions control during start-up – transient phases › Still attracts similar community opposition as combustion › Planning approvals risks and timeframes › Energy offtake market volatility
Questions to ask	<ul style="list-style-type: none"> › Track record and reference plants in similar applications › Process control and optimisation measures › Residue management approaches › Community engagement approach
Reference plant examples	<ul style="list-style-type: none"> › Lahti Energy gasification plant, Finland › Ebara fluidised bed gasification, Kawaguchi City, Japan › Energos, Sarpsborg 2 EfW Plant, Norway

32 <http://citycirclegroup.com.au/index.php/recycling/power-generation-project>

33 Indicative capital cost in 2017 for a 100,000 tpa capacity facility

FIGURE 11 GASIFICATION PROCESS FLOW



3.4.3 Dehydrators

De-hydration processes are used to rapidly dry wet organic wastes, mostly food waste, at the point of generation to reduce transport and disposal costs of managing the waste. Unlike the other thermal technologies discussed in this Guide, dehydration is not an energy recovery technology and it mostly competes with biological recovery processes for the treatment of organic wastes.

The food waste is placed in an enclosed vessel and is heated and agitated over several hours. Depending on the specific technology enzymes or microbes may, or may not, be added. The moisture is removed as a condensed liquor which can be sent to sewer (subject to approval by the local water authority and in compliance with a trade waste agreement if required). Alternatively, the condensate may be captured for use on site in grey-water applications such as bin cleaning or irrigation. The remaining solid fraction is similar in appearance to coffee grounds – a dry, brown powdery residue.

Outputs and residues

Technology providers claim that the solid residue can be applied directly to land sparingly as a soil amendment with high nutrient value, in a similar way to 'blood and bone' or chicken manure. However, users should be aware that the units do not substantially decompose the organic content of the waste and re-wetting of the residue could result in it becoming biologically active within the soil. There is potential for the residue to be subsequently processed through a biological stabilisation process (such as composting) to produce a more stabilised product, but this application has limited track record.

Track record

Dehydrators are commonly used to reduce the volume of food wastes generated on-site (by up to 85–90 per cent depending on the moisture content of the waste), and are particularly useful for reducing the spatial requirements associated with storing and handling large volumes of food waste for commercial operations where there are a number of restaurants or other food waste generating entities. The units also sanitise the material through the application of heat.

There are a number of units in commercial use in restaurant precincts, hotels, mining camps and institutions. An example includes the South Melbourne Market food waste recycling facility which receives source segregated food waste directly from a number of different market vendors, restaurants and hospitality businesses.

Challenges and benefits

The units require ongoing energy input, usually electricity or gas, to provide the heat for evaporation of moisture. The energy input will be a function of the moisture content of the waste and while the energy consumption is not prohibitive for small scale units, it does limit the scalability of the technology. The cost of energy needs to be weighed against the waste disposal and handling savings that can be realised.

Summary

A summary of key aspects of dehydrator technologies is presented in Table 16.

TABLE 16 SUMMARY OF ASPECTS FOR DEHYDRATOR TECHNOLOGIES

Technology Type	DEHYDRATORS
Commercial track record	Multiple commercial plants in operation, but only in small scale, niche applications.
Waste feedstocks	Food organics from commercial catering, other wet organics
Typical capacity range	Less than 1,000 tpa
Indicative capital cost range	Limited information, typical precinct scale plants thought to cost around \$250k
Operational cost factors	Energy consumption, management of outputs (including transport to outlets)
Indicative land-take	Very small, estimate 30-100 m ² total within an existing building
Factors for scaling	Modular units, potential for additional processing capacity, but still small scale only. At larger scale, energy inputs may become prohibitive.
Products / outputs	<ul style="list-style-type: none"> › Dried organics powder › Condensed wastewater
Key issues and main risks	<ul style="list-style-type: none"> › Disposal / recovery of the powder product › Risk of re-activating when re-wet in soil resulting in odour, decomposition, etc. › Limited capacity to deal with packaging / contaminants
Questions to ask	<ul style="list-style-type: none"> › Reference plants in similar applications › Output specifications and compliance with regulations for land application › Maintenance requirements
Reference plant examples	<ul style="list-style-type: none"> › South Melbourne Market › Prahran Market › Royal Melbourne Hospital › Royal Childrens Hospital

3.5 Reprocessing technologies

Reprocessing involves the conversion of waste materials which have been previously extracted or segregated, into a refined form which has added value as a commodity or is suitable as an input to the manufacturing of new products. Reprocessing provides the link between recovery and sorting processes and end-markets or manufacturers.

This section reviews a limited set of reprocessing technologies which may be deployed in Victoria to improve the recovery of waste materials that have been identified by the Government as priority materials in the SWRRIP and/or *Victorian Market Development Strategy for Recovered Resources*, requiring further infrastructure investment and/or strengthened markets for end products.

The priority materials identified by the Government as needing further investment in reprocessing infrastructure, include:

- › Organics (including timber)
- › Rubber (tyres)
- › E-waste
- › Plastics (flexible)
- › Glass fines
- › Concrete and bricks

This section provides an overview of technologies and product management for these priority materials with the exception of e-waste which is addressed as a sorting technology in Section 3.2.4 and biological recovery of organics which is addressed in Section 3.3. Mechanical processing of timber waste is addressed below.

This section does not cover reprocessing technologies which are already well-established in the Victorian context such as paper and cardboard mills, metal reprocessors or glass manufacturers.

It should be noted that there is some overlap between other the waste treatment techniques discussed above and those specific to the priority materials, which have been cross-referenced as necessary.

This section may be expanded in future to include a more comprehensive range of reprocessing technologies for the priority materials, as well as processing for other materials (such as rigid plastics and emerging materials), and technologies creating new products.

3.5.1 Shredding of timber waste

Timber waste which is separated from various sources (municipal, commercial, industrial and construction / demolition) can be shredded to produce a range of products, or as an intermediate step to prepare it for further reprocessing. Feedstocks in this context may include:

- › pre-consumer timber waste such as off-cuts from timber joineries
- › post-consumer commercial packaging waste such as pallets and cable reels
- › offcuts from construction activities
- › timber recovered during recovered demolition activities
- › Logs and prunings from Council's, and drop offs at transfer stations

The feedstock may be separated at source, or recovered via a mixed waste MRF process such as a C&D waste MRF.

The main shredded timber product may be used as mulch in landscaping applications, biomass fuel, animal bedding or as input to manufacturing of products such as particle boards. As such, the feedstock needs to be clean and free of chemical treatments, paint, glues and other contaminants.

This section does not apply to chemically treated or painted timber, laminated timber products, manufactured boards (such as MDF) or household items such as furniture which are likely to be coated and glued. Reprocessing of these materials is more challenging and generally not commercially viable with existing technologies. Thermal energy recovery technologies can potentially be applied to these materials (with appropriate emission controls) but this is unlikely to be commercially viable in the current market and landfilling is typically the best available solution.

This is a relatively simple form of processing and low in complexity, but under-utilised in the current market. Additionally, this processing technology requires that the input timber waste stream be relatively homogenous in its nature and free of contamination, to produce a useful end product of value.

The material also needs to be largely free of contaminants which may damage the shredder such as gravel and stones. Pre-consumer timber waste is typically lower in contaminants than post-consumer waste and material recovered from mixed waste (e.g. from demolition waste) is typically high in contaminants.

Shredded timber products range in particle size from as small as 6 mm up to 20-50 mm. Multiple shredding and screening stages may be required to achieve smaller particle sizes, following an initial crude size reduction stage. Timber shredding plants can either be fixed installations or mobile plant, located indoors or outdoors, and either electric or diesel powered.

Following the initial size reduction, contaminants such as, soil, grit, stones, and metals from nails can be removed mechanically. Ferrous metals can be removed automatically with magnets. It is typical for these contaminants to be present in post-consumer material recovered from C&D sources. The technologies that might be used to remove contaminants from these streams include:

- › Screening using trommels, vibrating deck screens or finger screens to separate fines based on particle size
- › Magnets for removal of ferrous metals
- › Wind sifting and air density separation for removal of lighter weight materials such as film plastic, paper and cardboard
- › Ballistic sorting for separating heavy materials such as concrete, stones and bricks
- › Manual sorting to remove contaminants or treated timber
- › Optical sorting can also be applied to chipped timber to separate chemically treated timber from clean material

This clean timber chip stream can then be further reduced in size to form dust, via processing through granulators and hammermills. Granulators are preferred when the pre-shred material is free of contamination, as they provide a precise cut and a uniform output. If the pre-shred material has a high level of contamination, hammermills may be employed. These are unaffected by abrasive particles and help dislodge them from the organic timber material. Both processes have high ongoing operational and maintenance costs so would only be employed if the end product markets made this viable.

Shredders can operate to cater for varying inlet particle sizes, with differing rotor diameters and drive capacities. The output timber granulate size can therefore be customised to meet the needs of the mulch or feed specification required. Generally, this process involves:

- › An infeed hopper
- › Feed roller to condition feed material prior to shredder
- › Shredder
- › Discharge conveyor

Additional processes, such as magnetic separation, can typically be incorporated into the unit. Typically, minimal manual intervention is required to operate the plant other than loading of the feedstock and managing the outputs. However operational costs can be high. Shredders consume a lot of energy, either electrical or diesel powered and the maintenance costs are high given the high wear and tear on the shredder components.

- If more complex contaminant separation is required, this can add to plant complexity and operational requirements. Where the timber source is fairly clean and output markets less strict, the additional separation processes may not be required.

Outputs and residues

This shredded timber waste can be used for mulch, as a bulking agent in organics processing technologies (e.g. composting) or as a fuel for bio-energy (Section 3.4).

Shredded timber from clean sources (mostly pre-consumer waste) can also be used in animal bedding for intensive agriculture (e.g. poultry farming) or as a feedstock for particle board manufacturing.

Track record

The equipment used in waste timber reprocessing is well established and proven. Its application in the Victorian market is mostly limited by commercial viability and lack of secure market outlets for the products.

Challenges and benefits

The main challenges with timber reprocessing include:

- Contaminant management / removal and particularly exclusion of chemically treated, painted or glued timber
- Identifying market outlets and competing with virgin products (forestry timber and residues)

Otherwise, it is a flexible and robust technology which can be tailored to the end-product required standards. There is potential for mobile plants to be developed which can be transported to regional sites, set up outdoors and fuelled by diesel.

D&R Henderson, Benalla (VIC)



D&R Henderson is a manufacturer of softwood timber, particleboard and laminated products for the construction industry located in regional Victoria. The particleboard is made from a mixture of post-consumer waste wood (10–20 per cent) together with sawmill residues. They have invested in a process to shred and decontaminated up to 25,000 tpa post-consumer waste wood from a range of sources for use in the manufacturing process.

Summary

A summary of key aspects of timber shredding technologies is presented in Table 17.

TABLE 17 SUMMARY OF ASPECTS FOR TIMBER SHREDDING

Technology Type	TIMBER SHREDDING PLANTS
Commercial track record	Well established - several plants around Victoria and Australia processing mostly clean timber streams. The technology is proven, but market constraints are limiting more widespread adoption.
Waste feedstocks	Source segregated timber or timber extracted by a mixed waste MRF
Typical capacity range	5,000-50,000 tpa
Indicative capital cost range	No data
Operational cost factors	Maintenance costs, fuel / energy costs, reject disposal costs
Indicative land-take	Small overall (20–50m ²), dependent on feedstock and product storage areas
Factors for scaling	Flexible to match required capacity, potential to expand with mobile equipment. The hourly capacity of individual mechanical equipment is main parameter.
Products / outputs	<ul style="list-style-type: none"> ➤ Mulch ➤ Biomass fuel ➤ Animal bedding ➤ Feedstock to particle board manufacturing
Key issues and main risks	<ul style="list-style-type: none"> ➤ Markets for products and associated revenues
Questions to ask	<ul style="list-style-type: none"> ➤ Maintenance costs ➤ Energy consumption ➤ Contamination removal efficiency ➤ Operating throughput flexibility
Reference plant examples	<ul style="list-style-type: none"> ➤ Australian New Energy, Moolap ➤ Bark King mulch, Montrose ➤ D&R Henderson particle board factory, Benalla

3.5.2 Mechanical recovery of rubber products

Mechanical processing of rubber is the primary means of recycling waste rubber in Australia, particularly end-of-life tyres but also other materials such as conveyor belt rubber. These materials may also be subjected to thermal processing technologies, of which the main focus of current development activities is around pyrolysis, as discussed in Section 4.2.

Mechanical recovery involves reducing the particle size of end-of-life tyres (or other rubber products) into uniform grades, with the reinforcing materials such as steel and textile fibres, and other inert contaminants, removed.

There are several processes for manufacturing these products. The two most common methods are ambient grinding and cryogenic processing. Firstly, the end of life tyres need to be reduced in size through an initial shredding phase during which the steel and fibres are removed. Commonly, this involves a pre-shredding with the use of rotary shear shredders which are able to shred both longitudinally as well as vertically.

In some cases, a de-beader can be used to remove steel beads from truck tyres prior to shredding. The de-beading process significantly reduces the wear and tear on the subsequent shredder. It is reported that up to 70 per cent of the wear and tear in shredders and grinding machines is from steel, even though steel only presents about 10 to 15 per cent of the weight of a truck tyre³⁴.

This initial phase of pre-shredding can be completed with mobile equipment. This allows pre-processing at the storage site into coarse pieces of rubber which is more easily transported to the final processing facility.

Tyre shredding is a mature technology, with many reliable machines and suppliers in the market. These shredders are typically either diesel powered (for mobile outdoor units) or electrically powered for fixed plants and can have a typical capacity of two to six tonnes per hour, depending on the input material and the size of the chips produced.

Two approaches are commonly used to further size reduce and refine the tyre shred:

- Ambient grinding
- Cryogenic recycling

The most common process of tyre reduction is ambient grinding which has a number of steps:

- The pre-shredded chips enter a granulator, where the chips are reduced to a size of 10 mm or smaller, liberating most of the steel and fibre from the granules (if not already removed)
- Finer rubber crumb, which is most valuable, is produced through a process of consecutive grinding steps. Machinery used for this process includes:
 - Secondary granulators
 - High speed rotary mills
 - Extruders or screw presses
 - Cracker mills

This process can produce fine crumb material in the range of 10 to 30 mesh (a unit to describe particle size distribution for granular material).

Cryogenic tyre recycling is an alternative process, where whole tyres or tyre shed chips are cooled down to a temperature below minus 80°C. Below this temperature, the rubber becomes as brittle as glass. Size reduction is achieved through crushing and breaking. The benefits of this process are that less energy and fewer pieces of machinery are needed compared to ambient size reduction, and that removal of steel and textiles is much easier, leading to a cleaner end product. However, the cost of liquid nitrogen for cooling is a significant expense.

Outputs and residues

Generally speaking, there are two broad categories of rubber product groups that can be produced:

- Rubber granules - generally less than 30 mm. Rubber granules can be used in soft surfacing; rubber flooring and mat products; playground soft-fall surfaces; sports facilities; moulded products; and as inorganic mulches.
- Crumb rubber and powder - is a fine crumb or powder material that can be used in a number of applications, but is widely used in Australia as an adhesive additive; spray seal bitumen additive and 'top-dressing' material for artificially turfed sporting fields (Astroturf). Whilst crumb rubber is a valuable product, its manufacture generally incurs high capital and processing costs.

As thermal energy recovery facilities are developed in the future, mechanical processing facilities may start to provide pre-processing services or prepared tyre-derived fuel feedstock to those facilities.

34 Reschner,K., Scrap Tire Recycling, A Summary of Prevalent Disposal and Recycling Methods, <http://www.entire-engineering.de/>

Track record

Mechanical recovery of rubber involves well established and proven technologies which are well understood and served by various suppliers in the market.

Challenges and benefits

The primary challenges for all tyre recyclers in recent years have been market based. Domestic markets for rubber crumb and granule products are somewhat limited and already well served by existing suppliers. Some applications, such as spray seal bitumen, could absorb much greater volumes than present and are the subject of ongoing market development activities by various industry and government stakeholders.

Historically, tyre recyclers have relied on sending their excess tyres and shredded tyres to export markets as tyre derived fuel. However sustained low global energy prices over recent years have significantly undermined the viability of this outlet. This reiterates the need to develop new domestic product markets.

In the face of challenging end-markets, tyre recyclers are often faced with the need to stockpile products and/or raw tyres. This presents a number of risks including the risk of fire which could have a significant impact on the environment and local community. Tyre Stewardship Australia has published guidelines on the best practice storage of tyres to manage this and other risks³⁵. As well as this, the Victorian EPA have developed a guideline for the management and storage of combustible recyclable and waste materials³⁶.

Summary

A summary of key aspects of dehydrator technologies is presented in Table 18.

TABLE 18 SUMMARY OF ASPECTS FOR MECHANICAL RECOVERY OF RUBBER PRODUCTS

Technology Type	MECHANICAL RUBBER PROCESSING
Commercial track record	Well established and proven technology with several plants around Australia including in Victoria.
Waste feedstocks	Separated end-of-life tyres, conveyor rubber
Typical capacity range	20,000-50,000 tpa
Indicative capital cost range	No data
Operational cost factors	Maintenance costs, fuel / energy costs, labour, cryogenic cooling costs (if relevant)
Indicative land-take	0.5 – 0.8m ² / tpa capacity, including tyre and product storage
Factors for scaling	Flexible to match required capacity, potential to expand with mobile equipment or by increasing operational time.
Products / outputs	<ul style="list-style-type: none">› Tile adhesive additive› Spray seal bitumen additive› Rubber flooring and mat products› Playground soft-fall surfaces› Sports facility surfaces› Moulded products› Inorganic mulch
Key issues and main risks	<ul style="list-style-type: none">› Markets for products and associated revenues› Stockpiling of feedstock and product› Fire risks
Questions to ask	<ul style="list-style-type: none">› Maintenance costs› Energy consumption› Operating throughput flexibility
Reference plant examples	<ul style="list-style-type: none">› Tyrecycle, Somerton

³⁵ <http://www.tyrestewardship.org.au/tsa-knowledge/tyre-storage-guidelines>

³⁶ <http://www.epa.vic.gov.au/our-work/publications/publication/2017/november/1667-1>

3.5.3 Plastics reprocessing

A significant proportion of the plastics recovered in Victoria are sent to reprocessors overseas, with the remainder are reprocessed within the state. Plastics are complex in their composition, which translates to complexities in their collection, sorting and cleaning processes. For recycling and reprocessing purposes, sorting products by their polymer and resin type allows for the pure feedstock to be obtained for reprocessing and subsequent manufacturing.

Both rigid and flexible plastics (films) are recyclable but flexible plastics are more challenging to commercially collect and separate. This section looks broadly at plastics but with a particular focus on flexible plastics as well as expanded polystyrene, which are traditionally not recycled in significant volumes due to constraints on reprocessing options and end markets. Some of the key challenges with recycling all plastics are:

- Plastics generally need to be separated into resin types for remanufacturing into new products. Given the large number of plastic resins and products, this can be challenging. The increasing use of optical sorters in MRFs is improving the separation of plastics by resin type.
- Many plastics contain dyes, fillers and additives, which are difficult to remove in the recycling process and may affect product quality.
- Contamination of plastics with soil, food residues, chemicals and other unwanted residue from the original use can be a challenge.

Typically, the main treatment stages of reprocessing sorted plastics include:

- Pre-treatment. The plastic resin is shredded and washed, to remove contaminant substances such as paper labels, glue and other residues. A process called agglomeration may be used during the pre-treatment stage. This consists of heating the plastic to just below their melting point to reduce the size, before shrinking it into small pieces. Granules or crumbs are formed this way.
- Extrusion and pelletising. This process involves homogenising the plastic with heat. The granules are passed through a pipe with a rotating screw, which forces the granules forward into a heater barrel, where melting occurs. The melted plastic is then cooled and turned into pellets for manufacturing.
- The recycled plastics are then manufactured into products through injection moulding. Plastic pellets are melted through a second extrusion process and forced into mould cavities to produce the desired shape. The plastic can be reheated and also stretched with high pressure air, through a process known as stretch blow moulding, which is used to make bottles.

Expanded polystyrene (EPS) and film plastics present additional complexities in reprocessing as discussed below.

EPS

EPS ideally requires segregation before it enters the waste stream to minimise contamination and because it is prone to breaking up and therefore difficult to extract from mixed waste.

It is lightweight, low density and expansive in nature (approximately 98 per cent air). Therefore collection and transportation costs are challenges to its recycling. Reprocessing involves EPS being fed into granulating units which then feeds into a hopper where it is stored and compressed into continuous lengths. These are then split into lengths suitable for pelletising. These plants are available as package units in a range of scales, including small scale units that can be installed at a collection point to improve transport efficiency.

There is little demand for recycled EPS product in Australia and most of the material is exported for further reprocessing. Recovered EPS can be used in production of synthetic timber, stationary products and plant pots.

Soft plastics

Flexible plastics, such as product wraps and bags present various issues due to their physical nature. Most flexible plastics are made of LDPE however other polymers can be used, including HDPE and PP. Their polymer structure is markedly degraded during reprocessing, meaning that the products are typically of lower value and reduced technical performance than the original products.

Options to convert post-consumer flexible plastics into similar reusable products are limited. Pre-consumer flexible plastics that are generated in the plastics manufacturing industry are commonly reused. The extensive clean up that is required of post-consumer flexible plastics, and separation into individual plastic streams makes recycling of this stream possible, but commercially challenging.

Source separated streams of flexible plastics, such as agricultural film, which is mostly made of LDPE, are partly collected for recycling but most of that material is currently exported. Film collected from the agricultural industry is usually contaminated by soil, moisture, vegetation and pesticides. The film can be shredded into flakes with grinders but unlike rigid plastics, shredded film is more likely to tear and carry contaminants within pockets of film. Furthermore, when transported film is compressed into bales, it is difficult to note the type and degree of contamination.

The collected film typically undergoes a washing process. Due to moisture from the washing process or accumulation of moisture from storage (including outdoor storage), the film might undergo a pre-drying phase. The settings of this are dependent on the moisture content, but approaches may include venting or air flushing.

Following the cleaning and drying phases, the film can be melted. To generate high quality granulate, the degree of purification needs to be high and depending on the type and amount of contaminants present, gas can be formed. This can cause foaming in the melt and entrap air in the final product granulates, which results in flawed and sub-standard products. Therefore, specifically designed degassing units are employed to remove air bubbles. Subject to quality, the final granulate product can be suitable for a wide range of applications.

In terms of other post-consumer flexible plastics recycling, Replas in Victoria has designed a solution that has evolved over two decades of operations. They are able to process a variety of soft plastics to produce products such as park benches and fitness equipment.

Replas Ballarat



At its recycling facility in Ballarat, Replas currently turns well over 3,000 tonnes per annum of recovered plastics including a lot of which is flexible plastics sourced from places like the major two supermarket chains and also hospitals into a range of over 200 products that include, wheel stops, bollards, signage and street furniture along with infrastructure products like pit lids and marker posts. The unique Replas technology designed in house over the last 25 years allows for the mixing of different plastic polymers to create complex three dimensional shapes. Once the required blends are mixed they are then fed into fully automated production lines that are tended by robots to ensure the highest quality with minimal manual handling of the heavy products.

Some innovative trends that have been noted of recent times in this area include:

- Low cost recycling systems to remove print from plastic film through water based solution of grinding, solvent-free de-inking, rinsing, drying and extrusion.
- Unilever sponsored technology for pilot recycling plant of single use plastic sachets (used for toiletries and cosmetics), following eight years of R&D. These are usually made of a laminated film of plastic and aluminium. The new technology is called CreaSolv and has been adapted from a method used to separate brominated flame retardants from e-waste equipment polymers. The process uses solvents to selectively dissolve targeted polymers so that they can be separated from other plastics and contaminants. A precipitating agent is then used to recover the polymer from the solution so it can be recycled.

Other new technologies are expected to emerge for recovering post-consumer soft plastics as consumption increases and the use of composite packaging increases.

Alternatively, plastics can be used as a high calorific energy source in a thermal treatment process, given the organic nature of the constituent polymers. Technologies such as pyrolysis (Section 4.2) have been explored extensively to produce fuels from waste plastics.

Outputs and residues

The main product from plastic reprocessing is cleaned and pelletised polymer feedstocks suitable for input to manufacturing processes of new products.

Some facilities also go on to use the feedstock in the production of new plastic items such as outdoor furniture, bollards, fence posts, decking boards and manhole pit lids.

Track record

Many of the component technologies and equipment used in plastics reprocessing are proven and available in the market. Their application in Victoria has been limited to a small number of relatively small to medium scale operators.

Challenges and benefits

Contamination is a significant issue, particularly for flexible plastics, which can complicate the reprocessing requirements and be detrimental to the end product quality.

The increasing use of lamination of film plastics with metal foils adds to the complexity of recycling, by making it difficult to separate the plastic component. New technologies to manage these composite materials are likely to emerge in the future.

In terms of plastics which are already recovered (mostly rigid plastic) and other materials which could potentially be recovered in greater volumes (flexible plastics), there is a significant volume of potential feedstock in the Victorian market, most of which is sent overseas for reprocessing.

Export markets have become more constrained in recent years and this is set to continue with China, the primary destination for plastics, announcing plans to further limit plastic waste imports from 2018.

However, most plastic consumed in Australia is imported and the capacity of the domestic manufacturing market to consume reprocessed feedstock is likely to be limited, so securing reliable product markets may be challenging for plastics reprocessors.

Stockpiling of plastic materials (both feedstocks and product) is a risk, particularly when market conditions are not favourable. This presents significant fire risks which need to be assessed and mitigated appropriately.

Summary

A summary of key aspects of plastics reprocessing technologies is presented in Table 19.

TABLE 19 SUMMARY OF ASPECTS FOR SOFT PLASTICS AND EPS RECOVERY

Technology Type	PLASTICS REPROCESSING
Commercial track record	Well established and proven component technologies but limited to small scale existing facilities in Victoria
Waste feedstocks	Separated plastics including flexible plastics and EPS
Typical capacity range	2,000 – 20,000 tpa
Indicative capital cost range ³⁷	\$10M
Operational cost factors	Energy costs, labour, contamination management, wastewater treatment and disposal, residual and sub-standard product disposal, maintenance costs, product revenues (volatile)
Indicative land-take	0.2 – 0.4m ² / tpa capacity, including feedstock and product storage
Factors for scaling	Some flexibility depending on operational time, some modular equipment
Products / outputs	<ul style="list-style-type: none"> ➤ Cleaned and pelletised polymer feedstocks ➤ Final products including outdoor furniture, bollards, fence posts, decking boards and manhole pit lids
Key issues and main risks	<ul style="list-style-type: none"> ➤ Markets for products and associated revenues ➤ Stockpiling of feedstock and product in challenging market conditions ➤ Fire risks
Questions to ask	<ul style="list-style-type: none"> ➤ Energy consumption ➤ Product quality ➤ Contamination limits and management measures ➤ Maintenance costs ➤ Operating throughput flexibility
Reference plant examples	<ul style="list-style-type: none"> ➤ Replas, Lilydale ➤ GT Recycling, Geelong

3.5.4 Glass fines beneficiation

Glass materials from the commingled recyclable stream, are typically sorted into two major output streams from a clean MRF (see Section 3.2.1) as below:

- Cullet is the larger, cleaner pieces of glass (usually over 50mm particle size) and the higher-value proportion of the recovered glass stream which can be colour sorted and crushed to be readily fed into glass manufacturing furnaces with virgin material (sand, limestone and soda ash) to produce new glass containers.
- Glass fines – a lower grade output stream from the MRF (usually less than 50mm particle size) which is predominantly glass but contains a significant proportion of other small residual waste materials such as bottle caps, batteries, small pieces of paper and plastic, putrescibles and general soil / dirt. It also contains fragments of ceramics, pyrex and ovenware which are not compatible with recycling back into glass products. It is a low value stream which is often stockpiled or landfilled, but can be cleaned through additional processing to extract the glass particles for reuse

In Victoria, glass fines currently represent a negative value stream (a gate fee is likely required to make reprocessing viable). Glass fines can be recovered via two main pathways:

- Cleaned glass cullet or fine glass powder can be recovered, following extensive processing to remove contaminants and colour sort fragments, for use in glass manufacturing; or
- Production of sand and aggregates for use in a range of applications such as construction aggregate and sand for roadway construction, pavement application (asphalt), bedding and backfill, drainage and landfill cover

Both options require mechanical processing and manual sorting to separate the significant volume of non-glass materials, some of which can be recycled (e.g. metals). The latter option is constrained in Victoria by limited demand and capacity for domestic glass manufacturing. Production of glass sand is slightly less complex as there is no need to extract ceramics and stones, or colour sort the glass fragments.

Both pathways are net cost processes and when the value of the end products is low, industry tends to stockpile this stream. There are currently large stockpiles of glass fines at sites across metropolitan Melbourne, estimated by SV in 2015 to total over 300,000 tonnes³⁸. Also according to SV, 68 per cent of recovered glass is recycled back into glass cullet for glass manufacturing and the remaining 32 per cent is glass fines which is stockpiled or reprocessed into a sand substitute (in 2015–16).

Although the responsibility for managing glass fines resides with MRF operators and not directly with councils, it is important to recognise that the recovery of glass fines has a significant impact on recovery of commingled recyclables. Therefore, councils should be aware of the end destination of this stream.

37 Indicative capital cost in 2017 for a 10,000 tpa capacity facility

38 Sustainability Victoria – Glass waste investment factsheet, November 2015.

Glass Beneficiation

Recycling of glass fines back into glass manufacturing is possible but requires significant processing to remove contaminant materials, including glass-like materials such as ceramics, stoneware, Pyrex and clear plastic. It is difficult to separate these materials other than with advanced optical sorting technologies, and they can cause significant technical and safety issues if they are allowed to enter a conventional glass furnace due to their melting temperatures being higher than glass. They can also significantly affect the quality of the recycled glass products.

It is technically possible to process glass fines to recover a usable glass cullet with advanced sorting technologies and there is one such plant operating in Brisbane (see case study) where the glass output is returned to glass manufacturing to produce new bottles.

Glass aggregates

Efforts have been made in Victoria to recover glass fines as construction materials, but the construction market has not been receptive to recycled products based on perceptions that products manufactured from waste glass may be contaminated or substandard for their applications. It is also difficult for glass sand to compete with virgin sand on price and perceived quality.

There are several approaches to converting glass fines into recovered sand and aggregates. Firstly there will be a need to remove other contaminants which may be achieved through a series of mechanical sorting processes such as:

- › Trommel screens to break up glass and remove oversize waste
- › Wind-sifting or similar to extract light materials (paper, film plastic, including labels)
- › Magnets and eddy current separators to recover metals (ferrous and non-ferrous)

Once those main contaminants are separated from the glass, the glass fines themselves then need to be crushed. Some plants use impaction techniques such as crushers, vertical shaft impactors and various types of grinders. More recent technology includes glass 'imploders' which vibrate the glass at high frequency, causing it to fracture.

The crushed glass would then be screened, usually in a vibrating screen, to separate out a number of size fractions. Depending on the process used to crush the glass, particle sizes may range from small gravel sized pieces down to a fine powder.

It may also be necessary to incorporate some form of drying stage, particularly if the glass fines have been stored outdoors. Wet material is more difficult to separate and process.

Dust emissions can be an issue, arising from glass grinding, and dust extraction and capture systems will be needed to protect workers and prevent offsite dust emissions. Reprocessors that have a yearly throughput of greater than 10,000 tonnes per annum now require an EPA licence.

Outputs and residues

The recovered glass fines from a glass beneficiation process can be recycled back to glass manufacturing, along with clean cullet.

Glass fines converted into recovered sand and aggregates can be used in various construction applications in place of virgin sand, including:

- › asphalt
- › sand/abrasive grit blasting
- › construction, piping and road aggregates
- › concrete aggregate
- › sports turf/drainage
- › brickmaking additives

Other higher value uses are also possible but yet to be fully realised in the market, including:

- › glass wool insulation
- › filler powder for resins, paints, glues
- › water filtration media

Track record

The technologies for both applications of glass fines recovery are established and operating at commercial scale within Australia. The glass beneficiation process incorporates advanced optical sorting technologies which are a new technology but have been shown to work well in existing plants.

Glass Recovery Services (GRS) - SKM, Coolaroo (VIC)

The GRS glass recycling facility, operated by SKM in Coolaroo can process up to 45 tonnes per hour of recycled glass for up to 8 applications at any one time. The system has an inbuilt pre-screening and rotary dryer to produce optimum quality product.

The facility is spread over 4 factories for processing glass, including an inside storage area and outside undercover storage area for all pre-processed material. The plant can process waste glass into optically sorted glass by colour, as well as process crushed, screened, cleaned and sized glass in one process.

Challenges and benefits

One of the main challenges with glass fines recovery is the high proportion and range of contaminants that are present in the stream – effectively any fine materials from the MRF which are less than 50mm. Separating these materials effectively from the glass, including many glass-like ceramics, requires a combination of advanced technologies.

End markets are a challenge for any of the potential products. As noted in Section 2.7, glass manufacturing is declining in Australia in the face of competition from cheaper imports and switching to other packaging materials. For glass sand products, the end markets are mostly un-developed. Construction markets have been constrained by perceptions of safety risks and substandard products. Other high value markets need considerable market development effort to realise.

The fines are likely to contain a small proportion of putrescibles which can cause odour issues for storage and handling of the feedstock and may require enclosed waste reception and storage areas. The fines may also contain hazardous items including syringes, which require appropriate staff protection measures.

Dust management can be an issue and especially for aggregate production where the glass fines are ground to quite fine particle size, resulting in production of glass dust. Appropriate ventilation and filtration systems will be required, as well as high quality dust protection for workers.

Summary

A summary of key aspects of glass fines recovery technologies is presented in Table 20.

TABLE 20 SUMMARY OF ASPECTS FOR GLASS FINES RECOVERY ³⁹

Technology Type	GLASS FINES
Commercial track record	Proven technologies across a small number of commercial facilities in Australia
Waste feedstocks	Glass fines stream from a clean MRF
Typical capacity range	5,000 – 100,000 tpa
Indicative capital cost range ³⁹	\$3M
Operational cost factors	Energy costs, labour, contamination management and disposal, dust management, product revenues
Indicative land-take	0.1 – 0.2m ² / tpa capacity, including feedstock and product storage
Factors for scaling	Some flexibility depending on operational time of mechanical processing
Products / outputs	<ul style="list-style-type: none"> › Crushed, sorted glass cullet; or › Glass sand of various size fractions for use in construction and other applications
Key issues and main risks	<ul style="list-style-type: none"> › Markets for products and associated revenues › Effectiveness of contaminant removal › Stockpiling of feedstock and product in challenging market conditions › Safety management including dust exposure, hazardous items (e.g. syringes)
Questions to ask	<ul style="list-style-type: none"> › Energy consumption › Product quality and applications › Feedstock quality constraints › Maintenance costs › Operating throughput flexibility
Reference plant examples	<ul style="list-style-type: none"> › Owens Illinois glass beneficiation plant, Crestmead, Qld › Mineraltec glass aggregates plant, Brisbane

³⁹ Indicative capital cost in 2017 for a 30,000 tpa capacity facility

3.5.5 Concrete and brick reprocessing

Concrete and bricks are major constituents of C&D waste (by weight) that are generated through building demolitions, infrastructure projects as well as smaller scale domestic renovations. Consequently, concrete and bricks are part of the C&D waste stream which is often processed by the private sector but smaller volumes may be received as drop-off material at transfer stations.

Whilst significant C&D waste sorting and reprocessing infrastructure has been established in metropolitan Melbourne, smaller scale operations are generally lacking in regional parts of Victoria. The North East and Grampians Central West WRRGs have identified a need to procure solutions to manage concrete and bricks within their regions.

Concrete and brick can be segregated at source or separated from mixed C&D waste through a mixed waste MRF process (see Section 3.2.2). It is typically crushed to produce a secondary aggregate which has applications in road-base, structural fill, concrete mix, drainage and landscaping. The recovered aggregate is a direct substitute for virgin aggregates and becoming more widely used and accepted by contractors.

Techniques for reprocessing concrete and brick are not complex and are well established. The process generally involves sorting, crushing, screening and contaminant elimination. The equipment is often mobile and can be set up outdoors, fuelled diesel, but fixed electric equipment can also be used.

The challenge for smaller scale applications is to aggregate sufficient feedstock volume to justify the investment in processing equipment. In such cases, it may be preferable to employ mobile plant which can service a number of sites.

Specifically, a typical crushing plant includes:

- Powerful crushers which allow for embedded materials such as steel reinforcement, and any contaminants such as soil, glass and plaster to be liberated. These crushers can involve primary jaws, cones and/or large impactors which reduce the size of the rubble. Processes might undertake a primary and secondary level of crushing, depending on the set-up.
- The crushed concrete and brick aggregate can then be run through a screening process (usually a trommel or vibrating deck screen) to capture and sort the rubble into different size fractions. Screening processes remove dirt and foreign particles from the crushed concrete. There can be a range of screens to capture particles of different sizes.

Depending on the end market and application, further cleaning may be employed to ensure the recycled concrete is free of dirt and other particles. This can be done through a number of processes, which include:

- Water floatation
- Hand picking
- Air separators
- Magnetic separators to recover metals

Alex Fraser Recycling, Clarinda (VIC)



Alex Fraser operates a series of modern C&D recycling plants across Melbourne. The Clarinda plant services Melbourne's south eastern suburbs and surround.

The 22 hectares, state-of-the-art C&D recycling facility opened in 2009. It accepts hundreds of thousands of tonnes of waste brick/mixed rubble, clean concrete and clean asphalt for recycling.

The highly-automated plant can crush, screen and blend waste materials at a rate of 500 tonnes per hours to process high quality construction materials to Vicroads' specifications.

The strict quality assurance processes on site ensure the finish products compete openly with virgin materials produced at quarries. The use of these quality recycled construction materials can reduce the carbon footprint of projects by up to 65%.

Alex Fraser's Clarinda Recycling facility has provided recycled roadbase and sand for major infrastructure projects such as the Dingley Bypass, Peninsula Link and Eastlink.

Outputs and residues

The main product of concrete and brick reprocessing is one or more grades of secondary aggregate, screened by particle size to suit market requirements. Variations may be offered such as a washed aggregate or sand product. Concrete products can be contaminated, and this can be avoided by carefully selecting the incoming feedstock. Some testing of concrete products may also be necessary.

Track record

The technology to reprocess concrete and bricks into aggregates is well established and proven, and widely available from a number of different suppliers. There are numerous existing plants in Victoria, mostly incorporated within larger C&D recycling facilities (mixed waste MRFs) in and around Melbourne.

Challenges and benefits

The processing technology used for recycling concrete and bricks can result in significant dust emissions and noise impacts, as well as high energy consumption for the crushing technology. However, it is noted that these processes are essentially the same as those used in natural aggregate processing. There are several ways to mitigate these risks including choosing an appropriate site away from sensitive receptors and implementing control measures (dust suppression, noise attenuation, buffer distances).

The benefits of processing recycled concrete include reducing landfill consumption, reduced use of virgin aggregates and reduced transportation costs associated with delivering virgin materials from remote quarries to urban construction sites.

Summary

A summary of key aspects of concrete and brick recovery technologies is presented in Table 21.

TABLE 21 SUMMARY OF ASPECTS FOR CONCRETE AND BRICK RECOVERY ⁴⁰

Technology Type	CONCRETE & BRICK REPROCESSING
Commercial track record	Well established and proven technologies with multiple plants in operation and systems available
Waste feedstocks	Separated concrete and brick (and other masonry products)
Typical capacity range	5,000 – 500,000 tpa
Indicative capital cost range ⁴⁰	\$30M
Operational cost factors	Energy costs, maintenance and wear/tear components, labour, residue disposal
Indicative land-take	0.05 – 0.2m ² / tpa capacity, including feedstock and product storage
Factors for scaling	High degree of flexibility depending on operational time, modular / mobile equipment that can expanded, duplicated
Products / outputs	<ul style="list-style-type: none"> Recovered aggregate
Key issues and main risks	<ul style="list-style-type: none"> Cyclical nature of markets for products leading to stockpiling Product value relative to processing cost Dust and noise impacts High maintenance demand on equipment
Questions to ask	<ul style="list-style-type: none"> Energy consumption Maintenance costs Product quality Operating throughput flexibility
Reference plant examples	<ul style="list-style-type: none"> Alex Fraser, Brooklyn C&D recycling facility City Circle, Brooklyn ResourceCo, Hallam

⁴⁰ Indicative capital cost in 2017 for a 200,000 tpa capacity facility

4 Emerging Resource Recovery technologies

In global attempts to recover value from waste, a wide range of innovative technologies have been, and continue to be, developed to extract reusable materials and high value energy outputs from different waste streams. Resource recovery technologies are constantly evolving and improving, and technology developers are constantly inventing new approaches or finding ways to apply existing processes to waste materials. However, processing waste materials is fraught with a number of risks and challenges, particularly compared with processing most comparable 'clean' virgin resources. It typically takes many years and significant investment to develop, test and commercialise a new resource recovery technology.

While it is important that new innovations are supported and encouraged, project proponents and investors need to be informed about the risks associated with emerging waste technologies that have not yet been proven in operation at commercial scale, over a reasonable period of time. Councils need to be particularly cautious and prudent before committing ratepayer funds to emerging technologies.

Of the larger scale technologies, mechanical heat treatment, pyrolysis and plasma gasification are the more widely known and a number of attempts have been made to establish commercial scale facilities internationally, but it is generally considered that these technology solutions have yet to establish the necessary technical and commercial track records for them to be considered as mainstream resource recovery solutions. A discussion of these technologies is presented below.

In addition, overviews of the more early-stage resource recovery solutions (including torrefaction and technologies to produce fuels from waste) are also presented in this section.

4.1 Mechanical heat treatment (MHT)

Mechanical heat treatment (MHT) combines both mechanical and thermal treatment methods. The mechanical treatment methods are similar to those used in MBT processes. Heat treatment methods include autoclaving and thermal drying, designed to sanitise and stabilise mixed non-hazardous waste feedstocks. Both techniques require significant energy input in the heating process.

MHT is effectively a separation process. The application of heat, usually via steam, breaks down the putrescible and fibre fractions (paper and cardboard) so that they can be screened off from the inorganic materials. The organic rich fibre is then either processed biologically or dried for use as a biomass-rich fuel. The inorganic fraction is further sorted to recover recyclables or produce a fuel. As such, MHT on its own is not a complete recovery system and must be coupled with viable recovery of the fibre fraction to be successful.

Autoclaving is a well-established batch process for sterilising various materials using high pressure saturated steam at temperatures around 150°C. It is used widely, including in Australia, to sterilise medical waste prior to disposal or processing. However its use in mixed waste recovery systems is less common and MHT remains a relatively new process, with few commercial plants in operation globally.

Thermal drying process is an alternative process to the autoclave that uses the application of heat to dry the waste, not under pressure, for example by drying the waste in a continuously fed, heated drum. The concept is that the waste is more easily separated into recycle after it has been dried, leaving a fraction potentially suitable for use as a high calorific value fuel.

Outputs and residues

Mechanical Heat Treatment is potentially effective at separating the organic components of municipal or commercial residual wastes, however its track record internationally is varied and its viability is largely a function of the outlets and value in fibre / fuel fractions derived from the process. Compost produced from the fibre will have very limited applications subject to contamination levels, while fuel products would need to be recovered in a thermal system designed for waste fuels.

Track record

There is one MHT facility operating in Australia – the Biomass Solutions plant at Coffs Harbour. A recently constructed facility in the UK (Plymouth Aerothermal facility, 75,000 tpa capacity) is combining MHT with anaerobic digestion of the organic fibre fraction, with claims that autoclaving enhances the digestion of organics extracted from mixed waste.

At least three large scale facilities were previously constructed in the UK and subsequently shut down after operating for short periods of between 3 to 5 years.

Biomass Solutions – Coffs Harbour, NSW



This facility uses a rotary drum autoclave to process mixed residual waste. The sterilised waste is then screened through a trommel and the organic-rich fine fraction is composted in enclosed, automatically turned composting bays. This produces a compost product that is used as a soil conditioner on broad-acre farms under strict quality and contamination protocols.

The same facility also processes source separated kerbside organics (food and garden) with a total capacity of 50,000 tpa and overall diversion rate of 72%.

Challenges and benefits

MHT treatments are high energy users, however there is insufficient available information to determine a reliable parasitic load for these technologies. The overall recovery performance varies and is largely dependent on whether a fuel is produced from the inorganic fraction.

Summary

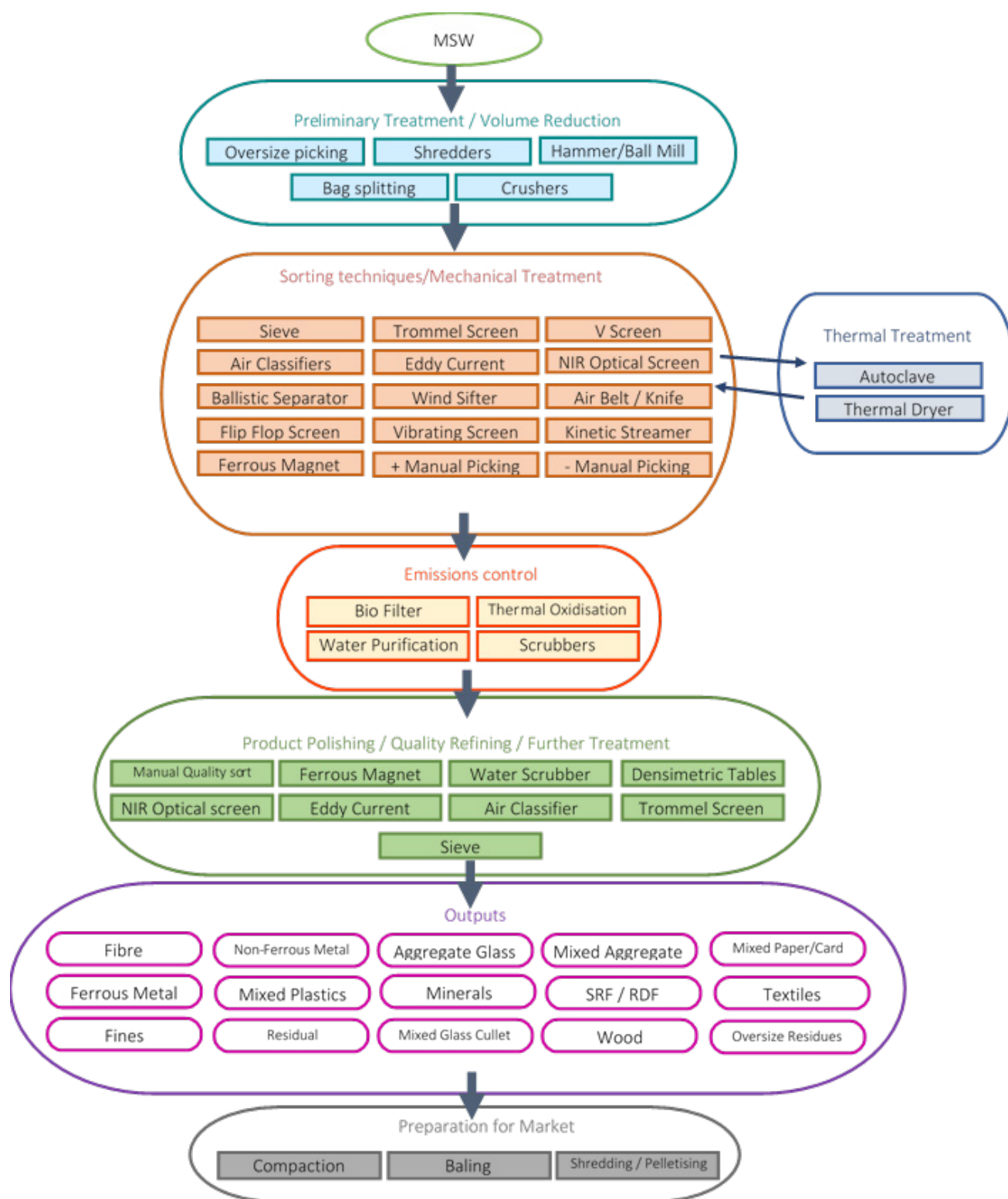
A summary of key aspects of MHT technologies is presented in Table 22 and a generic process flow is presented in Figure 12.

TABLE 22 SUMMARY OF ASPECTS FOR MHT TECHNOLOGIES

Technology Type	MECHANICAL HEAT TREATMENT
Commercial track record	Limited track record – one facility in Australia but otherwise limited examples operating commercially on mixed residual waste; issues with markets / outlets for products and safety has resulted in several failed projects overseas.
Waste feedstocks	Mixed residual wastes (municipal and commercial)
Typical capacity range	75,000-300,000 tpa
Indicative capital cost range ⁴¹	\$40M
Operational cost factors	Energy consumption, fibre / fuel processing or recovery costs, maintenance costs associated with materials handling, reject disposal costs
Indicative land-take	0.07 – 0.11m ² / tonne
Factors for scaling	Variety of systems available, limiting factor is the heat treatment phase which is usually a batch process undertaken in a rotating drum. The largest known facility in Gateshead UK, had capacity of 320,000 tpa but is no longer operating.
Products / outputs	<ul style="list-style-type: none"> › Organic rich fibre – low grade soil conditioner › RDF from inorganic fraction – to thermal process › Recyclables (low grade)
Key issues and main risks	<ul style="list-style-type: none"> › Markets / outlets for products › Contamination in fibre product › Explosion risk and high pressure vessels › High operating costs › Landfilling of fibre product
Questions to ask	<ul style="list-style-type: none"> › Safety track record of technology provider and hazard mitigation systems in place › Full cost including post-processing of the fibre, and fibre distribution
Reference plant examples	<ul style="list-style-type: none"> › Biomass Solutions, Coffs Harbour (NSW) › Plymouth AeroThermal Waste Treatment Facility, Plymouth (United Kingdom)

41 Indicative capital cost in 2017 for a 100,000 tpa capacity facility

FIGURE 12 MHT PROCESS FLOW



4.2 Pyrolysis

Pyrolysis is the thermal decomposition of carbonaceous waste or biomass materials in the absence of oxygen. A pyrolysis process requires a relatively consistent waste stream, such as RDF or pre-treated / single-stream waste, and the track record of the technology to date is mostly based on plastics, tyres or other dry, energy-rich single stream feedstocks. The application of pyrolysis to mixed wastes and RDF from mixed waste has proven challenging and is not yet commercially proven.

Pyrolysis is a broad group of technologies with significant variation in terms of the type of reactor vessels used, the method of applying heat and the process conditions. Numerous technology providers have adopted alternative terminology such as thermal decomposition, carbon depolymerisation and destructive distillation; perhaps in response to bad press from tyre pyrolysis plants in South East Asia (see below). These technologies are effectively variants of pyrolysis but share the core characteristic that waste materials are thermally treated in the absence of oxygen to vaporise the carbon content.

The segregated waste or RDF will usually be fed into the pyrolysis chamber either on a continuous or batch basis where it will be heated to between 300°C and 800°C in an oxygen-free environment. Initially, the waste dries and moisture is released and as the temperature increases, a series of reactions take place which cause the carbon to breakdown and volatilise to form a syngas which is a mixture of a hydrogen, methane, carbon monoxide and a wide range of volatile hydrocarbons.

As the syngas is cooled and condensed, it may produce liquid oil products (pyrolysis oils) which can be further refined into fuels and solvents. The remaining uncondensed syngas can be used to heat the process or for energy production. There is also a solid product (char) which still retains a high energy content, much like charcoal, and can be used as fuel itself.

Unlike combustion and gasification, pyrolysis is not self-sustaining in terms of energy. It requires an external heat source to generate and maintain the process temperatures which could come from combustion of the syngas, combustion of the char or external sources such as natural gas or electricity.

Green Distillation Technologies – Warren, NSW

GDT's version of pyrolysis, termed destructive distillation, involves loading whole tyres into a sealed chamber and heating them in the absence of oxygen. No initial processing of the tyres, such as shedding, is required. Heat is applied, which drives the thermal decomposition of the tyre rubber into a range of hydrocarbon compounds. This is collected and condensed into a 'manufactured oil', with the carbon residue and steel extracted, cooled and separated.

GDT constructed the pilot plant in Warren in 2010 in order to prove the concept of their pyrolysis process, termed destructive distillation. The process converts tyres to oil, steel and carbon powder which is proposed to be sold as a coking coal substitute in steel making.

Following trials over several years, the company started developing a full-scale commercial plant with 12 processing tube modules, due for completion late 2017. That plant will process around 600,000 tyres per annum.

Outputs and residues

There are potentially three outputs, all with energy value – syngas, oils and char – and the relative proportions and quality of each product is a function of the process conditions and feedstock. Lower temperatures tend to produce more liquid oil products, whereas higher temperatures produce more gaseous products. Slow systems with long residence times tend to produce more char, while 'flash' pyrolysis systems, where the feedstock is rapidly heated, produce more oils and gas. Pyrolysis is a complex set of reactions and chemical products with many variables, which are not fully understood and near-impossible to accurately model.

The syngas, depending on its quality, can be combusted in a gas engine generator or other power generation plant. For larger operations it could be combusted in a boiler to generate steam which is fed into a steam turbine. The liquid oils can be further refined and distilled to produce a range of fuels and solvents, although many plants have found it challenging to produce stable fuels that comply with regulatory standards.

Pyrolysis of woody biomass and organic wastes can be used to produce biochar, which can be applied as a soil conditioner and has been shown to have a number of benefits for soil health and crop yields, whilst permanently sequestering carbon in the soil (making it a potentially carbon negative process). There is no accepted general specification for biochar products and it is important that producers take steps to demonstrate the product is fit-for-purpose for its intended use and will not cause adverse impacts to land or water. Producers of biochar are advised to seek EPA guidance on appropriate applications and specifications for use of these materials. Char can also be used as a solid fuel itself and tends to have an energy content equivalent to low grade coal.

Pyrolysis of tyres also allows recovery of a powdered carbon residue. Some proponents call this 'carbon black' and claim that it has similar applications and market value as carbon black (a raw ingredient in new tyres and high value commodity) although the quality of this product and market offtakes is mostly yet to be proven in commercial production. Achieving required carbon black quality standards has been challenging for most technologies to date.

Track record

Pyrolysis technologies have had limited success on mixed waste feedstocks and have experienced issues when processing wet or moist waste streams. A high degree of pre-treatment and drying is usually required. As noted above, the technologies are best suited to dry and more consistent, single material feedstock where more reliable process outputs can be achieved.

Internationally, there are numerous plants running on waste tyres. Pyrolysis has been widely deployed to process tyres into oil throughout the world, to varying standards and degrees of success. There were a number of plants established in South East Asia for example, but many are not capable of meeting modern environmental standards and in recent years, governments including the Malaysian and Philippine Governments have cracked down on these operators, resulting in closures.

In Australia, there are several companies developing tyre pyrolysis technologies at demonstration and pre-commercialisation phase, but most are yet to run continuously and reliably for an extended period.

There has also been significant focus on processing mixed plastics to produce fuels. A Canadian company (Plastic2Oil) has developed a conversion process for unwashed, unsorted mixed waste plastics into clean, low sulphur oil. The process involves melting the plastics and then cracking long chain hydrocarbons into shorter chains via a catalytic process. This proprietary process is still in development and has yet to reach commercial scale.

There are examples of small scale plants designed specifically to produce char or biochar. In most of those technologies, the gas and vapour streams are usually burned to heat the process. This approach, with minimal focus on recovering energy, is simpler to achieve but more limited in its application. An example includes PyroCal, based in Queensland, which manufactures a range of char and biochar products for use as soil improvers, from various agricultural and other organic waste streams.

A considerable amount of academic research has been undertaken into the soil health and carbon sequestration benefits of biochar during the last decade, but to date the product has not been commercialised on any significant scale. While the soil benefits have been demonstrated in field trials, few customers have been willing to pay the high prices that producers are expecting for the product.

Challenges and benefits

One of the key challenges with pyrolysis is producing a consistent high quality product, particularly gaseous or liquid streams, and dealing with the by-products of the process such as tars. Tars have been a particular issue for the reliability of processes, leading to fouling and blocking of gas clean-up and condensation systems. Some of the by-products and wastewater streams can be quite hazardous, containing carcinogenic hydrocarbons, so careful environmental regulation and control is required.

Like gasification, there are versions of pyrolysis where the syngas is immediately combusted in a subsequent furnace. In those cases, the syngas is rarely suitable for other applications that require a clean gas stream.

One main advantage of pyrolysis is its potential to be deployed at small scales in modular format, allowing for decentralised process close to the waste source. Many of the technologies in development are designed to operate as small-scale modular units, often skid mounted or containerised and transportable by truck. A typical module might process around one tonne per hour. Larger plants then can then be formed by installing multiple modules in parallel.

Summary

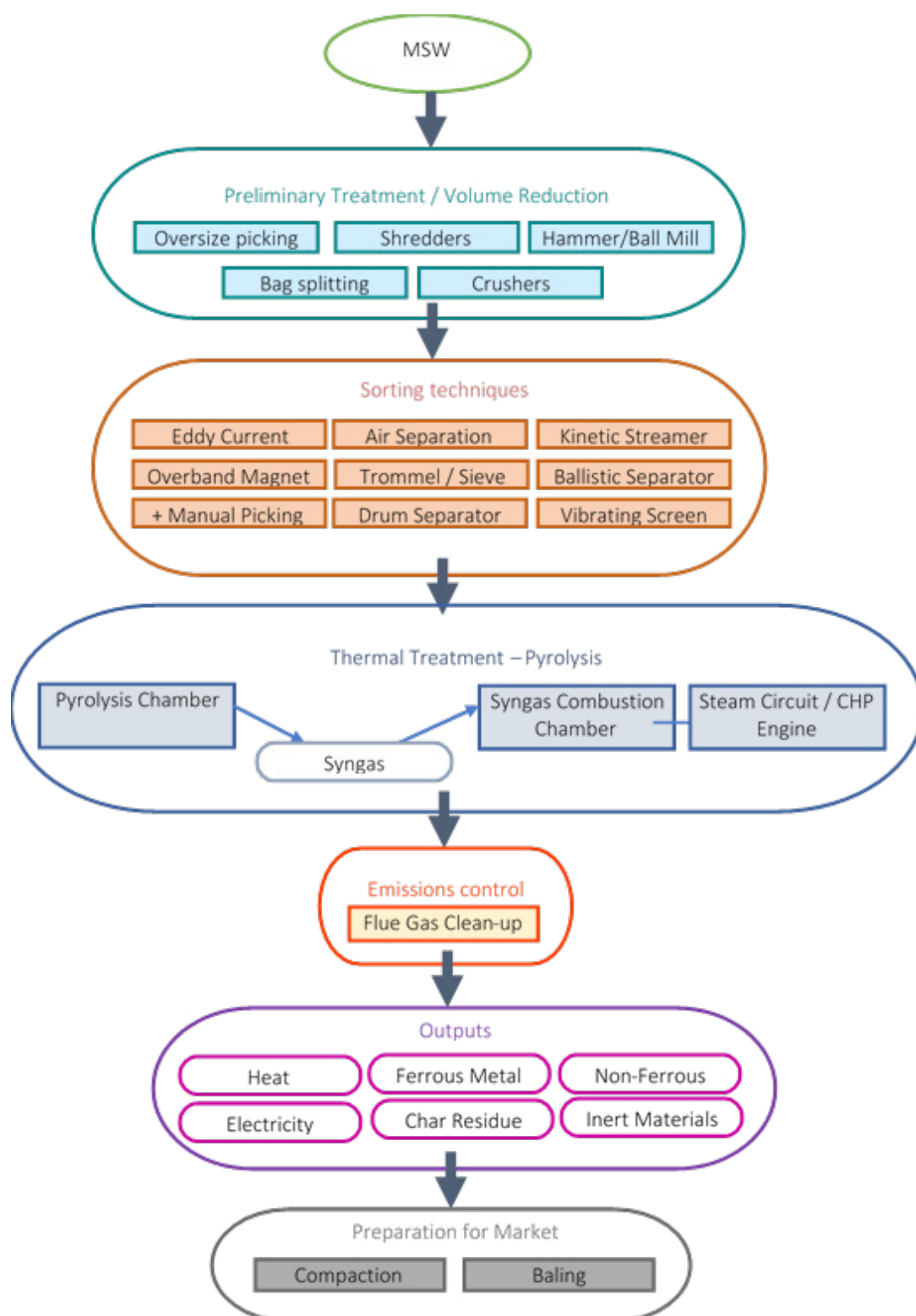
A summary of key aspects of pyrolysis technologies is presented in Table 23 and a generic process flow is presented in Figure 13.

TABLE 23 SUMMARY OF ASPECTS FOR PYROLYSIS TECHNOLOGIES

Technology Type	PYROLYSIS
Commercial track record	Limited – several tyre pyrolysis facilities in developing countries but mostly not capable of complying with western environmental standards. A number of tyre technologies are close to commercialisation in Australia but not yet run continuously and reliably for extended periods. Pyrolysis of other waste streams, particularly mixed waste or wet wastes, has been found to be particularly challenging.
Waste feedstocks	Tyres, plastics, dry biomass, RDF
Typical capacity range	10,000-100,000 tpa
Indicative capital cost range ⁴²	\$30M
Operational cost factors	Process heating costs, maintenance and cleaning, refining of products (syngas and oils), disposal of residues (tars, wastewater)
Indicative land-take	0.12 – 0.4m ² / tonne
Factors for scaling	Modular units, potential to expand capacity easily. Quick deployment and installation of skid-mounted or containerised plants.
Products / outputs	<ul style="list-style-type: none"> › Liquid oil, fuels, solvents › Syngas - electricity, heat › Char – biochar, carbon black › Recyclables – mostly metals (e.g. from tyres) › Gas clean-up residues (hazardous)
Key issues and main risks	<ul style="list-style-type: none"> › Quality and stability of liquid fuels and oils and compliance with standards › Quality of carbon black outputs › Issues around tar formation, clogging › Production and management of toxic wastewaters and by-products
Questions to ask	<ul style="list-style-type: none"> › Track record of commercial operation including continuous running › Process availability, reliability, maintenance costs › Quality data on process outputs and compliance with relevant standards › Costs and equipment for refining oil outputs into saleable products
Reference plant examples	<ul style="list-style-type: none"> › Green Distillation Technologies demonstration tyre pyrolysis plant in Warren, NSW › Hamm Pyrolysis Plant, Hamm, Germany

42 Indicative capital cost in 2017 for a 20,000 tpa capacity facility

FIGURE 13 PYROLYSIS PROCESS FLOW



4.3 Plasma gasification

Plasma gasification is a variation of gasification which uses a plasma torch / arc to generate ultra-high temperatures to essentially break waste down into the most simple of compounds. The plasma arc can create reactor temperatures from 1,200°C up to 10,000°C, which is claimed to result in a very clean syngas of hydrogen and carbon monoxide. Technologies differ slightly in the application of the plasma arc, whether it is applied directly to the waste feedstock or to the syngas produced from a more conventional gasification chamber.

Some plasma gasifiers require a homogenised feedstock (RDF), while others can process mixed wastes through an initial crude gasification stage, followed by plasma application to the syngas.

Outputs and residues

The high temperatures that can be achieved using a plasma arc, break down or melt virtually any form of waste material, including mixed residual waste, hazardous wastes, inert materials, glass and metals. Any organic matter present in the waste is decomposed into its constituent molecules to produce a syngas stream (mostly carbon monoxide and hydrogen) with few contaminants or heavier hydrocarbons.

The syngas is particularly clean and homogenous, compared to other forms of gasification and can potentially be used to generate electricity through a gas engine generator, gas turbine or fuel cell. It could also be used in the manufacture of chemicals in place of fossil fuels or converted to liquid fuel via the Fischer-Tropsch process as discussed below in Section 3.3.5.1. There are trials ongoing in the UK to refine this syngas for injection into the main gas distribution grid.

Cleaning of the syngas is still required to remove acid gases and volatilised heavy metals (including mercury), which results in a small volume of hazardous process residues.

Inorganic matter on the other hand, is turned into molten slag and metal which forms two distinct flowing layers that can be separated as they flow out of the base of the furnace. The molten metal is solidified and sent for recycling. The molten slag, which contains all the other inert materials, is cooled to a glass-like material that can be further processed into a secondary aggregate. This slag material is very effective at encapsulating and immobilising any hazardous components without fear of them leaching out in the future, which means that hazardous wastes can potentially be co-processed with other materials.

Track record

Plasma arc technologies have been applied commercially to destruction of hazardous wastes and have been used in Japan to melt and vitrify ash from waste combustion plant, but the technology is yet to be proven in commercial applications on mixed wastes for energy recovery.

There are a number of demonstration plants in operation (particularly in Japan and the UK). There have also been some notable project failures including the Air Products Tees Valley project in the UK, in which two very large parallel processing lines were constructed using Westinghouse plasma technology. The plants were designed to process a total 700,000 tonnes of residual waste per annum and generate 50MW. The project was abandoned in 2016 whilst the first plant was still in commissioning with reported losses of up to \$1 billion. Media articles sighted unforeseen design and operational challenges that were too costly to rectify.

Another once promising technology developer, Plasco of Canada, failed financially in 2015 after missing several deadlines on its first commercial project with the City of Ottawa. Other technologies have been very slow to reach commercialisation stage.

French company CHO / Europlasma has a commercial demonstration plant in Morcenx (France) processing biomass (wood chips) and RDF from commercial waste (mostly paper, cardboard and wood). That plant took a long time to reach its nominal design capacity and but has been fully operational since June 2017. UK company Advanced Plasma Power has been running a pilot plant in Swindon (UK) for many years but has not yet progressed to a full scale operation.

Challenges and benefits

If the technology can be made to work, it holds significant promise in terms of the diverse range of applications of the clean syngas and its high recovery rates / low proportion of residues. However, the failure of the Air Products project, the largest of its kind in the world, has been a major blow to future investments in plasma gasification.

Plasma gasification requires a very high energy input in order to power the plasma torches which is greater than for comparable gasification and combustion technologies. The anticipated energy output from this technology is higher, with examples in the order of 1500 kWh/t of wood feedstock identified, however there is little commercial evidence of this being achieved, particularly on municipal waste type feedstocks.

Summary

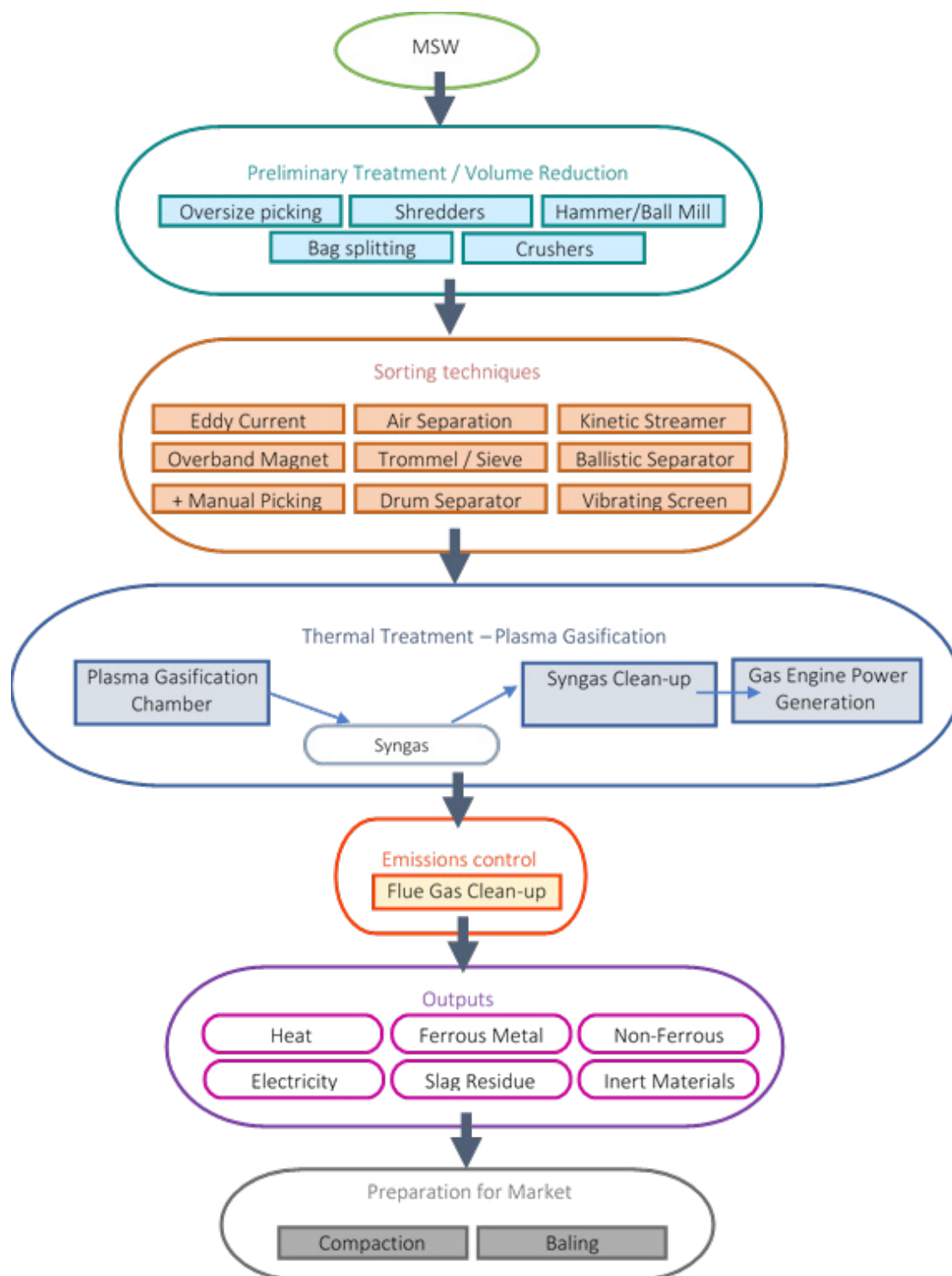
A summary of key aspects of plasma gasification is presented in Table 24 and a generic process flow is presented in Figure 13.

TABLE 24 SUMMARY OF ASPECTS FOR PLASMA GASIFICATION TECHNOLOGIES

Technology Type	PLASMA GASIFICATION
Commercial track record	Not yet proven in commercial application to mixed waste streams. Notable large scale failures overseas.
Waste feedstocks	Mixed residual waste, RDF, wood, hazardous wastes
Typical capacity range	100,000-350,000 tpa
Indicative capital cost range ⁴³	\$100M – No data
Operational cost factors	Electricity consumption, operational and maintenance costs, gas clean up residue management
Indicative land-take	0.12 – 0.2m ² / tonne
Factors for scaling	Modular units, potential to expand capacity.
Products / outputs	<ul style="list-style-type: none"> › Syngas – clean, carbon monoxide + hydrogen, can be used for electricity, heat, fuels, chemicals › Slag – aggregate product › Metals › Gas clean-up residues (hazardous)
Key issues and main risks	<ul style="list-style-type: none"> › Process unproven at large scale › High energy inputs › High operational and maintenance costs › Complex process, with exotic high temperature materials
Questions to ask	<ul style="list-style-type: none"> › Track record of commercial operation, at-scale, including continuous running › Process availability, reliability › Lifecycle and maintenance costs › Serviceability and local technical support for plasma and other complex elements › Overall energy recovery efficiency
Reference plant examples	<ul style="list-style-type: none"> › CHO Morcenx plant (France)

43 Indicative capital cost in 2017 for a 100,000 tpa capacity facility

FIGURE 14 PLASMA GASIFICATION PROCESS FLOW



4.4 Torrefaction

Torrefaction is a technology usually applied to biomass but could be used for some single-stream organic waste materials such as waste wood, some organics and forestry or agricultural residues. The process operates much like a low temperature version of pyrolysis and operates at between 200°C and 400°C in the absence of oxygen. The carbonaceous biomass is slowly cooked so that the mass is reduced (typically by around 30 per cent) but 90 per cent of the energy content is retained.

The resulting product is a brittle, charcoal or coal-like solid fuel, sometimes called bio-coal, which is potentially suitable as a substitute for coal or for co-firing at power stations.

There are a number of commercial and demonstration scale biomass torrefaction demonstration plants in the US, Canada and Europe (in particular the Netherlands), which torrefy wood, forestry wastes and straw for co-firing at coal-fired power stations. Hence it can act as a pre-treatment phase to produce fuels which can be used in existing energy infrastructure, or transported to a centralised thermal treatment plant.

In addition, there are systems in development where biomass torrefaction is combined with power generation in a single installation, including a demonstration facility in operation in the UK.

Broader application of torrefaction to other waste materials will be constrained by concerns over chemical contaminants, which may require significant modifications to downstream combustion systems and associated emissions control equipment.

Typical costs for a torrefaction facility might be in the region of AU\$8-10m for a 60ktpa facility, or around AU\$20m for a 160ktpa facility, based on feedstock throughput, although these can only be considered indicative, as there are few full-scale commercial facilities in operation.

4.5 Advanced fuel production

A variety of fuel products can be manufactured from waste materials through a variety of different approaches and technologies. Most of the technologies are still in early stages of development and commercialisation. Pyrolysis is one approach to producing liquid fuels from certain feedstocks as discussed in 4.2. Below is an overview of some of the other emerging technologies in this area.

4.5.1 Fermentation

An emerging process for waste streams such as food processing residues, waste timber, paper and cardboard, forestry residues, agricultural crop residues; is second generation fermentation. Fermentation is a biological process to convert cellulose into ethanol or bio-ethanol. First generation fermentation processes, use cellulose-rich crops such as sorghum, sugar cane or corn as feedstocks. New and emerging fermentation technologies are focusing on extracting sugars (cellulose) from the lignin content (woody biomass) present in organics. Various methods can be used to liberate and extract the sugars from waste materials including enzyme or acid hydrolysis, and steam heating. Once the sugars are liberated, conventional fermentation processes can be applied whereby microbes (e.g. yeasts) convert the sugars to ethanol, in a process akin to brewing. The ethanol is then distilled off and refined into fuel grade quality.

4.5.2 Gas-to-Liquids

One area of significant research and technology development is in gas-to-liquids technologies. If a clean consistent syngas stream can be produced from waste via gasification (including plasma gasification) there is potential to further process the syngas into biofuels.

One approach is the Fischer-Tropsch (FT) process which is a set of reactions that convert hydrogen and carbon dioxide (in syngas) into synthetic crude oil - a mixture of liquid hydrocarbons that can be further refined into various fuel fractions. The FT process has been around for some time – it was used in wartime Germany to produce fuels from coal. It is in commercial use at a small number of plants around the world producing liquid fuels from natural gas or coal (via gasification). It is generally considered an expensive method of producing fuels from those fossil feedstocks, which is only viable in limited circumstances. With the ongoing discoveries of natural gas and oil, and development of unconventional fossil fuel resources, it became a somewhat redundant technology and was never broadly adopted or matured.

Its application to waste and biomass feedstocks is relatively new and there are a number of processes in development and early stages of commercialisation. Fuels manufactured using the FT process are drop-in fuels that can be used in existing fuel distribution networks and blended with fossil derived fuels, requiring no modifications to engine designs. It is a concept that has attracted interest and investment from several major international airlines.

One of the more advanced providers is US-based Fulcrum BioEnergy which uses mixed municipal waste as a feedstock. The waste is first mechanically prepared to remove inert components and recyclable materials, then the resulting RDF is gasified and the syngas subjected to the FT process. Further refinement produces either drop-in diesel or jet fuel that complies with all relevant fuel standards.

The first commercial scale modular plant is being commissioned at the Sierra BioFuels Plant in Nevada which is designed to process 200,000 (US) tons per annum of prepared mixed waste feedstock (RDF) to produce 10 million gallons of renewable 'syncrude' which will be further refined into fuel products (approximately 210 litres syncrude per tonne of prepared RDF). Full commercial scale operations are not expected until early 2019⁴⁴.

In Canada, Enerkem has developed a methanol and ethanol production process from mixed municipal waste and is currently bringing it into commercial scale production. Prepared residual waste is the feedstock and the process also uses gasification together with FT to produce biofuels. The company's Alberta (Canada) plant is the first commercial scale demonstration plant. The project was originally due to open in 2012 but suffered several delays and was not declared fully operational and meeting performance requirements until April 2017.

4.5.3 Hydrothermal Liquefaction

Hydrothermal liquefaction (HTL) is an emerging thermal process where wet biomass feedstocks are subjected to high pressures and moderate temperatures (250-374 °C) in a liquid phase, resulting in conversion of the carbon into bio-crude, which can be further refined into liquid fuels.

HTL is similar in nature to pyrolysis but occurs in liquid phase. Unlike most other thermal processes, there is no need for wet feedstocks to be dried first. This means it can potentially be applied to a wide range of feedstocks from very wet materials such as biosolids, food processing slurries and manures, through to ground woody biomass and other high lignin wastes.

The temperature is high enough that organic solids breakdown into liquid components, as in pyrolysis, while the high pressure ensures that a liquid phase is maintained. At temperatures above 374 degrees Celsius, gasification reactions start to occur (carbon is partially oxidised by oxygen in the water) resulting in production of syngas rather than liquid hydrocarbons.

The process is not new – it has been tested since the 1970's, and while there has been many pilot scale demonstrations, it is yet to be successfully applied to waste feedstocks on a broad commercial scale. Development efforts have increased in recent years in an effort to develop new renewable fuels and to produce a substitute for crude oil that can be refined in the same way.

The bio-crude produced is similar in many ways to natural petroleum crude oil in that it is a mixture of a range of hydrocarbon molecules of differing molecular weights, and it can be refined using similar distillation methods. However, chemically, it contains significantly more oxygen than typical crude oil and must be processed to remove oxygen through processes such as catalytic hydrotreating, prior to distillation. The quality of the bio-crude depends on the feedstock properties and process parameters.

Research is ongoing around the use of catalysts to improve efficiency and bio-crude quality. The process produces a hydrocarbon contaminated water stream which needs to be treated and a small amount of solid residue, which may contain concentrated nutrients, depending on the feedstock.

Development of the technology is continuing and it is being studied by a number of agencies and private companies, particularly in North America and Europe. The technology has been demonstrated at small scale in labs and pilot plants but there are no known commercial scale operations. An Australian company Licella (based near Sydney) has developed a pilot catalytic thermal process to convert waste biomass and end-of-life plastics into high-quality oil, which is suitable for blending with standard hydrocarbon fuels to displace raw fossil fuels.

In Canada, the Metro Vancouver group of local authorities is planning to build a demonstration plant using HTL to convert biosolids into bio-crude.

5 Technology Summary

This section provides a summary of the key information presented in the preceding chapters 3 and 4. From that information, it is apparent that the process of selecting an appropriate resource recovery solution to meet the requirements of a particular situation has to take into consideration a variety of factors, including:

- › The quantity and composition of the waste and material types that are the proposed feedstock for the process
- › The intended purpose of the project, in terms of its environmental, social and financial outcomes, including value adding to the recovered material stream
- › The resources (including financial) that are available to support the selection, procurement, deployment and operation of the solution
- › The characteristics of the available site, or criteria in the site selection process

Moreover, the information that is presented in this report demonstrates that resource recovery technologies:

- › Are multi-faceted and available in a variety of configurations at different scales
- › Can provide a variety of outcomes for a given feedstock
- › Have varying track records, even within a given technology category
- › Present a range of risks which should be understood by those procuring, assessing or investing in a project

Table 25 overleaf presents a simple, colour-coded comparison of the different resource recovery technologies that are presented in this Guide (Sections 3 and 4), cross-referenced against the different types of waste (Section 2).

The comparison is based on a consideration of the ability or fitness for purpose of the individual technologies to recover value from the identified waste streams and their track record in that application from an international perspective.

Combinations of technologies and wastes that are appropriate and are supported by a strong technical and commercial track record are identified with green dots; combinations that are technically possible, but are not preferred in terms of maximising the value of the recovery activity, or lack a commercial track record, are identified with yellow dots. Combinations that are not appropriate are identified with red dots.

TABLE 25 COMPARISON OF RESOURCE RECOVERY TYPES AGAINST DIFFERENT SOURCES AND TYPES OF WASTE

Technology	Mixed Wastes				Organics				Separated streams for reprocessing					Comments
	Mixed municipal residual waste	Mixed C&I residual waste	Mixed C&D residual waste	Mixed dry recyclables	Source separated garden waste	Source separated food waste	Source separated C&I organics	Source separated timber (clean)	E-waste	Tyres & rubber	Plastics	Glass fines	Concrete & brick	
SORTING PROCESSES														
Mixed waste MRF	●	●	●	●	●	●	●	●	●	●	●	●	●	Recovers hard recyclables from mixed waste
Clean MRF	●	●	●	●	●	●	●	●	●	●	●	●	●	Recovers hard recyclables from source separated waste
MBT	●	●	●	●	●	●	●	●	●	●	●	●	●	Separate reception / processing line for different waste streams
MHT	●	●	●	●	●	●	●	●	●	●	●	●	●	Intended for mixed residual streams, Lacks commercial track record
E-waste recycling	●	●	●	●	●	●	●	●	●	●	●	●	●	Specific to e-waste
BIOLOGICAL PROCESSES														
Open windrow composting	●	●	●	●	●	●	●	●	●	●	●	●	●	Generally suited to garden organics
Aerated static pile composting	●	●	●	●	●	●	●	●	●	●	●	●	●	Suited to garden and food organics
In-vessel composting	●	●	●	●	●	●	●	●	●	●	●	●	●	Suited to a wide range of organics
Anaerobic digestion	●	●	●	●	●	●	●	●	●	●	●	●	●	Suited to garden and food organics
Vermi-composting	●	●	●	●	●	●	●	●	●	●	●	●	●	For putrescible organics only

Technology	Mixed Wastes				Organics				Separated streams for reprocessing					Comments
	Mixed municipal residual waste	Mixed C&I residual waste	Mixed C&D residual waste	Mixed dry recyclables	Source separated garden waste	Source separated food waste	Source separated C&I organics	Source separated timber (clean)	E-waste	Tyres & rubber	Plastics	Glass fines	Concrete & brick	
THERMAL TREATMENT PROCESSES														
Combustion	●	●	●	●	●	●	●	●	●	●	●	●	●	Primarily suited to mixed waste
Gasification	●	●	●	●	●	●	●	●	●	●	●	●	●	Primarily suited to mixed waste
Pyrolysis	●	●	●	●	●	●	●	●	●	●	●	●	●	Lacks commercial track record
Plasma gasification	●	●	●	●	●	●	●	●	●	●	●	●	●	Lacks commercial track record
Dehydrators	●	●	●	●	●	●	●	●	●	●	●	●	●	Only for wet organics
Torrefaction	●	●	●	●	●	●	●	●	●	●	●	●	●	Lacks commercial track record
ADVANCED FUEL PRODUCTION														
Fermentation	●	●	●	●	●	●	●	●	●	●	●	●	●	Lacks commercial track record
Gas-to-liquids processes	●	●	●	●	●	●	●	●	●	●	●	●	●	Lacks commercial track record
Hydrothermal Liquefaction	●	●	●	●	●	●	●	●	●	●	●	●	●	Lacks commercial track record
REPROCESSING SOLUTIONS														
Timber Shredding	●	●	●	●	●	●	●	●	●	●	●	●	●	Specific to one material
Mechanical recovery of rubber	●	●	●	●	●	●	●	●	●	●	●	●	●	Specific to one material
Plastics reprocessing	●	●	●	●	●	●	●	●	●	●	●	●	●	Specific to one material
Glass fines beneficiation	●	●	●	●	●	●	●	●	●	●	●	●	●	Specific to one material
Concrete & brick recycling	●	●	●	●	●	●	●	●	●	●	●	●	●	Specific to one material

6 Delivering Resource Recovery Solutions

This section outlines a range of considerations for the procurement and delivery of resource recovery solutions. While it is difficult to provide general guidance for such a diverse range of technologies and feedstocks, the information in this chapter is intended to prompt further specific investigations and assessment.

6.1 Managing environmental impacts

6.1.1 Site suitability and separation distances

Selecting and securing a suitable site will be critical to the success of a given resource recovery solution over its life. International experience in deployment of thermal treatment solutions for example, has shown that local government procurement exercises have failed due to a lack of suitable sites or projects have faced significant hurdles in the approvals phase due to inappropriate site selection.

The footprints of resource recovery facilities vary depending of the nature (technology type) and scale (processing capacity) of the operation and the extent to which other waste and resource recovery operations are undertaken on the same site. Indicative land-take requirements are provided for each technology in Chapters 3 and 4 but these are generally broad ranges and application-specific assessments are required.

The locational considerations of resource recovery solutions include:

- › Required capacity and plant footprint
- › Proximity to feedstock sources and product markets
- › Heavy vehicle access and transport links
- › Appropriate zoning in local planning schemes (see Section 6.1.3 on planning and approvals)
- › Proximity to sensitive receptors, particularly residential properties and other areas regularly occupied by people
- › Proximity to surface waters – uncontrolled leachate and contaminated runoff from processing and waste storage areas could contaminate sensitive surface waters
- › Groundwater conditions – sites with high water tables or in groundwater recharge areas may not be suitable or may require additional engineering controls
- › Avoiding potential sites or areas within sites that contain sensitive flora, fauna or ecological habitats protected by State or Federal legislation. Removal of particular grasses, trees, groundcover or indeed, site clearance could trigger the need for additional environmental approvals or costly mitigation measures
- › Access to adequate power, water supply (for process, wash down and fire-fighting purposes) and sewer connection
- › Fire management for feedstocks
- › Appropriate separation distances (or 'buffers') between the site or core processing operations, and sensitive receptors such as schools, housing and hospitals. Ideally, buffers will be within the site boundary but external buffers may be used if they are protected from future development (e.g. easements, reserves, agricultural land).

Reference material:

- › EPA guideline for *Recommended Separation Distances for Industrial Residual Air Emissions* (EPA Publication 1518, March 2013)
- › EPA guideline for *Designing, Constructing and Operating Composting Facilities* (EPA Publication 1588.1, June 2017)
- › EPA guideline for *Management and storage of combustible recyclable and waste materials* (EPA Publication 1667.1, 6 November 2017)

6.1.2 Sources and control of emissions

Pollution and emission controls. Resource recovery facilities must be appropriately designed, constructed and operated to prevent adverse effects to air, water and land.

Within Victoria a statutory system of regulatory controls of waste and resource recovery operations exists (see Section 6.1.3) and operations have to implement process controls and/or abatement technologies to prevent pollution and harm to human health. Ongoing monitoring is essential and another cost to consider.

The potential pollution sources and control measures implemented depend on the technology that is being deployed, such as:

Potential pollution source	Example control measures	
<ul style="list-style-type: none"> › Odour emissions from the storage or processing of putrescible wastes › Dust emissions from the mechanical processing of dry materials › Flue gas emissions from thermal processes › Leachate and wastewater streams from storage and processing phases › Contaminated run-off from waste, product and residue storage areas › Storage and management of hazardous residues extracted or produced during the process › Noise emissions from mechanical plant, particularly heavy duty crushers, shredders, screens and other high impact equipment 	<p>Extensive operations that take place in the open air e.g. Windrow composting</p> <p>▼</p> <p>Locational controls e.g. large buffers, combined with good operational practices</p>	<p>Intensive operations that are housed within a building e.g. MBT and combustion processes</p> <p>▼</p> <p>Building and process controls e.g. fast acting roller doors, negative pressure air circulation systems</p> <p>Emission abatement systems e.g. biofilters, flue gas treatment systems</p>

Greenhouse gas emissions

One of the drivers for resource recovery is the avoidance of greenhouse gas emissions from landfill disposal of waste and from the extraction and processing of virgin materials.

Assessing the greenhouse gas impacts and benefits of proposed resource recovery solutions is possible using tools such as:

- › Easetech (Denmark)⁴⁵
- › Waste and Resource Assessment Tool for the Environment (WRATE) (UK)⁴⁶
- › Municipal Solid Waste Decision Support Tool (MSW-DST) (USA)⁴⁷
- › Solid Waste Management Greenhouse Gas (SWM-GHG) Calculator (Germany)⁴⁸
- › It is important to note that in the design assessment phase of new waste and recycling infrastructure must give regard to the *Climate Change Act 2017*.

However, presenting generic normalised examples is problematic given the wide range of technologies and configurations that are available. Also, experience has shown that greenhouse gas assessments are strongly influenced by factors that are local to an existing or proposed facility, including:

- › The sources and types of waste that are under consideration
- › The business-as-usual management pathway for those wastes (e.g. if landfilled, what standard of landfill?)
- › The transport distances and methods that are necessary for the delivery of waste and export of products and residues.

The main problem associated with using tools developed for other jurisdictions is that the assessment process may not accurately reflect the local energy mix or waste disposal practices, and the data sets that sit behind some of the existing tools may not be current. Some of the tools allow some changes to the underlying parameters and data sources.

6.1.3 Planning and approvals

Before proceeding with development of a resource recovery facility, it is important to determine which planning and environment legislation applies and whether or not any regulatory approvals need to be obtained. This also applies to upgraded (or new) supporting infrastructure such as roads, power infrastructure (power lines, substation upgrades), water or gas supply pipelines. This can make a difference to the overall cost of the development, completion time, stakeholder consultation requirements and delivery approach. Regulators have significant influence over the design, construction and operation of some facilities and their location.

Environment and planning legislation exists at local Government, State and Federal (Commonwealth) level and addresses issues such as: visual impact of a facility, noise, odour, air quality, traffic, community consultation, contamination, groundwater, creeks and rivers (surface water), consistency with local planning conditions, cultural heritage (aboriginal and built heritage), ecology (flora and fauna), and waste management, to name a few.

Environment and planning regulators include: local councils; the Environment Protection Authority Victoria (EPA); State Departments (addressing Planning, Environment, Health); Aboriginal Victoria; Registered Aboriginal Parties (RAPs); local water authorities (for sewer and mains water); local catchment management authorities (CMA's); and emergency services (Police, ambulance, fire brigade). In some cases, Federal regulators will get involved if the project impacts on Commonwealth owned land or on issues of Commonwealth significance. A brief summary of the relevant legislation and approvals processes is presented below. This focusses on primary approvals to proceed with construction and operation of the facility. A number of secondary approvals may be needed in some cases.

Advice from a statutory planner and environmental specialists is likely to be required in order to identify the need for and compile these approval applications. Table 26 provides a summary of planning and environmental approvals that may be required for a resource recovery project.

⁴⁵ Easetech: <http://www.easetech.dk>. A comprehensive lifecycle analysis tool for resource recovery solutions developed by DTU in Copenhagen. The tool is complicated to use and there is a significant licence fee per user.

⁴⁶ WRATE: www.wrate.co.uk. A tool for assessing environmental impacts of advanced waste treatment solutions including greenhouse gases, water quality, ecotoxicity and other parameters. Note, this tool is now unsupported freeware and is not maintained.

⁴⁷ MSW-DST: <https://mswdst.rti.org/>. A free tool for registered users.

⁴⁸ SWM-GHG Calculator: http://www.iswa.org/uploads/tx_iswaknowledgebase/Spies.pdf. A free tool developed in Germany indicates that it is broadly applicable for use in other jurisdictions.

TABLE 26: SUMMARY OF PLANNING AND ENVIRONMENTAL APPROVALS FOR RESOURCE RECOVERY SOLUTIONS.

Relevant legislation / regulation / policy	Detail
Statutory framework	
Planning: <i>Planning and Environment Act 1987</i>	<p>The <i>Planning and Environment Act 1987 (P&E Act)</i> and the Planning and Environment Regulations establish the legal framework for the planning systems, including the use, development and protection of land in Victoria to meet current and future needs.</p> <p>A key objective of the <i>P&E Act</i> is for land use planning and policy to be easily integrated with environmental, social, economic, conservation and resource management policies at state, regional and municipal levels.</p> <p>The Victoria Planning Provisions (VPPs) are a comprehensive set of planning provisions for Victoria, used to source and construct local planning schemes. It is a statutory device to ensure consistent provisions for planning matters are maintained across Victoria. All planning schemes in Victoria include reference to waste and resource recovery infrastructure policy.</p> <p>Waste and resource recovery land uses are normally sited on land which is zoned Industry. Those seeking to develop resource recovery should consult with their local council to determine any specific planning requirement.</p>
Environmental protection: <i>Environment Protection Act 1970</i>	<p>The <i>Environment Protection Act 1970</i> is a key legislative tool used in Victoria to protect the environment. Subordinate legislation under the Act includes:</p> <ul style="list-style-type: none"> › state environment protection policies or SEPPs for specific segments of the environment such as air, noise and groundwater › waste management policies governing the management of specific wastes › environment protection regulations. <p>Resource recovery facilities must comply with relevant environmental protection legislation, policies and regulations. Facilities should also be consistent with the local and regional waste management plans relevant to their location.</p>
Premises that require works approvals and licencing by EPA: <i>Environment Protection (Scheduled Premises) Regulations 2017</i>	<p>The <i>Environmental Protection (Scheduled Premises and Exemptions) Regulations 2017</i> prescribe the industrial premises that are subject to works approval and/or licensing by EPA, and provide for exemptions in certain circumstances. The regulations provide a means to effectively manage these premises in a transparent way, which ensures an adequate level of community confidence is maintained.</p> <p>There are specific provisions under this Regulation that apply to premises that recover energy from waste, reprocess electronic and glass waste, treat organics, biosolids and other PIWs, and that store waste tyres.</p> <p>Generally, a materials recovery facility (MRF) that processes non-prescribed (non-hazardous) wastes doesn't require a Works Approval or operational Licence, unless it triggers the general provisions of the Regulations. An exception is for glass processing, whereby from 25 June 2017, Scheduled category H05 of the Scheduled Premises Regulations requires premises in Victoria with the capacity to reprocess more than 10,000 tonnes of glass waste per year to apply for an EPA Works Approval before they are built or modified and an EPA licence to operate. In the regulations, reprocess means to change the physical structure or properties of a waste material to allow for further use.</p> <p>The general provisions of the Regulations specify threshold limits for noise, air, land or water impacts and wastes, and any facility/premises that exceeds any of these thresholds would trigger the Regulations and may require a Works Approval and subsequent operational Licence.</p>

Relevant legislation / regulation / policy	Detail
Industrial waste: <i>Environment Protection (Industrial Waste Resource) Regulations 2009</i> (IWR Regulations)	<p>The <i>Environment Protection (Industrial Waste Resource) Regulations 2009</i> (IWR Regulations) provides schedules of “prescribed” or hazardous waste. These are wastes that pose environmental, health and amenity risks and cannot be managed through conventional landfilling. Prescribed wastes must be managed by premises scheduled and licensed to receive the materials, and transported by approved vehicles and operators using waste transport certificates to track the correct transport and management of materials.</p> <p>Some prescribed wastes such as biosolids, food processing wastes, grease trap and paunch waste have organic loads and can be managed through biological technologies such as composting and digestion or may be suitable to thermal technologies. Any facility receiving such materials must be licensed to do so and complete waste transport certificates for materials received.</p> <p>Generally, plastics, concrete and brick, and the wastes that typically make up mixed residual waste and mixed recyclables are classed as Schedule 1 Industrial Waste under the IWR Regulations and are therefore not <i>prescribed</i> (Schedule 2) wastes. However, if these wastes are contaminated with a prescribed waste (e.g. asbestos in mixed concrete and brick pieces) then they are likely to trigger the Regulation and need to be treated as a Schedule 2 waste.</p>
OH&S: <i>Occupational Health and Safety Act 2004</i> <i>Occupational Health and Safety Regulations 2017</i> (OHS Regulations) and <i>Equipment (Public Safety) Regulations 2017</i> (EPS Regulations)	<p>The <i>Occupational Health and Safety Act 2004</i> establishes the statutory framework for providing a safe working environment. Like the <i>Environment Protection Act 1970</i>, this Act has subordinate legislation and several guidance documents relevant to resource recovery.</p>
Environmental management requirements: State Environment Protection Policies (SEPPs)	<p>Victorian SEPPs aim to safeguard public health, community amenity and the natural environment, and protect these from the effect of pollution and waste. SEPPs define the environmental quality objectives and describe the attainment and management programs that will ensure the necessary environmental quality is maintained and improved.</p> <p>Under the <i>Environment Protection Act 1970</i>, the requirements in environmental regulations, works approvals, licences and other regulatory tools must be consistent with SEPPs.</p>
Biosecurity management requirements: <i>Plant Biosecurity Act 2010</i> <i>Catchment and Land Protection Act 1994</i> (CaLP Act) <i>Livestock Disease Control Act 1994</i> (LDC Act) <i>Livestock Disease Control Regulations 2017</i> <i>Agriculture and Veterinary Chemicals (Control of Use) (Ruminant Feed) Regulations 2015</i> .	<p>Under the Plant Biosecurity Act 2010, landholders have an obligation to manage biosecurity risks but all parties along the recycled organics supply chain have a role to play, including organic waste collectors, transporters, processors and product distributors.</p> <p>For processing facilities, careful and considered sourcing of feedstock, clearly defined acceptance criteria, and transparency along the feedstock supply chain are critical to manage biosecurity risks. During processing, effective pasteurisation is essential, as are procedures to prevent cross-contamination between raw feedstock and finished product, by ensuring cleaning of plant and equipment and separation of feedstock and product areas.</p> <p>The CaLP Act covers noxious weed and pest animal management in Victoria, to protect primary production, Crown land, the environment and community health from adverse effects. The CaLP Act prohibits the movement and sale of noxious weeds and weed seeds of all categories anywhere in the State.</p> <p>The LDC Act and subordinate regulations place restrictions and conditions on the management of certain materials to prevent livestock from feeding on, or coming in contact with, food wastes that may contain animal products, due to the risk of spreading exotic diseases such as foot-and-mouth disease.</p> <p>The sale and distribution of unpasteurised products from biological processing poses a significant biosecurity risk which may contravene these regulations.</p>

Relevant legislation / regulation / policy	Detail
Approvals and licencing	
Planning approval: <i>Planning and Environment Act 1987</i> <i>Planning and Environment Amendment (General) Act 2013</i> <i>Victoria Planning Provisions</i>	<p>Those seeking to develop resource recovery should speak to their local councils planning section to determine whether a planning permit is required. Early discussion will also identify any other council requirements which may need to be met. This should be done prior to finalising contracts or purchasing a property.</p> <p>Any resource recovery facility which processes more than a set threshold of waste are likely to require a planning permit and are not permitted in, or within a recommended threshold distance of, land zoned for sensitive uses, such as residences, business districts, schools or hospitals. The threshold distances are stipulated in section 52.10 of planning schemes, and provide the minimum permitted distance from any part of the land of the proposed use or buildings and works, or the site where the resource recovery facility is to be developed, to land zoned for sensitive uses.</p> <p>Where a planning permit is required, applicants will need to provide supporting information to the local council or other responsible authority. This information may include an assessment of the potential impacts of the facility on the environment, traffic and surrounding land use.</p> <p>Planning permits may be specifically required to remove native (protected) vegetation from the development site.</p> <p>In some cases, the planning zone on the land is not appropriate for development of a resource recovery facility, or alternatively is not conducive to future upgrades. Although it is better to utilise sites with appropriate zoning, in some cases the developer may request to amend the zoning (from farming zone to industrial zone for example) to facilitate development. In this case an amendment to the planning scheme is required, which involves a formal application to council and State Minister for Planning.</p>
R&D approval: Research, Development and Demonstration Approval Form (EPA Publication 1369.3)	<p>If you are the occupier of scheduled premises, or would become scheduled with the installation of your proposed project, you may apply for RD&D approval, provided the works are for genuine research, development or demonstration. Prior to completing an application form, the RD&D pathway must first be confirmed by the EPA.</p> <p>In relation to the emerging technologies presented in this Guide, the R&D approval pathway is likely to be the most viable way forward to collect and provide data on and validate emerging technologies (and associated feedstocks) under Australian conditions, and to allow commercialisation of a previously untested technology in Australia.</p>

Relevant legislation / regulation / policy	Detail
<p>EPA works approval:</p> <p>Approvals Proposal Pathway (EPA Publication 1560.2)</p> <p>EPA's Works Approval Assessment Process (EPA Publication 1657)</p> <p>Works Approval Application Guideline (EPA Publication 1658)</p> <p>Selected Scheduled Premises Prompt Sheets (EPA Publication 1659)</p> <p>Recommended Separation Distances for Industrial Residual Air Emissions (EPA Publication 1518)</p>	<p>Under the regulations, certain resource recovery facilities/premises that meet set threshold criteria must have EPA works approval and in most cases an operating licence. In addition to this, some developments are exempt from a Works Approval. Refer to Section 10, 11 and 12 of the Regulations, or Section 19A and Section 20 (l) of the <i>Environment Protection Act 1970</i>. Depending on the nature of the facility, additional approvals may be required for other activities e.g. power generation, storage of other industrial wastes.</p> <p>An application for a works approval should be completed in consultation with the EPA, as all EPA works approvals and licences will reflect specific site and process circumstances. Reference should be made to instructions for completing works approval, licence and licence amendment applications (EPA Publications 1560.2, 1657, 1658 and 1659). Prior to submitting a works approval, the developer is advised to meet with the EPA and to submit an Approvals Proposal Pathway form to the EPA (see publication 1560.2). This assists in determining if a works approval is required, the approval pathway EPA have nominated for the project (fast track or standard) and if an exemption is possible.</p> <p>In assessing works approval applications, EPA will, among other things, consider the need for the following:</p> <ul style="list-style-type: none"> › An assessment for historical compliance performance for existing sites › Limits on the tonnage of waste that may be received by the facility › The use of best practice technologies › The enclosing of part or all of the process and use of appropriate odour controlling technologies to treat air removed from the facility, if applicable › Minimum separation distances to sensitive land uses (for example, residential) › Noise generated by the facility at local houses or other sensitive uses such as schools, hospitals › Discharges (if any) to land or surface water › The installation of energy recovery facilities where the process generates significant greenhouse gases <p>A works approval focusses on potential environmental risks during construction and operation. However, it is not an approval to operate. A works approval only allows the developer to construct and sometimes commission the facility. An EPA Licence is required for ongoing operation (refer below).</p> <p>In assessing the works approval, the EPA will require the developer to consider the minimum separation distance between the industrial site and nearest residences, equivalent to a development "buffer". Reference should be made to the Recommended Separation Distances for Industrial Residual Air Emissions (EPA Publication 1518).</p>
<p>EPA licence to operate:</p> <p><i>Environment Protection Act 1970</i></p>	<p>Prior to, or during commissioning of a Scheduled Premises, the owner will negotiate the terms of the operating Licence with the EPA. Licence conditions set by the EPA typically include the following principles:</p> <ul style="list-style-type: none"> › no detection of offensive odours beyond site boundaries › no discharge of nuisance particles beyond site boundaries › no burning of waste or compost at the site › no discharge of waste, wastewater or litter to land, groundwater or water environments › no visible matter (such as scum, colour or litter) in stormwater runoff from the site › Noise levels to meet requirements of the SEPPs at all nearby residences or sensitive uses › acceptance of EPA approved waste types only › ongoing annual performance reporting in accordance with EPA licence approval conditions. <p>An EPA licence will require the operator to report their environmental performance on an annual basis through an online reporting system (known as the Annual Performance Statement). Licence conditions may also require mandatory sampling and environmental monitoring activities take place to confirm performance levels are being met.</p>

Relevant legislation / regulation / policy	Detail
Other approvals	
EPBC Referral – Federal government	Under the <i>Environment Protection and Biodiversity Conservation Act 1999</i> (the EPBC Act), when a proposed project could potentially have significant impact on a matter of national environmental significance protected by the EPBC Act, a written referral must be sent to the Australian Government Minister for the Environment. The purpose of the referral process is to determine whether or not a proposed action will need formal assessment and approval under the EPBC Act. A referral is the principal basis for the Minister's decision as to whether approval is necessary and, if so, the type of assessment that will be taken.
EES Referral – Victorian government	Under the <i>Environment Effects Act 1978</i> , when a proposed project could potentially have significant environmental effects, a written referral must be sent to the Victorian Minister for Planning requesting a decision on whether an Environment Effects Statement (EES) is required. A project may be referred by a proponent or decision-maker. If deemed significant, then an Environment Effects Statement (EES) is required. An EES usually contains: <ul style="list-style-type: none"> › A description of the proposed development › An outline of public and stakeholder consultation undertaken during investigations and the issues raised › A description of the existing environment that may be affected › Predictions of significant environmental effects of the proposal and relevant alternatives › Proposed measures to avoid, minimise or manage adverse environmental effects › A proposed program for monitoring and managing environmental effects during project implementation.
Cultural Heritage Management Plan (CHMP) – Victorian government	If a proposed development could affect Aboriginal cultural heritage, a Cultural Heritage Management Plan (CHMP) prepared by a Heritage Adviser may be required. A CHMP usually contains an assessment of the potential impact of a proposed activity, and measures to be taken in order to manage and protect Aboriginal cultural heritage in the affected area. A CHMP is required when high impact activities are planned in an area of cultural heritage sensitivity, as defined by the <i>Aboriginal Heritage Regulations 2007</i> . In such an area, planning permits, licences and work authorities can't be issued unless a CHMP has been approved for the activity.

Planning and approvals timelines

The variation in scale and technical complexity of resource recovery projects results in a wide range of possible timeframes for the planning and approval processes. This may range between 3 months to over 2 years, depending on issues such as technical complexity of the process, whether or not the technology is proven, the likely environment impact of the facility and level of community interest.

For example, obtaining approvals for a sorting facility such as a clean MRF is likely to take significantly less time to obtain approval (less than 12 months) compared with a waste combustion plant where there are no other examples of operating plants in Victoria. Internationally, there are examples of large-scale waste to energy projects that have taken a decade or more to develop, with most of the delays occurring in the planning, consultation and approvals phase.

The timeframes presented below are indicative only and should be validated against the specific requirements of the project. Furthermore, the timeframe below applies only to technology which is currently employed in Victoria and is well understood by planners and regulators. Longer timeframes can be expected for new and emerging technologies and complex processes or proposals which attract a high degree of community interest and opposition (e.g. thermal treatment projects).

TABLE 27 APPROXIMATE PLANNING AND APPROVALS TIMEFRAME FOR A RESOURCE RECOVERY SOLUTION.

Project Requirement	Timeframe	Time extensions / High risk areas
Research, development and demonstration (RD&D) Approval	30 days	Allow time for developing application and the necessary technical inputs and justification e.g. Literature search, design layout for pilot plant, process descriptions, environmental assessments associated with temporary operations e.g. Air quality impacts.
Works Approval (EPA Victoria)	6 weeks (fast track) to 4 months (standard) for obtaining approval.	<p>Allow 3 – 4 months for completion of supporting studies.</p> <p>Add another 6 – 12 months for VCAT challenges for high risk/ impact project.</p> <p>Significant community concerns over project may extend timeframe by more than 12 months.</p>
Works approval exemption	2 – 4 weeks for a determination from EPA.	Allow 1 – 4 months for completion of supporting studies.
Planning scheme amendments (if required)	6 – 12 months.	<p>Allow 3 – 4 months for completion of supporting studies.</p> <p>Add another 6 – 12 months for VCAT challenges for high risk/ impact project.</p> <p>Significant community concerns over project may extend timeframe by more than 12 months.</p>
Planning permit (including completion of studies)	4 – 12 months.	<p>Allow 3 – 4 months for completion of supporting studies.</p> <p>Add another 6 – 12 months for VCAT challenges for high risk/ impact project.</p> <p>Significant community concerns over project may extend timeframe by more than 12 months.</p>
Cultural heritage management plan (if required)	3 – 6 months.	Allow additional time for site sampling/ testing for higher risk sites
EPBC referral	3 – 6 months.	Allow up to 18 months for high risk/high impact project.
Environmental Effects Statement (EES) (Victorian Department of Planning)	1 – 2 years.	Unlikely but may occur if there is a significant impact on Commonwealth protected flora, fauna or other matters identified in the EPBC Act. This includes projects with a significant impact on the community.

6.2 Managing community impacts

6.2.1 Jobs and employment

Resource recovery solutions have the potential to create jobs for the local community, with a positive change in employment in moving from landfill disposal to resource recovery. The skills requirements vary across the different technology options and the number of personnel required to operate a facility will depend on the scale and complexity of the technology.

For example, less complex technologies such as simple sorting operations and composting operations require manual operatives who work under the supervision of a small supervisory / management team. Whereas mechanical biological treatment and waste to energy facilities require a workforce that is comprised of a mix of manual operatives, skilled technicians and engineers as well as supervisors and managers, and may directly employ 50-80 staff, with further jobs created in supporting and subcontracting roles in providing maintenance and other related services for the duration of the plant life.

6.2.2 Community and stakeholder engagement

Waste and resource recovery facilities represent some of the most contentious land uses that operate within today's society. Proposals for resource recovery solutions can cause concern within the surrounding communities and may also attract the attention of the media.

The successful deployment and operation of resource recovery facilities will require the owner/operator of the facility to gain and maintain the approval of the local community (i.e. a social licence to operate). The social licence to operate is defined by the Australian Centre for Corporate Social Responsibility as the level of acceptance or approval continually granted to an organisation's operations or project by the local community and other stakeholders. Based on the principles of environmental justice, the environmental benefits and impacts of a resource recovery facility should be distributed proportionately and affected communities should be able to participate in decision making.

For waste and resource recovery planning in Victoria, this means the community must be involved in determining the waste and resource recovery priorities and have opportunities to participate in the decisions and long term planning to establish a safe, integrated waste and resource recovery system. The local community and other stakeholders must be properly engaged in a meaningful way and their concerns addressed.

Evidence from resource recovery procurements internationally indicates that public participation improves the quality of the decisions that are made by the procuring authority, although time, funds and expertise must be allocated to the engagement process for managing and solving conflicts between the procuring authority and stakeholders.

Stakeholder analysis is the process of systematically gathering and analysing qualitative information to determine whose interests should be taken into account when undertaking a procurement. At a minimum, a Working Group should identify people and organisations towards whom the procuring authority has legal, financial or operational responsibilities; people who are likely to be affected by the outcome of the procurement; and people who are likely to influence the procurement process and the success of the solution.

Stakeholders may be classified as community, statutory or strategic and can include residents, elected representatives, local government, government agencies (e.g. Sustainability Victoria, EPA, WorkSafe Victoria, etc.), non-governmental organisations (NGOs) and solution providers. Potential participants should be identified and brought into the procurement planning process as early as possible.

Stakeholders have different contributions to make and different involvement needs at each stage of the decision-making process. At different stages, involvement may take the form of sharing information, consulting, entering into dialogue with certain parties, or providing opportunity for stakeholders to deliberate on decisions.

A project-specific Stakeholder Engagement Plan will be required. A number of approaches have been found to be effective in gaining community buy-in to proposed resource recovery projects, which have included:

- › Good design practice that minimise the visual and traffic impacts associated with locating large-scale waste management and resource recovery facilities in urban areas.
- › The inclusion of district heating and cooling networks that provide financial and social benefits to the local community in terms of reduced domestic energy bills.
- › Promoting local ownership of a proposed resource recovery facility by enabling local residents to play a role in guiding the selection, deployment and management of the facility through a properly constituted steering group.
- › During operations, plant owners and managers should maintain regular contact with local residents and interested stakeholders and consider establishing regular communication forums such as community meetings and newsletters. Nearby residents should be provided with a contact number and other means to lodge complaints or suggest improvements.
- › Reference material:
 - › Metropolitan Waste and Resource Recovery Group (MWRRG) Community and Stakeholder Engagement Guide (2016)
 - › EPA guideline A Planning Process for Community Engagement (EPA Publication 1145.1, 2010)

6.3 Management of outputs and residues

6.3.1 Markets for products

Resource recovery solutions generate outputs and residues from the waste that they process. These outputs are ideally turned into saleable products. The viability of a particular type of technology is often predicated on the existence of a secure and sustainable market for the products that are recovered. Indeed, some of the technologies discussed in this Guide have not been widely employed in Victoria to date, not because of concerns about their technical viability, but because the end-markets for the products are not yet fully developed. Markets may be influenced by a number of factors including:

Markets for waste-derived materials	Markets for energy or fuel produced
<ul style="list-style-type: none"> › The market price for similar virgin materials › Macro-economic factors including global commodity price impacts and construction cycles › The quality of the recovered materials (particularly contamination levels) › The cost of transporting the materials to end-users or reprocessors. 	<ul style="list-style-type: none"> › The market price with existing energy sources or fuels (with or without government subsidies) › The cost and access to distribution networks › Quality requirements, such as Australian Standards or the quality required by engine and boiler manufacturers.

6.3.2 Disposal of process residues

Processing waste through a resource recovery facility leads to the inevitable generation of residues which will require management or disposal in accordance with Victorian Government regulations. This may mean that some residues have to undergo further treatment before they are sent to landfill. Disposal or treatment of process residues to landfill can represent a significant cost to the operator of the facility which needs to be factored into the business case analysis.

The principal residues from resource recovery facilities and disposal options are:

Principal residues	Current and emerging disposal options
<ul style="list-style-type: none"> › Bulky, oversize and hazardous items removed from the feedstock › Residues from sorting processes, including fines and dusts › Non-target materials such as inerts removed from RDF, or contamination from a clean MRF › Rejected feedstock or sub-standard products › Bottom ash from waste combustion and gasification facilities › Char from pyrolysis processes › Air pollution control residues (fly ash and residues from the cleaning of flue gases from thermal processes) › Liquid residues and wastewater streams 	<p>Current:</p> <p>Solids – most solid residues from sorting processes are sent to a non-putrescible landfill (e.g. solid inert wastes), putrescible landfill (e.g. wastes with non-hazardous organics), or hazardous landfill (e.g. air pollution control residues).</p> <p>Liquids – liquid waste streams will either need to be disposed to sewer under an appropriate trade waste agreement or sent for treatment at a suitably licensed facility.</p> <hr/> <p>Emerging:</p> <p>There are further processing and recycling options available for some residues, such as the recycling of bottom ash a construction or engineering product (well established internationally), recent advances in recycling technologies for air pollution control residues, and some processing residues may be appropriate for use as RDF.</p>

6.4 Procurement and ownership

This section looks at some of the considerations around procuring resource recovery solutions and ownership options. It is primarily aimed at local governments seeking to procure a resource recovery facility or service.

6.4.1 Collaborative procurement

While some resource recovery solutions are designed for small-scale applications, the cost efficiency and technical performance of most waste processing infrastructure improves as the scale of the facility increases. Procurement of a medium or large-scale resource recovery solution requires a longterm commitment, typically at least 10 years and possibly up to 20 or 25 years (for large MBT or waste to energy projects).

For councils considering procuring waste and resource recovery services, the benefits of working jointly with neighbouring councils includes:

- Larger volume of feedstock to offer the market, resulting in greater interest and competition in the procurement
- Critical mass of feedstock to support preferred processing technology
- Potential to attract more advanced processing solutions
- Reduced processing costs, translating to lower gate fees for councils
- Improved processing efficiency and product quality
- Diversity of feedstock sources, which reduces the risk of feedstock disruption or quality fluctuations
- A wider range of potential sites for the facility
- Increased likelihood of a new facility being constructed in the region, with associated economic benefits

Collaborative procurement groups also need to consider:

- The costs and infrastructure requirements associated with aggregating and transporting feedstocks from across the region to a centralised facility
- Community perceptions in the area hosting the processing facility, which will receive waste from other council areas, and potential additional approvals risk
- Governance arrangements for the procurement and contract management to minimise risks for all parties

In Victoria, the Regional Waste and Resource Recovery Groups (WRRGs) are the best vehicle to lead collaborative procurements of resource recovery solutions. The WRRGs have a statutory function to facilitate efficient procurement of waste and resource recovery services and infrastructure for their region in accordance with the Environment Protection Act 1970 (EP Act). The WRRGs can help councils undertake collaborative procurements that are consistent with the SWRRIP and applicable Regional Implementation Plans.

The Collaborative Procurement Guidelines for Regional Waste and Resource Recovery Groups⁴⁹ developed by SV is designed to help WRRGs work with councils to:

- Aggregate and consolidate their volumes of waste and material streams
- Procure waste and resource recovery infrastructure and services in a way that delivers economic and environmental benefits to communities
- Work towards achieving the strategic directions of the SWRRIP and Regional Implementation Plans
- Support good procurement practice and provide a structured and consistent approach to procuring joint contracts in Victoria.

6.4.2 Procurement options

Before commencing on a procurement process for a resource recovery solution, there are a number of critical steps:

- Setting an overall strategy which identifies the strategic need for the project and high level objectives, in the context of other council services and activities
- Reviewing technology options and collating relevant background data
- Developing a business case and outline project specification (Outline Specification)
- Development of a reference project against which to test the business case and assess possible technology solutions
- Seeking senior level sign-off and commitment to the project (Board or elected Councillors), prior to proceeding with a formal procurement phases.

The procurement process will depend on the complexity of the proposed technology and scale of investment / financial commitment. Small-scale or relatively low risk solutions could follow a simple one-step call for tenders. Large-scale, more complex projects which require a significant financial commitment and are outside the typical technical capabilities of council, will likely follow a multi-stage procurement process. This may commence with a call for Expressions of Interest to gauge the market capability and interest in the project or a less formal market sounding exercise (see Section 6.4.3 below). There may then be one or more formal tender stages in which the field of tenderers is progressively narrowed and the level of detail in submissions improved, until an acceptable proposal (best and final offer) is chosen.

The procurement by local government should follow the Victorian Local Government Best Practice Guidelines 201350, which provide a set of principles and practices to help guide the procurement process. Bidders will make a substantial investment in time, effort and money in preparing their bids and they will scrutinise the decisions that are made by the procuring authority. A legal challenge from an unsuccessful bidder may cause major delays and cost implications for the project, so it is important that the procurement process adheres to a project-specific probity plan that promotes transparency and reduces the risk that the selection process will be challenged during or after the procurement stage.

49 Collaborative Procurement Guidelines for Regional Waste and Resource Recovery Groups (Sustainability Victoria, 2015) <https://www.sustainability.vic.gov.au/-/media/resources/documents/services-and-advice/local-government/collaborative-procurement-service/collaborative-procurement-guidelines-for-rwrrg-nov-2015.pdf>

50 Available to <https://www.localgovernment.vic.gov.au/strengthening-councils/procurement>

6.4.3 Working with solution providers

Prior to procuring a resource recovery solution, it is important that councils are well informed about the different technologies available and their characteristics, and the capabilities of contractors in the local market. Councils should be cautious about settling on a particular technology or solution prior to procurement, or being overly prescriptive in the tender specification, as this may preclude offers of innovative technical or commercial solutions. Tender specifications should focus on overall objectives and desired outcomes, rather than specifying how they should be achieved.

To become better informed, councils can refer to resources such as this Guide and the other references detailed in Section 7 of this guide. Professional advice and support should be sought from the WRRGs, SV and experienced consultants where necessary.

The other way to become informed about market capabilities is to undertake a soft-market testing or market sounding process. This can be done by council directly by issuing a call for Expressions of Interest of market sounding request for information. Alternatively, an independent consultant could be engaged to consult with the market on council's behalf.

Factors that may influence the market's interest in resource recovery solutions in Victoria include:

- Fluctuations in international exchange rates, which may introduce uncertainty into the pricing of any capital equipment sourced from overseas, with bidders seeking to price this risk into their proposals
- A lack of local knowledge may mean that 'off-the-shelf' technology solutions may not meet the requirements of applicable Australian standards, leading to delays while equipment is modified and subsequently approved by the appropriate regulator
- Limited awareness of potential subcontractors / partners to undertake the necessary construction works
- Limited understanding of local markets for process outputs (energy / recyclables).

Consultation with potential providers prior to a formal procurement process gives an opportunity to address some of these barriers. Noting that a significant proportion of specialist providers of resource recovery solutions are based overseas and only a small number have established a presence or have partner companies in Australia. Consequently many providers are likely to have only a limited understanding of Victoria's planning and environmental regulations, which may lead to delays as proponents acquaint themselves with the local requirements. This should be factored into the procurement process and the information that is provided to prospective tenderers.

6.4.4 Contract arrangements

A variety of contract arrangements can be established to cover the deployment and operation of a resource recovery solution, depending on the customer's risk appetite, technical capability and ability to fund the project:

- One contract for design and build of the facility, and a separate contract for the operation and maintenance of the solution (D&B contract + O&M contract) with council ownership
- A single contract that covers the design, build, operation and maintenance of the solution for a set term, with council funding and owning the asset
- A single contract for design, build, operation, maintenance and financing of the solution (build-own-operate) which may then be transferred to the council at the end of the contract period (build-own-operate-transfer)
- A service contract where a council engages a contractor to provide the resource recovery services, without specifying where or how that should occur, giving the option for the contractor to use an existing facility or build a new one
- Joint venture or alliance models, where council and the contractor agree to work in partnership, possibly through a separate jointly owned company, to deliver and operate the project with full sharing of funding and project risks.

The build-own-operate is the most common contract arrangement for large-scale or complex resource recovery projects that require specialist expertise and a significant capital investment.

When selecting a contract model for a resource recovery solution it may be necessary to consider how existing assets, for example transfer stations, recycling centres, and collection fleets, will be accommodated by the new arrangements. In some circumstances sites, fixed assets and equipment may be leased to the contractor, in other instances these items may be replaced. Similar considerations may also apply to existing waste and resource recovery personnel.

Choosing the right contract model is primarily a question of allocating project risks (see Section 6.5 on risks) to the party that is best placed and capable of managing them. It can have a major impact upon the success of a resource recovery solution. In addition to setting out how the councils requirements are going to be met over the contract term, the contract provides the best means of determining how the risks associated with delivering the contract will be shared between the councils and the contractor, for example:

Risks managed by contractor	Risks managed by council	Shared risks
Facility design, construction, commissioning and operation are best managed by the contractor as it will have a stronger technical understanding and control of the issues.	Local government is better positioned to manage and influence risks associated with political change, changes in legislation, and certain aspects related to stakeholder engagement and community concerns	<p>Risks associated with the sale of recovered materials and energy can be shared between the councils and the contractor/s.</p> <p>In order to benefit from the upsides of the deal – e.g. when markets for recovered material are strong and prices are high – both parties should also be prepared to take some of the downside when markets weaken and prices fall.</p>

6.4.5 Bankability of resource recovery solutions

'Bankability' is the term used to describe the extent to which a technology solution can attract the necessary investment funding. Financial investment may come from a number of sources including:

- › **Direct funding** – by council or a private contractor from existing capital resources.
- › **Debt** – funding made available by financial institutions (e.g. banks) in the form of a time-limited loan that has to be repaid. Debt funding usually has associated costs which include administration costs for setting up the loan; and interest payments on the loan. For some solutions (e.g. energy recovery), low interest debt funding may be available from bodies such as the Clean Energy Finance Corporation (CEFC).
- › **Equity** – funding that is obtained through the issue of shares in the commercial venture to shareholders who bear some of the financial risk of the project and in return receive an annual payment (dividend) that is taken from the operating profits of the venture. Shareholders exercise control over the venture through an appointed board of directors.
- › **Capital grants** – funding that may be made available from the public purse (e.g. by the State or Federal Government) to support investment in infrastructure for the public good, without an expectation of repayment.

The bankability of a particular technology and project is influenced by a range of factors such as:

- › The commercial track record of the technology in similar applications
- › The experience and track record of the main contractor and partners
- › The commercial viability of the project, including:
 - Contracts for the supply of waste
 - Certainty of gate fees
 - Certainty in capital and operating costs (see below)
 - The availability and the strength of markets for recovered materials and energy
- › Other factors may also be considered, such as political risks and the impact of future policy changes on the project viability.

Capital costs

The capital cost of deploying a resource recovery facility is determined by a number of factors, including:

- › The scale of the proposed facility (in terms of the installed processing capacity)
- › The complexity of the technology
- › The investment required to manage emissions to the environment
- › Architectural treatment of the facility to address any concerns about adverse impact on the visual landscape
- › Site specific factors, such as the cost of land and site preparation works
- › Exchange rates for equipment manufactured overseas
- › The cost of labour to construct the facility, which may be affected by construction industry cycles.

Realistic capital costs (capex) for resource recovery facilities can only be obtained through the receipt of tenders as part of a procurement exercise and are usually only provided by bidders during the 'best and final offer' stage of the process when the scope and boundaries are clearly defined.

Capex costs vary significantly between different technologies and even between different technology providers supplying broadly similar solutions, due to variations and differences in the pre-treatment modules that are required by the technology and feedstock; and the cost of emissions reduction equipment (particularly in the case of energy recovery technologies).

Operating costs

Realistic operating costs (opex) for different types of resource recovery facilities can only be obtained through a tender process, and generally include:

- › Labour costs and overheads
- › Operation, maintenance (O&M) and life cycle replacement costs
- › Process consumables, including supplementary fuel that may be required for the start-up of energy recovery facilities
- › Treatment and disposal of process outputs
- › Interest payments, amortisation of capital loans, and payment of dividends to shareholders
- › Contingency.

It is usual for the procuring authority (a council or cluster of councils) to specify their performance requirements for the contract across a range of aspects, which can have a significant impact on the operating costs, which are then passed through in the gate fee or service charge to council.

Revenues

There are three principal sources of revenue available resource recovery solutions:

- › Income from gate fees that are charged to receive waste
- › Revenue from the sale of recovered recyclables
- › Revenue from the sale of energy products (e.g. electricity, heat, or process steam).

For the majority of resource recovery solutions, gate fees provide the primary source of revenue and in this respect resource recovery solutions compete directly with landfills, although resource recovery solutions have the advantage that the landfill levy is not payable on waste diverted by recovery facilities.

6.5 Managing risks

This section provides an overview of approaches and considerations for managing a range of risks associated with a resource recovery project.

6.5.1 Identifying Project Risks

The table below summarises some of the key project risks which should be considered and assessed, to differing extents, in any resource recovery project. It is not an exhaustive list and certain technologies will present their own specific risks that need to be managed.

TABLE 28 OVERVIEW OF PROJECT RISKS TO BE CONSIDERED

Risk type	Example issues to consider
Procurement	<ul style="list-style-type: none"> › Tender specification risks, not being too limited / prescriptive › Collaboration between councils › Market competition › Probity risks, evaluation challenges › Educating / informing elected Councillors
Feedstock supply	<ul style="list-style-type: none"> › Security of feedstock volumes over the life of the project (contracted and/or merchant) › Diversity of feedstock sources › Impact of other recycling / recovery programs on future feedstock › Competition with other existing / future RR projects › Gate fee and competitiveness with alternatives (inc landfill)
Licensing and approvals	<ul style="list-style-type: none"> › Obtaining necessary approvals › Receiving Licence › Delays in approvals › Community opposition / political interference › Challenging or costly conditions on approval / licence
Feedstock quality / composition	<ul style="list-style-type: none"> › Understanding feedstock composition and its impact on the process (e.g. calorific value for thermal processing, impacts on biological processes) › How composition is likely to change over time and impact on the process efficiency and performance › What are the feedstock quality requirements and limitations › Ability to control feedstock quality within required limits
Technology and process	<ul style="list-style-type: none"> › Track record of chosen technology › Capability of main contractor in delivering technology › Process performance risks › Local technical support › Contingency options if process fails / underperforms › Risk of solution being superseded by new technologies
Capacity	<ul style="list-style-type: none"> › Matching plant capacity to future needs / volumes over the plant life › Flexibility to increase / decrease throughput
Product quality and markets	<ul style="list-style-type: none"> › Product quality management › Volatility in product / commodity prices › Market development risks
Energy markets	<ul style="list-style-type: none"> › Volatile energy price risks › Potential upsides from government incentives › Future government carbon / energy policy changes
Residues	<ul style="list-style-type: none"> › Residue management / disposal and associated costs

Risk type	Example issues to consider
Community and social	<ul style="list-style-type: none"> › Community acceptance of proposed solution › Approvals risk for controversial proposals › Ongoing operational stakeholder risks › Reputational risks
Financing	<ul style="list-style-type: none"> › Ability to secure finance under affordable / acceptable terms › Funders view on bankability of the project › Grant funding and associated conditions
Design	<ul style="list-style-type: none"> › Process design risks › Design for efficient operations / life cycle costs › Compliance with Australian Standards
Construction	<ul style="list-style-type: none"> › Risks of unforeseen issues during construction › Construction timeline / delay risks
Commissioning	<ul style="list-style-type: none"> › Commissioning and testing risks
Operations and maintenance	<ul style="list-style-type: none"> › Ability to optimise and improve the process performance › Labour costs › Energy and consumables costs › Maintaining expected performance over the full life of the project › Maintenance costs including life-cycle replacement and major refurbishments during project term
Health and safety	<ul style="list-style-type: none"> › Manual waste handling / sorting risks › Fire and explosion risks › Exposure to hazardous substances › High temperature / pressure environments › Site security
Regulatory and compliance	<ul style="list-style-type: none"> › Compliance with Licence conditions and environmental regulations › Compliance with regulations across OHS, employment, gas / electricity infrastructure, dangerous goods, etc › Risk of future changes in regulation
Biosecurity risks	<ul style="list-style-type: none"> › For movement of organic waste feedstocks and recovered organic products, pasteurisation performance
Subcontractor management	<ul style="list-style-type: none"> › Sourcing capable subcontractors / suppliers › Performance of subcontractors and suppliers › Managing interface risks between work packages
Decommissioning	<ul style="list-style-type: none"> › Cost of dismantling / removing the plant › Site contamination impacts and costs

6.5.2 Mitigating Project Risks

One of the main ways by which the procuring council (or other customer) manages many of the project risks is by engaging a capable contractor who has the experience and resources to mitigate the risks, and allocating those risks to that party through the contract terms (see Section 6.4.4 Contract arrangements).

The choice of contract and delivery model for the project therefore, should be made based on an assessment of the project risks and a realistic assessment of council's capability to manage and mitigate those risks.

A detailed assessment of risks should be undertaken by both council (in the pre-procurement phase) and the contractor in the tender phase. Details on identified risks and proposed mitigation measures should be part of the submissions during the tender process.

The risk assessment and mitigation measures then need to be continually updated throughout the design, construction, commissioning and operational phases to ensure they remain current and relevant.

6.5.3 Assessing Technology Risks

Technology risks are particularly pertinent to the discussion in this Guide. Once a technology has been chosen or a shortlist of technologies developed, the technology risks can be assessed through a variety of means including:

- › Review the project references and identify whether there are similar operating, commercial plants which are similar in scale and feedstock type to the proposed project
- › Contact the customers of relevant reference plants to get feedback on the technology / supplier performance
- › Consider visiting and inspecting a selection of reference plants where possible
- › Review the key performance parameters of the plant and benchmark them against similar plants by other providers
- › Review the process performance guarantees being offered (if any) and associated caveats and limitations
- › Consider engaging an experienced consultant to undertake a technology due diligence assessment which covers the items above, amongst other aspects

7 Sources of further information

This Section contains links to additional information, covering:

- Guidance
- Publications by Sustainability Victoria and Regional WRRGs
- Legislation
- Regulations and policies
- Australian standards
- Other sources of information

If you need help with any of the contents of this Guide or have additional questions, please contact Sustainability Victoria on +61 3 8626 8700.

Source, Title (Year)	Description, Link
SV, Regional WRRG and other publications	
Sustainability Victoria, Statewide Waste and Resource Recovery Infrastructure Plan (SWRRIP) (2015)	Victoria's 30-year state waste plan which provides a long-term vision and roadmap to guide future planning for waste and resource recovery infrastructure in the state. http://www.sustainability.vic.gov.au/our-priorities/statewide-waste-planning/2015-2020-priorities/statewide-waste-and-resource-recovery-infrastructure-plan
Sustainability Victoria, Victorian Organics Resource Recovery Strategy (2015)	This strategy is a key priority of delivering the 30 year SWRRIP. It provides a strategic statewide approach for government, business/industry and the community to better manage organic waste. http://www.sustainability.vic.gov.au/organicsstrategy
Sustainability Victoria, Victorian Market Development Strategy for Recovered Resources (2016)	This strategy is a key priority of delivering the 30 year SWRRIP. It has been developed to support initiatives to stimulate markets for the use of recovered materials. http://www.sustainability.vic.gov.au/our-priorities/statewide-waste-planning/2015-2020-priorities/victorian-market-development-strategy-for-recovered-resources
Sustainability Victoria, Victoria's Waste & Resource Recovery Infrastructure Investment Prospectus (2015)	The Prospectus presents significant opportunities for waste and resource recovery infrastructure in Victoria. In particular, the document highlights the principle material streams, which includes organic waste, which are of importance to the state. http://www.sustainability.vic.gov.au/services-and-advice/business/investment-facilitation-service
The seven Regional Waste and Resource Recovery Implementation Plans (2017)	The Regional Implementation Plans (one each for the seven Waste and Resource Recovery Groups, WRRGs), outline the waste and resource recovery infrastructure, service needs, and how these can be met over at least the next 10 years for each region. http://www.sustainability.vic.gov.au/our-priorities/statewide-waste-planning/2015-2020-priorities/regional-waste-and-resource-recovery-implementation-plans
Sustainability Victoria, Collaborative Procurement Guidelines for Regional Waste and Resource Recovery Groups (2015)	These guidelines are designed to support good procurement practice and provide a structured and consistent approach to procuring joint contracts for waste and resource recovery services and infrastructure by the WRRGs and councils in Victoria. https://www.sustainability.vic.gov.au/-/media/resources/documents/services-and-advice/local-government/collaborative-procurement-service/collaborative-procurement-guidelines-for-rwrrg-nov-2015.pdf
Sustainability Victoria, Victorian Waste Education Strategy (2016)	This strategy is a key priority of delivering the SWRRIP. It provides a consistent and coordinated approach to waste and resource recovery education. http://www.sustainability.vic.gov.au/our-priorities/statewide-waste-planning/2015-2020-priorities/victorian-community-and-business-waste-education-strategy

Source, Title (Year)	Description, Link
MWRRG, Community and Stakeholder Engagement Guide (2016)	<p>This guide has been developed to assist the waste and resource recovery sector to deliver meaningful and successful community and stakeholder engagement and delivers on one of the key actions outlined in the aforementioned Waste Education Strategy. The guide explains why community engagement is important in waste projects; principles that can be used to guide community engagement activities; best practice engagement planning; and engagement methods, templates and tips for site operators and project proponents.</p> <p>https://www.mwrrg.vic.gov.au/engagement/community-and-stakeholder-engagement-guide/</p>
EPA Victoria, A Planning Process for Community Engagement, publication 1145.1 (2010)	<p>EPA Victoria has developed a generic guideline on planning for community engagement which outlines the steps in developing a Community Engagement Plan. If a project is subject to an approval under environment and planning legislation (see Section 6.1.3), engagement with the community is usually mandatory.</p> <p>http://www.epa.vic.gov.au/our-work/publications/publication/2010/march/1145-1</p>
Sustainability Victoria, Kerbside Organics Collection guidance (2017)	<p>High level overview of kerbside organics collection options with links to more detailed guidance and selected case studies</p> <p>http://www.sustainability.vic.gov.au/services-and-advice/local-government/improving-kerbside-waste-and-recycling/kerbside-organics-collection</p>
Legislation and Regulations	
Environment Protection Act 1970	<p>The Environment Protection Act 1970 is a key legislative tool used in Victoria to protect the environment. Subordinate legislation under the Act includes: state environment protection policies or SEPPs for specific segments of the environment such as air, noise and groundwater; waste management policies governing the management of specific wastes and, environment protection regulations.</p> <p>Organics processing facilities must comply with relevant environmental protection legislation, policies and regulations. Facilities should also be consistent with the local and regional waste management plans relevant to their location.</p> <p>This Act is currently under review (at the time of writing).</p> <p>http://www.epa.vic.gov.au/about-us/legislation/acts-administered-by-epa#EPAAct</p>
Occupational Health and Safety Act 2004	<p>The Occupational Health and Safety Act 2004 covers the health and safety responsibilities, roles and rights of everyone involved in making workplaces safer. It is relevant to employers, those who manage and control workplaces, employees, manufactures and suppliers.</p> <p>http://www.worksafe.vic.gov.au/pages/forms-and-publications/forms-and-publications/occupational-health-and-safety-act-2004-summary</p>
Environment Protection (Scheduled Premises) Regulations 2017	<p>The Environmental Protection (Scheduled Premises and Exemptions) Regulations 2017 prescribe the premises that are subject to works approval and/or licensing by EPA, and provide for exemptions in certain circumstances. They provide a means to effectively manage these premises in a transparent way, which ensures an adequate level of community confidence is maintained.</p> <p>http://www.epa.vic.gov.au/about-us/legislation/regulations#Scheduled</p>
Environment Protection (Industrial Waste Resource) Regulations 2009.	<p>The Environment Protection (Industrial Waste Resource) Regulations 2009 provides schedules of prescribed waste. These are wastes that pose environmental, health and amenity risks and cannot be managed through conventional landfilling.</p> <p>These Regulations are currently under review (at the time of writing).</p> <p>http://www.epa.vic.gov.au/about-us/legislation/regulations#Scheduled</p>

Source, Title (Year)	Description, Link
Occupational Health and Safety Regulations 2017 (OHS Regulations)	<p>The OHS Regulations are made under the Occupational Health and Safety Act and prescribe what an employer must do to comply with the OHS Act duties and provide the foundation for Victorian businesses to deliver successful health and safety outcomes. They provide a range of duties and requirements about how work should be conducted around common workplace hazards and activities.</p> <p>https://www.worksafe.vic.gov.au/news/notices/ohs-regulations-reform-2017</p>
Regulatory Guidelines and Policies	
EPA Victoria, Demonstrating Best Practice, publication 1517 (2013)	<p>This guideline outlines how EPA assesses best practice and provides guidance on how to demonstrate compliance with best practice requirements.</p> <p>http://www.epa.vic.gov.au/our-work/publications/publication/2013/february/1517</p>
EPA Victoria, Recommended Separation Distances for Industrial Residual Air Emissions, publication 1518 (2013)	<p>Guideline on separation distances for industrial residual air emissions. EPA will assess the necessary separation distances required for resource recovery facilities with potentially significant emission profiles (thermal technologies) on a case by case basis using the methodologies set out in the guideline.</p> <p>http://www.epa.vic.gov.au/our-work/publications/publication/2013/march/1518</p>
EPA Victoria, Designing, Constructing and Operating Composting Facilities, publication 1588.1 (2017)	<p>This guideline outlines how the Environment Protection Act 1970 and associated policies and Regulations are applied to the assessment of proposals for thermophilic, aerobic composting. This guideline also provides advice on separation distances for composting facilities.</p> <p>http://www.epa.vic.gov.au/our-work/publications/publication/2017/june/1588-1</p>
EPA Victoria, Energy from Waste Guideline, publication 1559 (2013)	<p>This guideline outlines how the Environment Protection Act 1970 and associated policies and Regulations are applied to the assessment of proposals that recover energy from waste.</p> <p>http://www.epa.vic.gov.au/our-work/publications/publication/2013/december/1559</p>
EPA Victoria, Research, Development and Demonstration (RD&D) Approval Guideline, publication 1369.6 (2016)	<p>The RD&D approvals guideline supports occupiers of a scheduled premises (or a premises that would become scheduled with the installation of the proposed project) with a simple, specific approval procedure for genuine RD&D projects that would otherwise require works approval. Approvals are granted (or refused) within 30 days.</p> <p>http://www.epa.vic.gov.au/our-work/publications/publication/2016/july/1369-6</p>
EPA Victoria, Approvals Proposal Pathway, publication 1560.2 (2017)	<p>The approvals pathway guideline supports approval applicants to complete the approvals proposal form and pathway form, which includes assistance with applying for exemptions, fast track works approval, standard works approval and Research, Development and Demonstration (RD&D) approvals.</p> <p>http://www.epa.vic.gov.au/our-work/publications/publication/2017/june/1560-2</p>
EPA Victoria, Works Approval Assessment Process – information bulletin, 1657 (2017)	<p>This publication provides an overview of the works approval process. It does not provide detail on what is required in a works approval application (refer to publication 1658 below), but provides a high level of the process, including post decision processes.</p> <p>http://www.epa.vic.gov.au/our-work/publications/publication/2017/june/1657</p>
EPA Victoria, Works Approval Application Guideline, publication 1658 (2017)	<p>This guideline explains what information is required in a works approval application, and caters for all applications, ranging from a simple proposal through to highly complex ones.</p> <p>http://www.epa.vic.gov.au/our-work/publications/publication/2017/june/1658</p>
EPA Victoria, Scheduled Premises Prompt Sheets, publication 1659 (2017)	<p>This publication provides prompt sheets for a number of scheduled categories, which includes waste treatment, disposal and recycling, and Schedule A07 – Organic Waste Processing (as defined in the guidelines). It lists common operational activities, potential environmental impacts and examples of best practice for pollution controls from such facilities.</p> <p>http://www.epa.vic.gov.au/our-work/publications/publication/2017/june/1659</p>

Source, Title (Year)	Description, Link
EPA Victoria, Licence Management Guidelines, publication 1322.7 (2016)	<p>This guideline provides assistance to the licence-holder to understand and manage their licence by providing guidance on things to consider when complying with your licence and demonstrating compliance.</p> <p>http://www.epa.vic.gov.au/our-work/publications/publication/2016/september/1322-7</p>
EPA Victoria, Licence Assessment Guidelines, publication 1321.2 (2011)	<p>This guideline provides information to licence-holders of single-site, corporate and accredited licences on how to establish an appropriate monitoring program.</p> <p>http://www.epa.vic.gov.au/our-work/publications/publication/2011/june/1321-2</p>
Australian Standards	
AS4454: Australian Standard for Composts, Soil Conditioners and Mulches (2012)	<p>This Standard specifies requirements for organic products and mixtures of organic products that are to be used to amend the physical and chemical properties of natural or artificial soils and growing media. It applies to organic products and mixtures of organic products that have been treated by pasteurizing or composting procedures as defined by the Standard</p> <p>https://infostore.saiglobal.com/store/Details.aspx?ProductID=1512286</p>
International Standards	
ISO15270 Plastics – Guidelines for the recovery and recycling of plastics waste (2008)	<p>The international standard ISO 15270:2008 Plastics – Guidelines for the recovery and recycling of plastics waste was developed to assist plastics industry stakeholders in the development of infrastructure for plastics recovery and recycling and sustainable markets for recovered plastics materials and their derived manufactured products. The standard establishes the different options for the recovery of plastics waste arising from pre-consumer and post-consumer sources.</p>
Other sources of information	
DEFRA Energy from waste: A guide to the debate (2014)	<p>This guide was published by the UK Department of Environment, Food and Rural Affairs (DEFRA) to inform ongoing debate about future of EFW in the UK.</p> <p>https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/284612/pb14130-energy-waste-201402.pdf</p>
Bioaerosol emissions from waste composting and the potential for workers' exposure (2010)	<p>This study, funded by the UK Health and Safety Executive (HSE) and Environment Agency was undertaken with an aim of measuring bioaerosol emissions from a representative range of commercial UK composting facilities. The report provides data that could be used by composting facilities to better understand the likely bioaerosol emissions and therefore exposure controls that could be applied for such facilities</p> <p>http://www.hse.gov.uk/research/rrpdf/rr786.pdf</p>
Commonwealth Department of Environment and Energy, Food and Garden Waste Best Practice Collection Manual (2012)	<p>A step-by-step guide to planning and implementing a food and garden waste collection service, prepared by Hyder Consulting (now Arcadis)</p> <p>http://www.environment.gov.au/protection/national-waste-policy/publications/food-and-garden-organics-best-practice-collection-manual</p>
Tyre Stewardship Australia, Best Practice Guidelines on Tyre Storage and Fire and Emergency Preparedness (2017)	<p>The Best Practice Guidelines on Tyre Storage and Fire and Emergency Preparedness provides industry with guidance on the best practice and regulatory requirements for tyre storage and emergency preparedness (for each state and territory) in order to raise awareness, encourage compliance, and reduce the environmental and OHS risks associated with management end-of-life tyres in Australia.</p> <p>http://www.tyrestewardship.org.au/tsa-knowledge/tyre-storage-guidelines</p> <p>The TSA website also contains other information relevant to tyre recyclers – http://www.tyrestewardship.org.au/</p>

