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PACIFIC WASTE MANAGEMENT
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Assessment of Small-Scale Technology Suitable for Waste Management in the Pacific and Timor-Leste

November 2020

This report provides details of available small-scale waste management technology options that are suitable for use in the Pacific region and remote communities to manage waste and the viability of each technology in the project countries given the unique geographical settings

Author Credit:

ACCENT ENVIRONMENTAL

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Abbreviations

Acronym	Meaning
ACW	asbestos containing wastes
AD	anaerobic digestion
BAN	Basal Action Network
CA	criteria asbestos
CH	criteria healthcare waste
CO	criteria organic waste
CR	criteria recyclables
DAF	dissolved air flotation
€	Euro
EC standards	European Commission standards
EfW	energy from waste
ESS	environmental and social sustainability
FOGO	food organics and garden organics
GPT	gross pollutant trap
HDPE	high-density polyethylene
LDPE	low-density polyethylene
LLDPE	linear low-density polyethylene
MSW	mixed solid waste
NPDES	National Pollutant Discharge Elimination System
PET	polyethylene terephthalate
PP	polypropylene
PS	polystyrene
SPREP	Secretariat of the Pacific Regional Environment Programme
Tpa	tonnes per annum
US$	United States dollars
USEPA	United States of America Environmental Protection Agency

Glossary

Term	Definition
Alkaline hydrolysis	A process for the disposal of human and pet remains using a combination of water and potassium hydroxide (lye) to decompose bodies.
Anaerobic processes	Occurs in the absence of free or combined oxygen, and result in sulfate reduction and methanogenesis.
Aerobic digestion	The biochemical oxidative stabilisation of wastewater sludge in open or closed tanks that are separate from the liquid process system.
Asbestos	Six naturally occurring silicate minerals. All are composed of long and thin fibrous crystals; each fibre being composed of many microscopic 'fibrils' that can be released into the atmosphere by abrasion and other processes.
Autoclave	A pressure chamber used to carry out any process that requires a highly elevated temperature and pressure, such as medical waste disposal, and/or medical equipment sterilisation.
Biochar	A charcoal material generated from biomass via pyrolysis. It is used as a soil amendment for both carbon sequestration and soil health benefits. It is generated from biomass via pyrolysis.
Biogas	A mixture of mostly methane and carbon dioxide produced by anaerobic processes.
Bioleaching/ biometallurgy	A process that uses microbes to extract metals (e.g. from e-waste).
Bulky waste	Wastes that are too large to be accepted by regular waste collection services.
Clarifiers	Settling tanks built with mechanical means for continuous removal of solids being deposited by sedimentation.
Clinical waste	Any waste resulting from medical, nursing, dental, pharmaceutical, skin penetration or other related clinical activity.
Stock cultures	A culture of a microorganism maintained solely for the purpose of keeping the microorganism in a viable condition.
Cytotoxic agents	Cytotoxic drugs or cytostatics (also cytotoxic chemotherapy) are drugs used to destroy cancer cells. Cytotoxic drugs inhibit cell division and in this way cause cells to die.
Disaster waste	Waste resulting from catastrophic disaster events including earthquakes, floods and tsunamis.
Effluents	Liquid waste or sewage discharged into a river or the sea.
Enzymes	Biological molecules, typically proteins that work as catalysts speeding up chemical reactions.
Emissions	gaseous discharges into the atmosphere or liquid discharges to land or water.
E-waste	Discarded electrical or electronic devices.
Healthcare waste	Waste generated from diagnosis, treatment and immunisation of humans or animals.
Hypochlorites	Hypochorite is an anion with the chemical formula ClO^-. It combines with certain cations to form hypochlorites. Common examples include sodium hypochlorite and calcium hypochlorite.

Term	Definition
Hydrometallurgy	The use of chemicals such as acids or cyanide to leach metals from e-waste components.
Gasification	The conversion of organic- or fossil fuel-based carbonaceous materials into carbon monoxide, hydrogen, and carbon dioxide.
Irradiation	The use of ionising radiation to destroy micro-organisms.
Mechanical processes	Processes used to break up materials such as shredders, mixing arms, or compactors.
Organic waste	Wastes which consist of materials that are biodegradable and have the potential to disintegrate.
PacWastePlus Programme	Pacific Hazardous Waste Management Programme.
Pathological waste	Waste which consists of recognisable human derived tissues, organs, and body parts as well as vertebrate animal derived tissues, organs, and body parts used in research.
Pyrogas	The gas resulting from pyrolysis.
Pyrolysis	The thermal decomposition of materials at elevated temperatures in an inert atmosphere.
Pyrometallurgy	The branch of science and technology concerned with the use of high temperatures to extract and purify metals
Recyclables	Waste materials that can easily be recovered or made into other products.
Stoichiometric reaction	A chemical reaction in which the quantities of the reactants and products are such that all of the reactants are consumed, and none remain after completion of the chemical reaction.
Sub-stoichiometric reaction	A chemical reaction involving less than the stoichiometric amount of a reagent.
Syngas	Or synthesis gas, is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and very often some carbon dioxide.
Vitrification	The transformation of a substance into glass.
Volatile and semi-volatile	Easily evaporates at room temperature.
Windrow system	The production of compost by piling organic matter or biodegradable waste, such as animal manure and crop residues, in long rows.

Executive Summary

The Secretariat of the Pacific Regional Environment Programme (SPREP) engaged Accent Environmental (Accent) to undertake a literature review and desktop assessment of small-scale waste management technologies and provide PacWastePlus participating countries with information to assist with any technology investigations they may be planning.

The research sought to increase understanding of:

- available small-scale waste management technology options that are suitable for use in the Pacific region and remote communities to manage waste
- the viability of each technology in the project countries given the unique geographical settings.

An investigation of technology options and providers was undertaken for eight priority waste streams (healthcare waste, e-waste, asbestos, recyclables, organic waste, disaster waste, bulky waste and water impacted by solid waste) as identified by the PacWastePlus programme. The technologies under investigation are to be capable of assisting with the management of one or more of the waste streams.

Technologies were selected for consideration based on a combination of the experience and contacts of Accent supported by literature review. Many technologies were also selected in consultation with SPREP. Questionnaires seeking information were sent to almost 120 technology providers. However, there are many waste technologies globally that employ reuse, recycling, segregation, handling, storage, treatment, volume reduction and disposal methods for the waste streams covered in this study and it was not possible to contact a comprehensive list of technology providers. Thirty companies responded to the request for information.

The scope of technologies investigated was limited to those capable of managing the priority waste streams which are the focus of the PacWastePlus programme.

For each waste stream (where appropriate) and relevant type of technology, the following was outlined:

- **Context**
- **Name and description of the technology types**
- **Rationale behind any initial screening (such as 'technology at research stage/not proven')**
- **Shortlisting of technology classes (pros, cons and unknowns, taking into account the assessment criteria)**
- **Conclusions regarding most prospective types.**

An assessment was then undertaken of specific technologies at the technology provider level against ten criteria using an assessment matrix. The criteria included:

- **Operational**
- **Financial**
- **Environmental**
- **Community considerations**

The technologies assessed using the matrix are all considered to have some potential applicability for improved waste management in the Pacific island region.

Ultimately, the determination of whether a technology is applicable to the Pacific region will be based on feasibility analysis relating to specific projects.

Introduction

The Secretariat of the Pacific Regional Environment Programme (SPREP), with funding assistance from the European Union, is implementing the *European Union - Pacific Hazardous Waste Management (PacWastePlus) programme*, which seeks to improve and enhance waste management activities and the capacity of governments, industry and communities to manage waste to reduce the impact on human health and the environment.

The European Union-funded PacWastePlus programme is one of several regional initiatives being implemented to deliver the *Cleaner Pacific 2025: Pacific Regional Waste and Pollution Management Strategy 2016–2025*. This strategy is a comprehensive long-term approach for integrated sustainable waste management and pollution prevention and control in the Pacific region until 2025. It provides a strategic management framework to address waste, chemicals and pollutants that will reduce associated threats to sustainable development of the region.

This research was undertaken to gain an understanding of:

- available small-scale waste management technology options that are suitable for use in the Pacific region and remote communities to manage waste
- the viability of each technology in the project countries given the unique geographical settings.

This report:

- summarises the most appropriate waste management technologies with consideration to the inherent constraints of the Pacific island region. The waste streams investigated are:
    - **Hazardous Waste**: Health care waste, E-waste, Asbestos
    - **Solid waste**: Recyclables, Organic waste, Disaster waste, Bulky waste
    - **Wastewater**: Water impacted by Solid Waste
- outlines the context, methodology adopted
- presents the key findings and recommendations.

This research focused on investigating the range of technology options and providers for the priority waste streams. The technologies identified were deemed capable of assisting with the management of one or more of the priority waste streams.

The information obtained has been presented in a series of spreadsheets and matrices appended to this report.

Methodology

The research undertook on a literature review to assess the available small-scale technology options that can achieve safe and sustainable management of waste within the unique geographic settings of the Pacific region.

When considering waste management technologies in the Pacific, emphasis was placed on identifying proven, practical, and affordable technologies that will need to negotiate a range of local conditions and factors, including:

- climatic conditions (e.g. high humidity, exposure to salt air/water)
- geographic factors such as remoteness, isolation, rugged terrains, low-lying terrains
- disaster events including cyclones, tsunamis, earthquakes, and volcanic eruptions
- irregular power or limited power (e.g. availability of 3-phase power, unreliable power)
- limited economic resources
- potentially limited local technical knowledge and experience
- limited availability of technical parts (typically long lead times to receive delivery)
- irregular shipping/import and export schedule
- variability in population in settlements and countries (from small remote villages to large metropolitan centres)
- variability in cellular network range and access to internet.

The investigation focussed on identifying proven, practical, and affordable technologies suitable for the range of local conditions and factors in the Pacific region, and whether it can process the one or more of the eight priority waste streams of the PacWastePlus programme.

The ethos of the investigation has identified technologies and providers that can offer solutions to support behaviours and activities to reduce, reuse, recycle, recover and dispose (as the last resort) in the Pacific region.

The technologies discussed, and companies referenced are not an exhaustive list, but represent those able to be appropriately researched during the research period.

Data Collection

The research methodology was based on desktop investigation and was guided by the provision of questionnaires to relevant waste management technology providers. The research was guided and directed by the existing knowledge and experience of the Accent project team, supplemented by inputs of regional context from the SPREP team.

The desktop investigation of waste technologies drew upon the following resources:

- international knowledge of the project team
- previous work completed by the project team related to small scale anaerobic digestion (AD), plastics to energy, biochar production, small scale solutions for clinical wastes, small scale solutions for food organics and garden organics (FOGO)
- literature read by the team such as national and international waste management journals
- other international surveys or compilations of information on waste management technologies
- information from technology directories
- affiliations with waste management associations
- relationships with technology providers
- internet search

The work considered the following key characteristics of technology options:

- inputs
- outputs
- operating requirements
- cost
- evidence of performance

Criteria were developed that enabled the assessment of questionnaires, highlighting certain technologies that may exceed the upper cost limit and are not yet commercially deployed, etc.

In addition to the proven, practical and affordable nature of the technologies, emphasis was placed on the environmental performance of the technology itself and the nature of environmental and social benefits achieved by improved management of the particular waste stream(s) it treats.

Due to time limitations, less emphasis was placed on technologies used to store, handle, and prepare recyclables (e.g. storage, sorting, shredding, crushing technologies) than was placed on actual recycling technologies.

The technologies were assessed against the criteria listed in **Table 2.1** using a semi-quantitative system. The output from the assessment identified a list of potentially viable small-scale waste management technologies.

Table 1 Small-scale waste management technology assessment criteria for the Pacific

	Criteria	Guidance
1	The ability of the technology to process different waste streams	Some technology providers have different models for different waste stream combinations or have models that can be modified to treat different waste streams. The information provided is taken from the questionnaires but does not necessarily cover all waste stream options. It is recommended that technology providers be contacted directly for further information regarding their capacity to process different waste streams.
2	Whether the technology is considered proven (with examples of existing installations of the technology around the world)	The information provided is taken from the questionnaires, but references to facilities should be followed up to confirm that the technology is proven.
3	Maximum and minimum annual processing capacity (including scalability)	The optimum scale of a facility is project specific. However, it has been assumed that, in general, small-scale, and scaleable technologies are better suited to the Pacific region than large-scale technologies that may be cost-prohibitive or reliant on large volumes of feedstock.
4	Capital cost (ex-factory price), relative to the price range specified in the terms of reference (i.e. typically less than US$200,000 but up to US$5,000,000)	Depending upon the procurement model, the stated capital cost may not be a barrier to adoption of the technology (for example if technology rental is an option). The commercial aspects are project-specific, and a range of factors need to be considered.
5	Potentially recoverable and unrecoverable products and wastes (by weight or volume)	An end market assessment has not been undertaken. This criterion assesses potential for technology to produce recoverable products *if* market for those products exists.
6	Ease of operation of technology and potential social benefits (e.g. employment generator)	This criterion focusses on the number of people employed at the facility and the potential for in-country technical support, providing social benefits by way of local employment. It does not include other factors such as health and safety risks.
7	Potential for adverse emissions to air, water and land	Determining appropriate emission control standards can depend on risk factors such as the setting of the technology (e.g. urban area or remote from settlement) and the nature of its proposed use.
8	Energy efficiency and carbon footprint (during operations)	Determining energy efficiency, carbon footprint and other social, economic, and environmental sustainability factors can be a complex process. A more detailed assessment is required than was able to be undertaken for this project.
9	Potential application within each specific Pacific country or partnering countries	The potential application of a technology is project specific. This criterion provides only a high-level indicative assessment.
10	Commercial viability in the context of the Pacific region.	The commercial aspects of a technology are project-specific, and a range of factors need to be considered. This criterion provides only a high-level indicative assessment.

Technology Options

There are numerous waste technologies globally that employ reuse, recycling, segregation, handling, storage, treatment, volume reduction and disposal methods for the range of wastes covered in this high-level study. This section presents a summary of some of the most appropriate waste management technologies identified for the PacWastePlus programme's eight priority waste streams with consideration to the inherent constraints of the Pacific island region.

The list of technologies is not comprehensive.

For each waste stream (where appropriate) and relevant type of technology the following is outlined:

- context
- name and description of the technology types
- rationale behind any initial screening (such as 'technology at research stage/not proven')
- shortlisting of technology classes (pros, cons and unknowns, taking into account the assessment criteria)
- conclusions regarding most prospective types

Currency conversions to United States dollars (US$) are based on 24/08/2020 exchange rates.

Appendix A presents the small-scale waste technology assessment matrix, which assesses the information obtained at the technology provider level for those technology types that were shortlisted in the tables below.

Ultimately, the determination of whether a technology is applicable to the Pacific region will be project based. It was beyond the scope of this work to consider specific projects (specific locations, waste stream categories and volumes, operating parameters etc.).

HEALTHCARE WASTE

Overview

Current practices in the Pacific for managing healthcare waste impose health risks to areas where scavenging at waste disposal sites occur and /or at health facilities where manual sorting of wastes is undertaken. Recent surveys undertaken in the Pacific indicate that requires proper management of hazardous healthcare waste. Healthcare or medical waste can be defined as waste generated from diagnosis, treatment and immunisation of humans or animals.

It is useful to categorise the overall waste stream into the following four categories:

Municipal solid waste | **Infectious waste** | **Hazardous waste** | **Low-level radioactive waste**

Waste categories are specified in the European Waste Catalogue and might be further defined by national legislation. Although infectious waste is only a small part of the total waste generated by medical facilities, it accounts for a considerable portion of the costs incurred by a health care facility.

For the disposal of medical waste, high temperature thermal e.g. (incineration, pyrolysis, gasification) is the most used disposal route for large volumes of clinical waste however alternative less costly options are available.

Incineration involves combustion of medical waste at high temperatures reducing the combustible fraction to an inert disinfected ash containing sterile non-combustible matter. Emissions from flue gas are treated to meet local standards and costs are highly depended on the standards to be met. European Standards, under the Industrial Emissions Directive, are the most stringent in the world and are costly to meet.

Gasification uses sub stoichiometric air water or steam, unlike incineration where excess or stoichiometric air is used to create a Syngas which is then cleaned and used as a fuel in many processes and is subject to the same emissions standards as incineration in Europe. It is more generally used on other waste streams rather than healthcare waste due to its sensitivity to feeds that are non- homogeneous.

Pyrolysis generally uses the application of heat in the absence of air and is more suited to the production of a biochar which is why it is generally used more as a 'pyrolysis phase' in an overall incineration process when considered for healthcare waste.

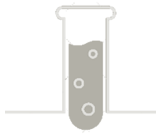
Initial screening of technology classes

The following technology classes were considered:

High temperature thermal – Ability to reduce to an inert ash non sorted waste.

Steam Disinfection – Proven technology with a broad range of clinical waste.

Microwave technology– Proven technology with a broad range of clinical waste.



Chemical technology – Proven and developing technologies at a potential reasonable cost.

Biological Technology - Placenta pits, others have not at this stage been included.

Electron Beam Technology – Proven and operating elsewhere on certain wastes.

Tables 3.1 – 3.6 provide details of the initial assessment. Please refer to the Technology Providers List (Appendix A) – for a list of example companies providing healthcare waste management and who were contacted for this literature review.

High temperature Thermal Treatment

Table 2 Assessment of high temperature thermal treatment for the management of healthcare waste

Assessment	**Comments**
The ability of the technology to process different waste streams, including collection separation and sorting of waste	Incineration can process all healthcare waste however in Europe and elsewhere it is highly regulated. The strengthening of the regulations has meant that small hospital-based incinerators have been replaced by large and highly expensive centralised facilities often privately run. There are smaller incinerator manufacturers who supply small facilities, however, there is a trade off with many on the emissions standards met. Incineration processes have the advantage of being able to take unsorted bags of mixed clinical waste. Air emissions are impacted by feedstocks containing potential pollutants such as mercury. Gasification uses substoichiometric conditions to produce a synthetic gas rather than complete combustion Gasification is more sensitive to non-homogeneous waste streams and requires the potential for more fuel preparation.
Whether the technology is considered proven (with examples of existing installations of the technology around the world)	Incineration is a proven technology and there are extensive examples of installations across the world handling clinical waste. Gasification and pyrolysis are less proven. It should be noted that flue gas clean-up technology to meet European air emission standards can be a major component of the cost of a clinical waste incinerator.
Maximum and minimum annual processing capacity (including scalability)	Available incineration technologies are scaled to process vide variety of daily tonnages.
Capital cost and indicative operational costs in relation to a price range of less than US$200,000, but up to US$5,000,000	Incineration costs are dependent on technology expectations and sizing. For example, Scholer Industries claim US$64,000 up to US$200,000 for small scale incinerators, whereas typical European prices to EC Standards tend to be more than the US$200,000 to US$5 million dependent on scale.
Outputs/waste products recoverable/unrecoverable including wastes	• Inert Ash for disposal to landfill • Waste liquids if wet scrubber is used • Dry waste products from emissions treatment systems if used
Ease of operation of technology and potential social benefits (income generator?)	Incineration technologies reviewed were highly variable in their ease of operation and operator requirements. Where incinerators are a simple small low-tech combustion chamber there are minimal operator requirements. More sophisticated larger scale technologies can involve sophisticated computer controls, flue gas clean-up systems and energy recovery systems with steam boilers requiring skilled operators. Potential for income generation is project specific and generally limited to heating and electricity generation. Operating costs generally exceed any revenue or savings from energy recovery due to the high energy input required for the process itself.

Assessment	Comments
Potential for adverse emissions to air, water, and land	Emissions to air can be rendered harmless with the use of advanced flue gas clean-up systems. If wet scrubbers are used liquid effluents may require costly treatment or special disposal. Solid wastes such as ash require disposal from filtration systems if used.
Sustainability and energy efficiency	High temperature thermal processes are energy intensive if correctly designed.
Potential application within each specific Pacific country or partnering countries	Quality and environmental performance of plant will vary depending on funds available.
Commercial viability in the context of the Pacific region.	Incineration is commercially viable in the context of the Pacific Region and there are numerous existing facilities. High-technology incineration may only be viable where large quantities of waste are to be treated. However, smaller low-tech incinerators are available for smaller projects and it becomes a balance between environmental performance and cost.

Advantages

- Complete destruction of pathogens including animal and plant
- Volume reduction: can reduce volume of waste by 90% dependent on composition of input and technology type.

Disadvantages

- Capital and operating costs – Generally considered high cost hence the need to be able to use energy, by-products or compensate for high alternate disposal costs.
- Technology has advanced and is now highly complex in modern incineration technologies This results in a need for higher operator skills and training requirements.
- Air emissions can be controlled but at a cost.
- Ash may not have a recyclable outlet and would need to be disposed of in a landfill.

Steam Disinfection

Table 3 Assessment of steam disinfection for the management of healthcare waste

Assessment	**Comments**
The ability of the technology to process different waste streams, including collection separation and sorting of waste	Steam disinfection, a standard process in hospitals, is done in autoclaves and retorts. More recent designs have incorporated vacuuming, continuous feeding, shredding, mixing, fragmenting, drying, chemical treatment and/or compaction, to modify the basic autoclave system. The types of waste commonly treated in autoclaves and retorts are: cultures and stocks, sharps, materials contaminated with blood and limited amounts of fluids, isolation and surgery wastes, laboratory wastes (excluding chemical waste), and soft wastes (gauze, bandages, drapes, gowns, bedding, etc.) from patient care. With sufficient time and temperature as well as mechanical systems to achieve unrecognizability, it is technically possible to treat human anatomical wastes, but ethical, legal, cultural, and other considerations may preclude their treatment. Some countries may allow the treatment of trace contaminated chemotherapy waste; facilities should check with their regulators. Volatile and semi-volatile organic compounds, bulk chemotherapeutic wastes, mercury, other hazardous chemical wastes, and radiological wastes should not be treated in an autoclave or retort. Huge and bulky bedding material, large animal carcasses, sealed heat-resistant containers, and other waste loads that impede the transfer of heat should be avoided.
Whether the technology is considered proven (with examples of existing installations of the technology around the world)	Well proven standard equipment in many hospitals and laboratories. There are numerous technology providers globally (see contact list).
Maximum and minimum annual processing capacity (including scalability)	Standard steam disinfection processes treat twenty to 1800 kilograms of waste per hour. Multiple units can be installed to increase capacity.
Capital cost (ex-factory price) and indicative operational costs in relation to a price range of less than US$200,000, but up to US$5,000,000. .	steam sterilisation costs are very dependent on the volume of material being sterilised. For example, the company Hydroclave builds autoclaves from $111,000USD (Hydroclave H-07) up to $545,000USD (Hydroclave 250).
Outputs/waste products recoverable/unrecoverable including wastes	As this is a sterilisation process the waste materials are not physically changed or destroyed, instead the material is disinfected. The materials are then safe to handle and be recycled if desired. Output by weight is approximately 50% of waste input. All liquids in most processes will have been sterilised and drained to sanitary sewer.
Ease of operation of technology and potential social benefits (income generator?)	With most technologies training can be provided, and the process is simple to operate. Only one operator is required with minimal training. As an example: Hydroclave H-07 and H-15B, operation cost would be about 5-8 Kw/hr per treatment cycle with maintenance costs estimated to be about $1,500USD per year
Potential for adverse emissions to air, water, and land	This technology can produce foul smelling air emissions. Additionally, there is also liquid discharge to sanitary sewer of septic systems.
Sustainability and energy efficiency	Steam disinfection only requires a small amount of water and power. For the Hydroclave technology (H-07 and H-15B) operation power demand would be about 5-8 Kw/hr per treatment cycle. Waste liquid is disposed to sewer and the remaining materials can be recycled or reused/recovered.
Potential application within each specific Pacific country or partnering countries	Steam disinfection could be applied in any Pacific country.
Commercial viability in the context of the Pacific region.	Steam disinfection is an ideal solution to treat healthcare waste in developing countries where high-end technical skills are not available and where cost constraints and economies of scale preclude other technologies.

Advantages

- Steam treatment is a proven technology with a long and successful track record.
- The technology is easily understood and readily accepted by hospital staff and communities.
- It is approved or accepted as a medical waste treatment technology in most countries.
- The time-temperature parameters needed to achieve high levels of disinfection are well established.
- Autoclaves are available in a wide range of sizes, capable of treating from a few kilograms to several tonnes per hour.
- If proper precautions are taken to exclude hazardous materials, the emissions from autoclaves and retorts are minimal.
- Capital costs are relatively low.
- Many autoclave manufacturers offer features and options such as programmable computer control, tracks and lifts for carts, permanent recording of treatment parameters, autoclavable carts and cart washers, and shredders.

Disadvantages

- The technology does not render waste unrecognisable and does not reduce the volume of treated waste unless a shredder or grinder is added.
- Any large, hard metal object in the waste can damage any shredder or grinder.
- Offensive odours can be generated but are minimised by proper air handling equipment.
- If hazardous chemicals such as formaldehyde, phenol, cytotoxic agents, or mercury are in the waste, these toxic contaminants are released into the air, wastewater, or remain in the waste to contaminate the landfill.
- If the technology does not include a way of drying the waste, the resulting treated waste will be heavier than when it was first put in because of condensed steam.
- Barriers to direct steam exposure or heat transfer (such as inefficient air evacuation; excessive waste mass; bulky waste materials with low thermal conductivity; or waste loads with multiple bags, air pockets, sealed heat resistant containers, etc.) may compromise the effectiveness of the system to decontaminate waste.

Microwave Technology

Table 4 Assessment of microwave for the management of healthcare waste

Assessment	**Comments**
The ability of the technology to process different waste streams, including collection separation and sorting of waste	Microwave technology is essentially a low-heat thermal process where disinfection occurs through the action of moist heat and steam, and/or dry heat. The types of waste commonly treated in microwave systems are identical to those treated in autoclaves and retorts. With sufficient time and temperature as well as mechanical systems to achieve unrecognisability, it is technically possible to treat human anatomical wastes, but ethical, legal, cultural, and other considerations may preclude their treatment. Some countries may allow the treatment of trace-contaminated chemotherapy waste; again, facilities should check with their regulators. Volatile and semi-volatile organic compounds, bulk chemotherapeutic wastes, mercury, other hazardous chemical wastes, and radiological wastes should not be treated in a microwave.
Whether the technology is considered proven (with examples of existing installations of the technology around the world)	Microwave technology is proven technology. For example, AMB Ecosteryl a leading medical waste treatment companies has installed over 170 of the systems in more than 60 countires.
Maximum and minimum annual processing capacity (including scalability)	Standard microwave technologies investigated could treat between twenty to 480 kilograms of waste per hour. Multiple units can be installed to increase capacity.
Capital cost (ex-factory price) and indicative operational costs in relation to a price range of less than US$200,000, but up to US$5,000,000.	Examples of AMB Ecosteryl microwave systems capital costs based on HC waste put through: • AMB Ecosteryl 75 can process 75 kilogram per hour at~$470,000USD to $520,000USD). • AMB Ecosteryl 125 can process 125 kilogram per hour at $710,000USD. • AMB Ecosteryl 250 can process 300 kilogram per hour at $940,000USD.
Outputs/waste products recoverable/unrecoverable including wastes	Similar to steam disinfection and liquid wastes can be discharged to sewer.
Ease of operation of technology and potential social benefits (income generator?)	With most technologies training can be provided, and the process is simple to operate.
Potential for adverse emissions to air, water and land	Similar to steam disinfection.
Sustainability and energy efficiency	Similar to steam disinfection above.
Potential application within each specific Pacific country or partnering countries	Microwave Technology could be applied in any Pacific country.
Commercial viability in the context of the Pacific region.	Microwave (steam or dry heat) technology is an ideal solution to treat healthcare waste in developing countries where high-end technical skills are not available and where cost constraints and economies of scale preclude other technologies.

Advantages

- Because many people have microwave ovens, it is easy for hospital staff and communities to understand and accept the technology.
- It is accepted or approved as an alternative technology, and units have been in operation for many years.
- If proper precautions are taken to exclude hazardous material, the emissions from microwave units are minimal.
- There are no liquid effluents from the Sanitec microwave unit.
- The internal shredder reduces waste volume up to 80%.
- The technology is automated and easy to use. It requires one operator.

Disadvantages

- If hazardous chemicals are in the waste, these toxic contaminants are released into the air or remain in the waste to contaminate the landfill.
- There may be some offensive odours around the microwave unit.
- Any large, hard metal object in the waste could damage the shredder.
- The capital cost is relatively high

Chemical Disinfection

Table 5 Assessment of chemical disinfection for the management of healthcare waste

Assessment	**Comments**
The ability of the technology to process different waste streams, including collection separation and sorting of waste	Chemical technologies use disinfecting agents in a process that integrates internal shredding or mixing to ensure sufficient exposure to the chemical. Until recently, chlorine-based technologies (sodium hypochlorite and chloride dioxide) were the most commonly used. Some controversy exists regarding possible long-term environmental effects, especially of hypochlorite and its by-products in wastewater. Non-chlorine technologies are quite varied in the way they operate, and the chemical agents employed. Some use peroxyacetic acid, ozone gas, lime-based dry powder, metal catalysts, or biodegradable proprietary disinfectants. The alkaline hydrolysis technology is designed for tissue and animal wastes as well as fixatives, cytotoxic agents, and other specific chemicals. Safety and occupational exposures should be monitored when using any chemical technology. The types of waste commonly treated in chemical-based technologies are: cultures and stocks, sharps, liquid human and animal wastes including blood and body fluids (in some technologies, this may be limited to a certain percentage of the waste), isolation and surgery wastes, laboratory waste (excluding chemical waste), and soft wastes (gauze, bandages, drapes, gowns, bedding, etc.) from patient care. Ethical, legal, cultural, and other considerations may preclude treatment of human anatomical wastes in chemical treatment systems. Volatile and semi-volatile organic compounds, chemotherapeutic wastes, mercury, other hazardous chemical wastes, and radiological wastes should not generally be treated in chemical treatment units. Large metal objects may damage internal shredders.
Whether the technology is considered proven (with examples of existing installations of the technology around the world)	There are numerous chemical treatment technologies at different levels of commercialisation.
Maximum and minimum annual processing capacity (including scalability)	A wide variety of processing capacity exists in this technology.
Capital cost (ex-factory price) and indicative operational costs in relation to a price range of less than US$200,000, but up to US$5,000,000	Costs are size and technology dependent. Further costs on different chemical technologies are available in the reference documents.
Outputs/waste products recoverable/unrecoverable including wastes	Waste liquids can be disposed of into the wastewater system. There are some concerns about downstream issues from use of certain chemicals such as sodium hypochlorate.

Assessment	**Comments**
Ease of operation of technology and potential social benefits (income generator?)	Some technologies are designed for simple operation. Technologies where chemicals are used could involve occupational exposure monitoring.
Potential for adverse emissions to air, water, and land	Waste liquids can be disposed to sewer, but dependent on the technology and the chemicals used there are some concerns about downstream issues from the use of certain chemicals such as sodium hypochlorate. Other technologies such as the ozonator technologies do not use the same chemicals. See individual data on website links in technology provider list (Appendix A).
Sustainability and energy efficiency	The lack of availability of some chemicals could preclude some processes from being executed.
Potential application within each specific Pacific country or partnering countries	Chemical technology could be applied in any Pacific country.
Commercial viability in the context of the Pacific region.	Suitable for use in the Pacific (recommend ensuring supplier knows the conditions to be installed, so they can advise on the most appropriate unit, and maintenance requirements).

Advantages

- Highly efficient disinfection under good operating conditions
- Some chemical disinfectants are relatively inexpensive

Disadvantages

- Requires highly qualified technicians for operation of the process
- Uses hazardous substances that require comprehensive safety measures.
- Inadequate for pharmaceutical, chemical, and some types of infectious waste.

Electron Beam Technology

Table 6 Assessment of electron beam technology for the management of healthcare waste

Assessment	**Comments**
The ability of the technology to process different waste streams, including collection separation and sorting of waste	Electron beam technology bombards medical waste with ionizing radiation, causing damage to the cells of micro-organisms. Electron beam technology does not have residual radiation after the beam is turned off. Shields and safety interlocks are necessary to prevent worker exposure to the ionizing radiation. The types of waste commonly treated in an e-beam technology equipped with a mechanical destruction process are: cultures and stocks, sharps, materials contaminated with blood and body fluids, isolation and surgery wastes, laboratory waste (excluding chemical waste), and soft wastes (gauze, bandages, drapes, gowns, bedding, etc.) from patient care. Volatile and semi-volatile organic compounds, chemotherapeutic wastes, mercury, other hazardous chemical wastes, and radiological wastes should not be treated in e-beam units.
Whether the technology is considered proven (with examples of existing installations of the technology around the world)	The basic technology has been used in other applications for about two decades and is familiar to hospital staff involved in cancer therapy.
Maximum and minimum annual processing capacity (including scalability)	BioSterile Technology1 has developed a compact electron beam system intended as an on-site unit to treat medical waste. The system uses a 5 MeV, 2 kW unit capable of handling approximately 180 to 225 kilograms of waste per hour.
Capital cost (ex-factory price) and indicative operational costs in relation to a price range of less than US$200,000, but up to US$5,000,000	No costs were received from suppliers for electron beam technology however internet research suggests capital cost could be in the region of $350,000USD.
Outputs/waste products recoverable/unrecoverable including wastes	Electron beam systems do not create any pollutant emissions except possibly for small amounts of ozone which breaks down to diatomic oxygen (O2). The residual ozone helps remove odours and contributes to the disinfection process in the treatment chamber, but it should be converted back to diatomic oxygen before being released into the environment or workspace. The waste residue looks exactly as it did before treatment since electron beam irradiation does not change the physical characteristics of the waste. Therefore, a mechanical process is needed to render the treated waste unrecognisable and reduce volume.
Ease of operation of technology and potential social benefits (income generator?)	Operating precautions must be taken to protect workers from radiation. These are among the reasons this method is not widely used, especially when heat treatment methods are typically just as effective.

Assessment	**Comments**
Potential for adverse emissions to air, water, and land	Electron beam systems do not create any pollutant emissions except possibly for small amounts of ozone. Electron beam systems may contain lead in the shielding; the lead should be recycled or treated as hazardous waste after the e-beam unit is decommissioned.
Sustainability and energy efficiency	Energy requirements and end of life disposal of radioactive material are key sustainability issues.
Potential application within each specific Pacific country or partnering countries	Electron beam systems may contain lead in the shielding; the lead should be recycled or treated as hazardous waste after the electron beam unit is decommissioned which could cause issues in application in Pacific and partnering countries. The equipment would also need to be housed in a building.
Commercial viability in the context of the Pacific region.	Less likely to be viable than other technologies.

Advantages

- Good disinfection efficiency under appropriate operation conditions

Disadvantages

- Relatively high investment and operating costs.
- Potential operation and maintenance problems.

Biological Treatment

Table 7 Assessment of biological treatment for the management of healthcare waste

Assessment	**Comments**
The ability of the technology to process different waste streams, including collection separation and sorting of waste	Biological processes such as the Bio-Converter, use enzymes to decompose organic waste. Placenta pits allow pathological waste to degrade naturally. As the waste decomposes pathogens will be destroyed as well. At present there are little data on how long it will take for all pathogens to die. These were designed to dispose of placentas and similar pathological waste. They cannot be used for solid wastes.
Whether the technology is considered proven (with examples of existing installations of the technology around the world)	Placenta pits have been used worldwide.
Maximum and minimum annual processing capacity (including scalability)	Placenta pits can be dug to the size required and duplicated however they need to be left for at least two years so are limited in quantity of material that they can receive
Capital cost (ex-factory price) and indicative operational costs in relation to a price range of less than US$200,000, but up to US$5,000,000	NA
Outputs/waste products recoverable/unrecoverable including wastes	For placenta pits liquid leaches into the ground and the remaining wastes biodegrade.
Ease of operation of technology and potential social benefits (income generator?)	Placenta pits involve placing material in pit.
Potential for adverse emissions to air, water, and land	For placenta pits liquid leaches into the ground and the remaining wastes biodegrade.
Sustainability and energy efficiency	For placenta pits there is no consumption of energy other than that used in their construction, they meet social requirements in relation to cultural issues and they are economic.
Potential application within each specific Pacific country or partnering countries	Placenta pits are used in Africa in countries such as Zimbabwe and Ethiopia. They need to be designed or located to prevent the ingress of water and hence may have limited acceptability in areas prone to flooding. They also would need to be considered an acceptable method in the Country in question.
Commercial viability in the context of the Pacific region.	Placenta pits are cheap to construct, but must meet cultural norms

Advantages

- Possible low-cost solution

Disadvantages

- Limited use for all healthcare waste

E-WASTE

Overview

Currently, there are e-waste stockpiles in several Pacific Island countries. E-waste inherently contains a range of hazardous materials that if left to accumulate will in turn release toxic substances and contaminate the environment. Efforts to effectively manage e-waste in the Pacific face many challenges due to access to disposal points, recycling markets and the high cost in transporting e-waste out of the region (PacWastePlus Programme, 2019).

Used electronics can be refurbished for reuse and resale, destroyed for material separation, and recycled into new products or converted to fuel for recovery or disposal via energy from waste technologies.

E-waste contains many components that can be recycled and reused. These resources include:

- plastics and glass
- non-ferrous metals
- ferrous metals
- hazardous materials

A typical process for managing e-waste includes collection from businesses and public drop-offs that are then sent to a recycling facility. The collected e-waste is then sorted, dismantled, and categorised into their basic material components, including plastics and glass, and components containing metals. Pre-processing where e-waste is sorted aims to reduce the volume (via crushing and shredding) of each component which can then be transferred to specific recycling and recovery processes efficiently.

For components of e-waste that contain metals, additional separation techniques are required to free the metals from the electrical components, they include:

Pyrometallurgy - involves heating metal components from e-waste to more than 1,000 °C. This process typically results in high energy use and the release of toxic gases.

Hydrometallurgy - uses chemicals such as acids or cyanide to leach metals from e- waste components. However, the process can generate toxic effluent.

Bioleaching/ biometallurgy - uses microbes to extract metals from e-waste, this method has been used in the mining industry traditionally to extract ore using bacteria. Wider application of this technology for separating trace metals from e-waste is still in its infancy.

Eddy current - employs an alternating magnetic field to separate conductive particles created by a magnetic rotating drum. The formation of a repulsive force then repels/deflects the metal components away from the flow of surrounding, non-metallic materials.

As e-waste is varied and complex in nature, it does not generally have single dedicated technologies, but relies upon separate technologies for sorting/separating, shredding, recovery, and recycling.

These technologies are often the same or modified versions of technologies used for other waste streams such as glass, plastics, and metals recycling. Accordingly, a general discussion is provided below on the use of technologies that support e-waste.

When selecting an e-waste management services, check to see if the business is committed to safe, ethical, and responsible standards for e-waste recycling and refurbishment.

basel action network

e-Stewards CERTIFIED

The Basal Action Network (BAN) is a non-profit organisation with a mission to champion global environmental health and justice including ending toxic trade of electronic wastes to countries where e-waste is more likely to be 'recycled' by burning circuit boards, soaking microchips in acid and burning plastics in an uncontrolled manner, threatening the health of people and the environment.

BAN has created an e-Stewards standard to ensure best practice e-waste recycling. e-Stewards is a voluntary based certification for e-waste to demonstrate compliance with all international and local e-waste laws. Currently, certificated e-waste recycling providers are in Canada, Singapore, Mexico, South Korea, United Kingdom and United States. Two e-waste technology providers have been contacted as part of this review namely Global E-waste Solutions based in Canada, US and Singapore and Restore Harrow Green in the United Kingdom. Refer to the Technology Providers List (Appendix A) for a list of example companies providing e-waste management and who were contacted for this literature review.

Refurbishment for reuse and resale

There is an opportunity to reduce volumes of e-waste requiring recycling or disposal and decrease demand for new electric and electronic equipment by refurbishing older devices. Refurbishment and resale are likely to be commercially attractive business in the Pacific region and is presumably already common, particularly in more urbanised areas.

Collection

Integral to any e-waste management system is the safe and accessible collection of e-waste. There are many e-waste management companies that offer, as part of their e-waste management service, a collection system for businesses and private users to drop off most if not all types of electrical or electronic devices.

E-waste collection and drop-off services are more viable in urban areas where population density is greater and the rates of ownership of electronic equipment such as computers is often higher.

As described for recyclables, compaction by balers or bin compactors can be employed to help store and transport recyclable materials. This can be particularly important if the e-waste is to be shipped to another country for recycling.

Sorting and separating into basic components for recycling (e.g. plastics, glass, and metals)

Separating and sorting of e-waste into their basic components is offered by a number of companies including Shred-X, who operates throughout Australia and ANZRP (TechCollect) that include manual dismantling of the respective components and a forty foot self-contained recycling container that can shred plastics, paper and cardboard).

As part of any reuse or dismantling process data should be destroyed under secure conditions. Materials are then separated into their basic components, glass, plastics, and metals. Ecocyle who operates throughout Australia and New Zealand is an e-waste management company that employs the eddy-current separation technique to extract metals from electronic componentry.

Other technologies for the washing, sorting, and shredding of recyclable material in preparation for producing new products or input into energy conversion technologies are described in the Recyclables section.

In the Pacific region, there are opportunities for the manual separation and sorting of e-waste components to provide employment. Automated sorting machines may also be an option, although tend to be more viable for high waste volumes and may not be a preferred option in most Pacific locations due to generally low e-waste volumes and low labour rates. Due to the potential for hazardous substances to be associated with e-waste, it is essential that strict health and safety procedures are implemented and adhered to if manual separation and sorting is to be undertaken.

The hazardous substances associated with e-waste also raise the potential for emissions to air (particularly if high temperatures are involved in the recycling process) and discharges to land and water. Appropriate, technology-specific controls would be required to acceptably minimise these risks.

E-waste management companies can elect to be certified by e-Stewards to demonstrate their commitment for ethical e-waste recycling that does not threaten the health of humans or the environment. Participating businesses can also gain recognition of an e-waste management plan via accreditation through the ISO1400 Environmental Management subsystem.

Commercial viability of e-waste recycling

It is likely that comprehensive, high-tech e-waste recycling in the Pacific region would not be commercially viable without government subsidies or international aid money - certainly outside of major urban centres. An economic analysis would be required to determine this which is beyond the scope of this review. However, there may be markets for some specific components such as copper wiring, or glass/plastics that are feedstocks for other local recycling processes.

If comprehensive in-country e-waste recycling is not viable, then there may be an option of sorting and preparing materials for export to an international facility for recycling. It is likely that international export, too, would rely on incentives (such as aid money) to be viable. Opportunities for transportation is being investigated through the Moana Taka Partnership, involving the use of available and empty shipping containers to transport recyclable materials internationally.

Issues associated with international export are discussed in below in relation to asbestos, and many of the same considerations would apply to e-waste.

Asbestos

Overview

Asbestos has been used in building materials for many years. It is a naturally occurring fibrous silicate material with inherent heat resistant properties but is harmful to humans. If asbestos is disturbed through abrasion and released into the atmosphere inhalation of fibres can lead to various serious lung conditions and diseases, including cancer.

PacWastePlus member countries have revealed that asbestos in the Pacific is not only a legacy issue as new building products containing asbestos continue to be imported into some countries. In addition, exposure to asbestos is heightened by the incidence of disasters and extreme weather events which could damage asbestos material and release airborne fibres. (PacWastePlus, 2019)

A survey of asbestos in the Pacific region undertaken as part of the PacWaste project identified 187,891m2 of confirmed, non-residential asbestos containing materials among the 13 countries surveyed, with 78% considered to present a moderate to high risk to human health (O'Grady, Rhyder and Kim 2016). Four countries (Nauru, Niue, Kiribati, and Vanuatu) account for 83% of this amount. A visual assessment of the presence of residential asbestos found variable presence across the region, ranging from nil to almost half of dwellings (in Funafuti and Tuvalu). As of 2016, none of the 13 countries had implemented a ban on asbestos.

Conventional management of asbestos waste is to double-bag it and place it in landfill. However, this reduces but does not remove the associated human health risk and leaves a potential legacy problem for future generations. Improved ways of treating asbestos to further reduce or remove risk are at various stages of development and deployment.

These techniques generally fall into the following five categories, with hybrid techniques also being developed (see OVAM 2016; Le Blansch, den Boeft, and Tempelman 2018):

- Thermal treatment: a combination of high temperatures (up to 1600°C) and (often) long residence times (up to several days) is used to decompose the crystal structure of the asbestos such that it is no longer hazardous. Thermal techniques include vitrification, ceramitisation, thermal denaturation, microwave heating, and treatment of asbestos waste that contains steel in a steel meting furnace.
- Chemical treatment: strong acids or bases are used to destroy the crystalline structure of the asbestos fibres.
- Mechanical treatment: dried and shredded asbestos waste is subjected to high-energy mills in which steel balls and sand rotate, generating very high temperature hot spots (above 1000 °C). Mechanical, thermal, and chemical processes combine to destroy the asbestos fibres and render the waste harmless.
- Biological treatment: the natural degradation of asbestos fibres is accelerated by the use of bacteria or fungi.
- Asbestos stabilisation: unlike the treatment options above, asbestos stabilisation does not seek to destroy the asbestos fibres, but to stabilise them such as by integration into a cement matrix. The stabilised asbestos can then be more safely deposited to landfill.

One hybrid technique is a thermochemical treatment process that uses pyrolysis, enhanced by chemical treatment processes, to destroy the asbestos fibres. It occurs at a high temperature (approximately 1,200°C), requires only a short residence time (e.g. 20 minutes) and can reduce waste volumes by 50-90%.

Note that in addition to employing treatment technologies or asbestos stabilisation, effective management of asbestos includes elimination of its use by implementing controls to reject importation of the material.

Summary of waste technology options

Thermal

Thermal treatment plants generally have high capital costs and, due primarily to high energy consumption, relatively high operating costs. They are also generally large, static operations that rely on reliable, high volumes of asbestos feedstock (Le Blansch, den Boeft, and Tempelman 2018). For example, a proposed hybrid thermochemical plant for Sydney, Australia, would consume the entire known backlog of non-residential asbestos in the Pacific region (187,891 m^2) in approximately three days. Due to their centralised nature, transportation costs for thermal (and thermochemical) plants can also be high. Due to their costs compared to landfill and the developmental nature of some thermal technologies, such facilities are not commonplace.

Chemical

Chemical treatment has inherent risks due to the use of strong acids or bases and the end product requires neutralisation before use. Commercial-scale use of the technology is not yet proven and Le Blansch, den Boeft, and Tempelman (2018) concluded that the “distance to market … still appears to be big”.

Mechanical

Mechanical treatment plants are generally less capital intensive and more mobile, flexible and scalable than other treatment techniques (Le Blansch, den Boeft, and Tempelman 2018). Their lower energy use also means a reduced carbon footprint. They therefore may be more suited to the smaller volumes of asbestos waste in the Pacific region and able to undergo short-term deployment to source areas. However, although promising, they are not yet a proven technology at a commercial scale.

Biological

Currently, biological treatment is technologically immature and unproven on a commercial scale.

Stabilisation

Asbestos stabilisation by encapsulation in cement is proven and is a potential option if in-country treatment options (or shipping internationally to treatment facilities) proves unviable. It is more expensive than simply double-bagging prior to disposal, but reduces the risk of future exposure to asbestos fibres.

Based on the above discussion, the following technology class is therefore considered in greater detail below:

- Asbestos stabilisation
- shipped internationally (outside of the Pacific island region) for treatment

Refer to the Technology Providers List (Appendix A) for a list of example companies providing asbestos stabilisation and treatment technologies and who were contacted for this literature review.

Table 8 Summary of waste technology options assessed for the management of asbestos

Assessment	**Asbestos stabilisation**	**Shipped internationally (outside of the Pacific island region) for treatment**
The ability of the technology to process different waste streams, including collection separation and sorting of waste	The stabilisation process does not specifically treat different waste streams. Contaminants such as wood, paper, plastics, and metals are typically removed from the waste prior to stabilisation. Depending upon the technology used, not all types of ACW are able to be stabilised.	Dependent on the nature of the treatment facility.
Whether the technology is considered proven (with examples of existing installations of the technology around the world)	The technology is proven (for example, the Rematt plant in Flanders has operated since 1993) (OVAM 2016).	Dependent on the nature of the treatment facility.
Maximum and minimum annual processing capacity (including scalability)	The Rematt plant in Flanders is licenced to process a maximum of 15,000 tonne/year of asbestos containing materials and 400 tonne/year of friable asbestos (OVAM 2016).	Dependent on the nature of the treatment facility. However, a large international treatment plant such as the thermochemical plant proposed for Sydney, Australia would comfortably be able to accommodate ACW from the Pacific region.
Capital cost (ex-factory price) and indicative operational costs in relation to a price range of less than US$200,000, but up to US$5,000,000	Capital and operational costs were unable to be sourced. However, the Rematt plant in Flanders charges on average approximately $1,300USD) per tonne of asbestos to be treated (OVAM 2016).	The use of a flexible intermediate bulk container such as a Hazibag would make the logistics of transportation relatively straightforward.
Outputs/waste products recoverable/unrecoverable including wastes	The stabilised ACW is disposed of into a landfill.	Dependent on the nature of the plant, but most treatment technologies purport to produce an inert waste suitable for use as construction aggregate.

Assessment	**Asbestos stabilisation**	**Shipped internationally (outside of the Pacific island region) for treatment**
Ease of operation of technology and potential social benefits (income generator?)	A reasonable level of expertise is likely to be required to operate the technology. However, the need for expertise should not be a major impediment if adequate training is provided. Due to the hazardous nature of asbestos, the main issue is implementing and maintaining strict health and safety procedures at every step of the process.	Due to the hazardous nature of asbestos, the main issue regarding its transportation to an international treatment plant would be maintaining strict health and safety procedures during the bagging, in-country transportation and loading of the asbestos onto the ship.
Potential for adverse emissions to air, water and land	The main risk is the release of asbestos fibres into the air where they pose a significant health risk. The use of cement as the stabilisation medium can also lead to dust emissions.	The main risk is the release of asbestos fibres into the air and land during the bagging, in-country transportation and loading of the asbestos onto the ship.
Sustainability and energy efficiency	The energy use associated with asbestos stabilisation is likely to be substantially less than for mechanical treatment. However, the use of cement as a stabilisation medium increases the carbon footprint of the process. In addition, if the cement is created from locally sourced limestone, then it may raise sustainability and environmental issues if over-extraction occurs.	The shipping of the ACW to an international treatment plant would have an associated carbon footprint, but this could be more than offset by the efficiency of treatment at a large, long-lived treatment plant compared with the separate construction and operation of a smaller in-country plant. If shipping to an international treatment plant was the only viable means of treating the asbestos and rendering it inert, then there would be sustainability and inter-generational advantages in doing so.
Potential application within each specific Pacific country or partnering countries	Asbestos stabilisation - particularly the stabilisation of friable asbestos - is likely to be a viable option for the Pacific Region from a technical and practical perspective. However, it may only be viable for those countries with higher tonnages of asbestos and where transportation of the asbestos to a central facility is feasible (although shipping from other countries may be possible). Provided it is implemented with adherence to strict health and safety procedures, it is likely to significantly reduce the risk of legacy issues that would be associated with the deposition to landfill of non-stabilised asbestos. Legacy issues are a particular risk following the decommissioning of an asbestos-containing landfill if adequate funds and controls are not put in place for the in-perpetuity maintenance of the landfill. The stabilisation of asbestos helps mitigate such legacy risk.	All countries would likely have access to international transportation of asbestos provided they were not too remote and their asbestos quantities not too small for collection by ship to be viable. As the asbestos would be classed as hazardous waste, the receiving country would need to appropriate authorisations to import it.

Assessment	**Asbestos stabilisation**	**Shipped internationally (outside of the Pacific island region) for treatment**
Commercial viability in the context of the Pacific region.	From an economic perspective, the capital and operational cost of asbestos stabilisation are likely to be much greater than that of landfilling without stabilisation. Asbestos stabilisation is unlikely to be a commercial proposition without significant government or international incentive/subsidy. Given the hazardous nature of asbestos, international aid funding may be possible.	All countries would likely have access to international transportation of asbestos provided they were not too remote, and their asbestos quantities not too small, for collection by ship to be viable. As above, however, international treatment is unlikely to be a commercial proposition without significant government or international incentive/subsidy.

Asbestos stabilisation

Advantages

- Substantially reduces human health risk relative to non-stabilised landfill deposition
- Mitigates long term risk associated with inadequate maintenance of decommissioned landfill

Disadvantages

- May only be viable in countries with larger asbestos tonnages
- Health and safety issues associated with additional asbestos handling (although manageable if strict protocols followed)
- Carbon footprint associated with cement use
- Requires government or international subsidy to be commercially viable
- Does not remove risk completely by destroying the asbestos fibres

Shipped internationally (outside of the Pacific island region) for treatment

Advantages

- Removes asbestos from Pacific island region
- Renders asbestos inert by destroying fibres
- Other advantages depend on the specific treatment technology

Disadvantages

- Health and safety issues associated with asbestos handling (although manageable if strict protocols followed)
- Requires government or international subsidy to be commercially viable
- Other disadvantages depend on the specific treatment technology

RECYCLABLES

Overview

Recyclable waste refers to waste that can be easily recovered or made into other products. Waste of this nature typically includes:

Recycling is a process to convert waste composed of potentially useful materials into a new product.

Pacific island countries face many challenges when managing recyclable waste, due to the:

- limited ability to avoid importation of large quantities of material and packaging due to the small proportion of local manufacturing and production of local goods
- unnecessary amount of waste produced by tourism
- limited options to dispose of waste particularly single use plastics
- limited waste stream segregation
- economic constraints to recycling, based on the small size of countries
- limited incentives to recycle and
- the relatively expensive transportation costs to other markets

In-country small-scale recycling facilities have been included in this investigation to identify opportunities in the Pacific to establish recycling facilities that can collect, sort, and recreate products from recyclable materials. Some technology providers that recycle and produce materials to market have been listed and contacted as part of this review.

Refer to the Technology Providers List (in Appendix A) for companies (predominately plastic recycling technologies) that produce materials such as fence posts, bricks, pavements and building materials, namely Conceptoplastics, Ecopavement, NevHouse, Plastic Fantastic, Precious Plastics and The Plastic Collective.

There are also businesses creating marketplaces connecting recycled product sellers to buyers, such as The Plastics Circle.

Initial screening of technology classes

Technologies to manage recyclable waste include:

- collection, separation and compaction
- washing, sorting, shredding or other methods to break down recyclable materials e.g. enzymatic bio-recycling that uses enzymes to help breakdown plastics
- melting, molding, extruding and reforming equipment e.g. injection molding, vacuum molding, and 3D printing
- recovery by waste to energy conversion technologies e.g. high temperature thermal processes including incineration, pyrolysis and gasification.

Although, managing recyclable waste via direct combustion (incineration) has not been considered appropriate or in accordance with the PacWastePlus programme objectives, waste that is converted to a gas, liquid or solid fuel via high temperature thermal processes including incineration, pyrolysis and gasification has been investigated for its potential to be used as an alternative fuel source option for the Pacific.

Refer to the Technology Providers List (Appendix A) for a list of example companies providing recyclable waste management and who were contacted for this literature review.

Summary of waste technology options

Table 9 Summary of waste technology options assessed for the management of recyclable wastes

Assessment	**Collection, separation, and compaction**	**Washing, sorting, shredding/crushing**	**Recycle: Melting, moulding, extruding and reforming equipment**	**Recovery: Waste to energy conversion technologies**
The ability of the technology to process different waste streams, including collection separation and sorting of waste	Collection of recyclable waste is ideally managed at the source site, where recyclable waste can be manually separated into their main categories e.g. paper, glass, plastic, ferrous and non-ferrous metal etc. from other general wastes. Compaction by balers or bin compactors are employed to help store and transport recyclable material, cardboard, plastics and metals. Australian companies such as Stalogix bin compactor and Tretheway Industries Autobaler are suitable for these applications where waste requires storage before transporting to recycling facilities. ANZRP (TechCollect) employ manual dismantling of the respective components of e-waste and a forty-foot self-contained recycling container that can shred plastics, paper and cardboard. Automated sorting machines such as the Beston Automatic Sorting Machine or Zenrobotics, a robotic sorting station are also available technologies to manage high volumes of waste.	There are many technologies offering capabilities in washing, sorting and shredding of recyclable material in preparation for producing new products or input into energy conversion technologies. Various scales of these technologies are available also, including Komptech various screening and shredding machinery and the Expleco Limited glass crusher. Some of which can be mobile or modular depending upon the scale and application such as the Kiverco Modular Compact Recycling Plant. Plastic Collective, Australia and Precious Plastic, Netherlands also offer modular plastic recycling and production equipment suitable for small scale processing.	Plastic waste in its various compositions e.g. High-density polyethylene (HDPE), Polypropylene (PP), Low-density polyethylene (LDPE) Linear low-density polyethylene (LLDPE), Polyethylene terephthalate (PET) and Polystyrene (PS) has grown in application in the modern throw-away society and as a result appears predominately in waste. Its persistence in the environment has prompted development in its recovery and repurpose. Reformation of plastic waste into various products for further production by companies Envorinex, Australia and though extrusion and reforming equipment by companies such as Plastic Collective, Fantastic Plastic and Precious Plastics are able, in varying degrees to recycle various forms of plastics.	Incinera8 Limited and Uneek Energy apply incineration technology to process all combustible materials, to heat water and air for energy production. Polyfuels Coast Rica applies pyrolysis technology converting plastics, tetrapack containers, rubbers and contaminated solvents into liquid fuel. Earth Systems Consulting produce solid fuel, Biochar from pyrolysis of paper, some plastics and dry biomass i.e. wood, straw and timber wastes.

Assessment	**Collection, separation, and compaction**	**Washing, sorting, shredding/crushing**	**Recycle: Melting, moulding, extruding and reforming equipment**	**Recovery: Waste to energy conversion technologies**
Whether the technology is considered proven (with examples of existing installations of the technology around the world)	Numerous applications of balers and compaction bins operating worldwide, in highly populated cities.	Numerous applications of these processes and technology worldwide.	Envorinex has their reprocessing and remanufacturing equipment installed in various locations within Australia. Expleco Limited have glass to sand bottle crushers operating in 93 countries.	Incineration technologies have been used in countries worldwide, Inciner8 for example has installations in over 180 countries worldwide. Earth Systems Consulting have multiple units installed in Australia, Hong Kong and Israel.
Maximum and minimum annual processing capacity (including scalability)	Readily scaleable, available in varying sizes, dependent upon type of unit and how many units are employed.	Readily scaleable, available in varying sizes, dependent upon type of unit and how many units are employed.	Readily scaleable, available in varying sizes, dependent upon type of unit and how many units are employed.	Readily scaleable, available in varying sizes, dependent upon type of unit and how many units are employed.
Capital cost (ex-factory price) and indicative operational costs in relation to a price range of less than US$200,000, but up to US$5,000,000	Typically, less than US $100,000 per unit.	Project specific	Project specific, typically less than US $200, 000 per unit	High temperature thermal processes for converting recyclable wastes to fuel can cost between US $200,000 to US $5000,000, however is dependent upon the project.
Outputs/waste products recoverable/unrecoverable including wastes	Compacted recyclable waste streams	Recyclable waste streams	Products from recycled plastics such as PE, PP include building products (tiles, floorboards, furnishings), landscape (fence posts, piping). Other output products can also be tailored to local requirements. Process efficiency depends on technology employed but can range from 5% (Precious Plastics) to 20% (Plastic Collective) waste or unrecoverable material. Glass conversion tends to at higher efficiency, where recovery of sand material can range from 95 to 99% glass to sand conversion.	Variable based on technology provider.

Assessment	**Collection, separation, and compaction**	**Washing, sorting, shredding/crushing**	**Recycle: Melting, moulding, extruding and reforming equipment**	**Recovery: Waste to energy conversion technologies**
Ease of operation of technology and potential social benefits (income generator?)	Typically, one person with minimum skill level required.	One to many people required depending upon the hours of operation and volume of plastic being processed. Medium skill level required to operate machinery and electronics. Skills can be obtained on-site or via remote training by most technology provider companies.	One to many people required depending upon the hours of operation and volume of plastic being processed. Medium skill level required to operate machinery and electronics. Skills can be obtained on-site or via remote training by most technology provider companies.	This technology tends to require higher surveillance and is dependent upon the operating requirements of waste to energy conversion technology. For example, the Balanced Energy Cost Rica pyrolysis reactor requires operation 24 hours per day, for as many continuous days as possible and requires three to four persons per shift. For incineration plants a similar approach applies requiring two person shift during the day and at night, in addition to other workers that may be required for the facility.
Potential for adverse emissions to air, water and land	Generally low to no emissions, operating on electricity or battery power, unless a diesel/ petrol baler or compactor was required for a location with no power.	For plastic recycling, wastewater from water baths are typically filtered before release and disposed to capture microparticles and residues. Plastic fumes released to air vary dependent upon plastics being melted. If PP or HDPE plastics are used and not burnt, the toxicity levels are minimal. PS typically has stronger fumes when melted.		Emissions to air are regulated, high temperature thermal processes require management of emissions which are controlled by thermal oxidisers and filtration equipment.

Assessment	**Collection, separation, and compaction**	**Washing, sorting, shredding/crushing**	**Recycle: Melting, moulding, extruding and reforming equipment**	**Recovery: Waste to energy conversion technologies**
Sustainability and energy efficiency	Low impact equipment. Little if any emissions to air or consumables.	Low energy and water consumption that is treated or could be potentially reused, dependent upon project.	Low energy and water consumption that is treated or could be potentially reused, dependent upon project.	Variable
Potential application within each specific Pacific country or partnering countries	Great potential to install these technologies in remote communities where storage might be necessary before transporting to a processing facility become viable.	These technologies promote community engagement through direct employment and education and inspire creation for new products and opportunities. If the process is accessible this will strengthen its take up amongst local community.	These technologies promote community engagement through direct employment and education and inspire creation for new products and opportunities. If the process is accessible this will strengthen its take up amongst local community.	These technologies promote community engagement through direct employment and education and inspire creation for new products and opportunities. If the process is accessible this will strengthen its take up amongst local community.
Commercial viability in the context of the Pacific region.	Promotes in-country employment, high rate of diversion to recycling and recovery processes if recyclable waste can be easily collected and handled.	As above and including ease of scalability and end product market potential, generating more business opportunities and reduction of importing recycled products, applicable to plastic, glass and metal products.	As above and including ease of scalability and end product market potential, generating more business opportunities and reduction of importing recycled products, applicable to plastic, glass and metal products.	Suited to highly populated countries/community centres.

Collection, separation, and compaction

Advantages

- Enables recyclable waste to be easily stored and transported, economical.

Disadvantages

- Equipment located in various locations, spread out, potentially intensive monitoring and maintenance program required.

Washing, sorting, shredding/crushing

Advantages

- Ease of scalability and end product market potential, generating more business opportunities and reduction of importing recycled products, applicable to plastic, glass and metal products.

Disadvantages

- Introduction of new industry, competition in new markets.

Recycle: Melting, moulding, extruding and reforming equipment

Advantages

- Ease of scalability and end product market potential, generating more business opportunities and reduction of importing recycled products, applicable to plastic, glass and metal products.

Disadvantages

- Introduction of new industry, competition in new markets.

Recovery: Waste to energy conversion technologies

Advantages

- Provide alternative fuel sources readily available in country.
- Volume reduction of wastes.

Disadvantages

- Emerging industry in the Pacific, not well-known by local communities, could cause concern or protest
- Air emissions.
- Production of ash.
- Generally, not economically viable in small nation states in the Pacific.

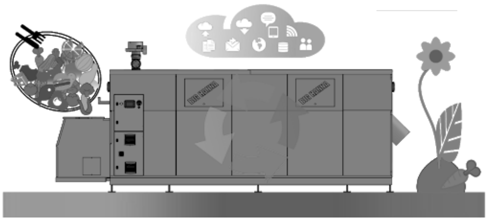
ORGANIC WASTE

Overview

Organic waste includes materials that are biodegradable. Organic waste materials typically include food waste, paper, and garden green waste. Most of the organic waste in the Pacific ends up in dumpsites or landfills.

Organic wastes can be managed through processes via aerobic digestions, such as composting and anaerobic digestion Other management processes employ high temperature thermal treatment of organics which have the potential to produce power, heat, fuel products and agricultural products. More details of these technologies are described below.

Composting



Composting can be performed without the need for an in-vessel system and is inexpensive. The choice of an in-vessel system will depend upon the raw material feedstocks, the volume of material to be composted, the capital available, and the site characteristics. The general types of in-vessel systems are:

- passive aerated bins,
- mechanical aerated containers,
- agitated-aerated containers,
- rotating drums, and
- agitated beds.

These containerised systems all require a:

- container that is supplied with air flow and leachate drainage,
- mixing and loading machine to thoroughly mix the raw materials and load them into the container,
- biofilter, which can be filled with finished compost or wood chips, to control odours,
- process monitoring of the operation,
- an unloading system, and
- a site for curing the compost

The general benefits of in-vessel systems include:

- a controlled process that contains odours and gases,
- reduced land requirements,
- reduced operational requirements (time involved to load and turn drum vs. time to build and periodically turn windrows),
- a more consistent final product, and
- aesthetically pleasing facilities.

Anaerobic Digestion (AD)

Anaerobic digestion (AD) for biogas production is a proven technology that is well known in the municipal waste and wastewater treatment plants. It is commercially ready to use and has multiple benefits (energy savings, waste management cost savings, reduction of environmental impact, reduction of carbon footprint, etc.). In Europe, the small-scale AD concept (<100 kW), applied soundly in the appropriate locations, is a sustainable solution from the economic (energy savings due to self-consumption, waste management savings), energy (self-consumption and reduced losses due to near use) and environmental (reduced or zero transport costs for raw materials and digestate, CO_2 emission abatement) point of view.

High Temperature Thermal

For the disposal/energy recovery of organic waste, high temperature thermal e.g. (combustion, pyrolysis, gasification) is the most used for woody organic wastes with a relatively high calorific value. Incineration involves combustion of organic waste at high temperatures reducing the combustible fraction to an inert ash. Emissions from flue gas are treated to meet local standards and costs are highly depended on the standards to be met. Gasification uses sub-stoichiometric air water or steam unlike incineration where excess or stoichiometric air is used to create a Syngas which is then cleaned and used as a fuel in many processes and is subject to the same emissions standards as incineration in Europe. It does have sensitivity to feeds that are non-homogeneous. Pyrolysis generally uses the application of heat in the absence of air and is more suited to the production of a biochar.

Fuel manufacture

Fuels can be manufactured from solid organic wastes in the form of pellets, briquettes, pucks, torrefied products, and floc. These can then either be used in a thermal facility or exported to an off-site facility or even transported overseas. Collection, separation, and sorting equipment is covered under the Recyclables section.

Initial Screening

The technology types described above are all considered to have potential applicability in the Pacific island region, with the likely exception of fuel manufacturing which relies on an end market and typically requires subsidies (such as carbon-incentives) to be viable. Biochar production, which is at the low-tech end of fuel production and can also be used in land application, has been included under high temperature thermal.

Table 10 Summary of waste technology options assessed for the management of organic waste

Assessment	**Composting**	**Anaerobic Digestion (AD)**	**High Temperature Thermal**
The ability of the technology to process different waste streams, including collection separation and sorting of waste	Composting can deal with all types of organic waste that are readily biodegradable and does not contain contaminants that could affect the quality of the final product.	Anaerobic digestion is most suited to easily digestible waste such as food waste, sludges, industrial wastewaters, certain green wastes, and slurries. As AD uses micro-organisms to process the waste the process can be very susceptible to any contamination that can kill the micro-organisms. ID Gasifiers has just completed a trial on coconut shells in the Solomon Islands.	Incineration is a well proven technology on all combustible organic waste and in particular woody wastes or wastes with an appropriate calorific value. Pyrolysis and gasification can also be applied to all combustible organic waste and in particular woody wastes or wastes with an appropriate calorific value. Emissions are dependent on waste composition and technology exists for cleaning the emissions however wastes which have the potential to produce unacceptable emissions could result in expensive flue gas or syngas cleaning options.
Whether the technology is considered proven (with examples of existing installations of the technology around the world)	Both open and in-vessel composing are well proven technologies and are used extensively all over the world	Anaerobic digestion is well proven technology and is used extensively all over the world particularly in the wastewater sector.	Incineration is a well proven technology and there are extensive examples of installations across the world handling clinical waste. Gasification has been used on coal since the late 1800's to produce town gas before the discovery of natural gas. It is however less popular than combustion in EfW due to higher sensitivity to fuel types. Pyrolysis plants focused on organics are operational in Australia amongst other countries globally and Earth Systems has produced systems that are operating in Australia, Hong Kong and Israel.
Maximum and minimum annual processing capacity (including scalability)	Composting technologies range from small scale domestic or restaurant level technologies to major 200,000 tonnes per annum facilities such as Edmonton in Canada. EcoGuardians provide facilities from 25 kg/day to 3,500 kg/day as detailed with their costs in the section below. NALG provide larger facilities ranging from 2000 tons per annum – 200,000 tons per annum.	AD Systems are generally specifically designed for each project based on material to be processed, anticipated gas production and quantity of material. Larger plant such as that designed by Aquatech Maxcon for Yarra Valley Water provide enough gas to power a 1 MW turbine whereas smaller plant such as that provided by Active Research can be sized for a restaurant complex and may just provide heat or be used for heat and power.	Mass burn incineration facilities can be sized at 1million tonnes per annum and the organics are combusted as a component of MSW and exceed the $5million USD Criteria. Medium sized combustion, gasification and pyrolysis systems e.g. 100,000 tpa can be used just on organics. There are also very small household wood waste burning to small commercial systems below 1kg/h. The Earth Systems Char Maker fits into a shipping container and can be set up as a mobile plant and deal with 9,000 tpa or less of organic material as required. ID Gasifiers provide gasifiers from 95 kg/h to 245 kg/h.

Assessment	**Composting**	**Anaerobic Digestion (AD)**	**High Temperature Thermal**
Capital cost (ex-factory price) and indicative operational costs in relation to a price range of less than US$200,000, but up to US$5,000,000	Domestic scale rotary drum composters can cost as little as $100 USD. Whereas larger commercial in-vessel systems can be well over $200,000USD but less than $1million for a 2000tpa facility. Windrow composting has a lower capital cost but requires a much larger footprint. EcoGuardians A500 – typical up to 25kg day US$22,000 A700 – up to 50kg day US$30,000 A900 – up to 100kg day US$35,000 A1200 – up to 400kg day US$160,000 B1400 - up to 1000kg day US$530,000 B2500 - up to 3500kg day US$1,200,000 NALG composting plant range from Cost varies from 500,000 to 30-40 million depending on annual tonnage. Tonnage range 2,000 to 200,000 tpa.	Active Research- up to US4.5 million dependent on scale. Bioferm – According to their web site provide AD plant in the range of 1,000 to 8,000 +_ tonnes per annum. Biogas3 – Biogas 3 provides a business model manual for guide to economics of AD plant at the following link http://www.biogas3.eu/eng/negocio.html Operational costs are dependent on energy costs and specific sites and economy of scale. See the following link for more information http://www.biogas3.eu/eng/negocio.html	High temperature thermal solutions can be expensive, and the economics are extremely variable dependent on the contamination in the waste stream and the environmental standards to be imposed. Economics are very project specific, dependent on use of energy as well as environmental specifics and generalisation could prove misleading. Capital costs are provided in some of the questionnaires appended and an example in relation to pyrolysis systems that are low in cost is the Earth Systems Char Maker with a capital cost of US$250,000 ex works for a 200 kg/hr machine, with a commissioning cost of US$30,000. A small quantity of gas or diesel is used on start-up and an operator is required for batch loading at the start and end of cycle. The system can be monitored remotely whilst unattended. Discussions with Earth Systems suggested that they could enter into a range of financial/contractual arrangements including sale of technology, rental and providing a service such as processing organics in a disaster situation as they have mobile facilities under construction for their own use.
Outputs/waste products recoverable/unrecoverable including wastes	Compost for application to agriculture and horticulture	Products are biogas for use as a fuel. Digestate can potentially be beneficially reused or will need to be disposed of dependent on local regulations and potential contaminants.	All thermal solutions can provide heat and power with ash as a byproduct which can be beneficially used as a product or would be a disposal item dependent on local market. Pyrolysis also has the potential to create a biochar and a pyrogas as well as in some cases wood vinegar Gasification produces a syngas and an ash product which has potential similar to incineration or can be required to be disposed of.
Ease of operation of technology and potential social benefits (income generator?)	Windrow operation is low skill with the need of potentially a front loader driver. In-vessel composting also does not require skilled workers. The potential social benefits are income from an agricultural product that can improve soils and crop production.	Potential to create power and heat as an income stream to displace diesel generators.	Potential to create power and heat as an income stream to displace diesel generators. Potential to produce biochar as a fuel of soil amendment project. Ease of operation varies with the level of technology with char makers being relatively simple to complex high technology combustion plants.

Assessment	Composting	Anaerobic Digestion (AD)	High Temperature Thermal
Potential for adverse emissions to air, water and land	• Airborne pathogens • Odour • Liquid effluent • Out of specification compost that requires disposal	• Digestate • Air emissions • Odour	• Air emissions from stack • Ash • Liquids form scrubbers if installed • Filtration residue if installed • Fly ash if relevant.
Sustainability and energy efficiency	Dependent on project and composting technology selected. In-vessel is more energy intensive than windrow generally and will provide more work for the community.	Dependent on project and the ability to beneficially use the biogas produced.	Energy intensive if no energy is recovered however can be energy positive and replace fossil fuels in the correct circumstances.
Potential application within each specific Pacific country or partnering countries	Composting is applicable to all Pacific countries as it is completely scaleable and provides a useful product where markets are available for the product.	AD is generally more complex than basic composting and is most suited to certain wastes referenced earlier in the table. It requires a market for the end fuel/biogas to make financial sense in most circumstances outside wastewater treatment.	High temperature thermal solutions could be cost prohibitive and many technologies can be complex. High temperature thermal solutions will be viable where there is no alternative or where there is a requirement for heat and/or power such as where process steam is required and there is a supply of organic fuel.
Commercial viability in the context of the Pacific region.	Viable in the Pacific region as the diversity and scale of options can adapt to individual project requirements.	AD will only be commercially viable in the correct circumstances outside the wastewater treatment sector. This will include the lack of more commercially viable alternatives.	The commercial viability of high temperature thermal is dependent on the contaminants in the organic waste stream such as heavy metals, halogens, etc. and the emissions standards to be met. The requirement for economy of scale could make the technologies unviable in many circumstances.

Composting

Advantages

In-vessel Composting

- Conserved space - The unit itself takes up little space, and therefore the amount of land that must be hard-surfaced is minimized.
- Enclosed process - The compost process is enclosed. Any odors that might arise from the decomposition would be contained. Since the system is impervious to weather, dust during dry times or leachate run-off during rainy periods would not be an issue. The organic material would continue to compost during cold winters. The tumbling agitation of the leaf and brush material inside the container would break it down and expose more surface area to the composting process, greatly speeding up the decomposition and making compost faster.
- Potential to apply to land– The compost produced by an enclosed rotating drum could probably be land-applied without a lengthy curing period.

Windrow System

- Lower capital costs - The equipment costs for windrow systems are much less than for in-vessel systems. The most significant capital expenditure for a windrow system is a good frontend loader with a large (3 or 4 cubic yard) bucket.
- Flexibility - A windrow composting program is flexible. It can be continued indefinitely because no specialized equipment would wear out. It could also easily be discontinued if that becomes necessary.
- Common - Many communities have experience with windrow composting systems, so common problems have been solved, and the operational knowledge exists to deal with them.

Disadvantages

In-vessel Composting

- Potential for imbalances – Even though the process is self-contained, and in the more expensive systems the monitoring, addition of process air, exhaust of gases, and leachate management are controlled and automated, it is still very important to remember it is a biological process. Even with all the latest sophisticated machinery, imbalances in the critical parameters of oxygen levels, moisture levels, temperature, and pH can occur.
- Imbalances more difficult to correct – If biological imbalances do occur, they are more difficult to correct in an enclosed container.
- High capital costs – The capital cost of a system is high compared to windrow solution.
- High replacement costs – A vessel has a limited life span. Given the corrosive nature of the composting process, particularly if food waste were to be added, it may be worn out in seven to ten years.

Windrow Systems

- More space required - Windrow systems require more land area, and hard surface area, than in-vessel systems.
- Weather Impacts - Weather affects windrow composting systems. During a cold winter, decomposition may slow or stop. During a rainy spring or summer, piles may become saturated with water, causing leachate run-off and anaerobic conditions, and additional labor costs may be needed to spread the windrow out to dry and then rebuild it.

Anaerobic Digestion (AD)

Advantages

- Produces a biogas - Produces a biogas from which energy can be recovered.
- Proven Technology - proven technology that is well known in the municipal waste and wastewater treatment plants.
- Sustainability - AD has the potential to provide multiple benefits (energy savings, waste management cost savings, reduction of environmental impact, reduction of carbon footprint, etc.).

Disadvantages

- Capital cost - AD can be more expensive than windrow composting
- Digestate disposal - Digestate may need to be treated prior to disposal or reuse to agriculture.
- Sensitivity to contamination - hard objects can damage up front shredding equipment such as labels in food waste from restaurants and contaminants such as pesticides in green waste can kill the micro-organisms on which the process relies.

High Temperature Thermal

Advantages

- Produces Energy - syngas, pyrogas and/or biochar - Potential to produce energy or agricultural products dependent on technology.
- Complete destruction of pathogens - Complete destruction of animal and plant pathogens.
- Volume reduction - Can reduce volume by 90% dependent on composition of input and technology type.
- Air emissions - As stated above air emissions can be controlled but at a cost.

Disadvantages

- Capital and operating costs – Generally considered high cost hence need to be able to use energy, byproducts or compensate for high alternate disposal costs to be viable in many cases.
- Technical complexity - Technology has advanced and is now highly complex in modern incineration technologies used in Europe. Less complex technology is available however dependent on waste input there is a trade off with atmospheric emissions as much of the cost is in the air emission clean up technology. This also results in a need for higher operator skills and training requirements.
- Air emissions - As stated above air emissions can be controlled but at a cost.
- Ash disposal - Ash if produced by the technology may not have a recyclable outlet and may have to be disposed of to landfill from certain facilities.

DISASTER WASTE

Overview

Disaster waste is typically generated during a natural disaster, causing sudden devastation, from:

Cyclone

Flood

Earthquake

Tsunami

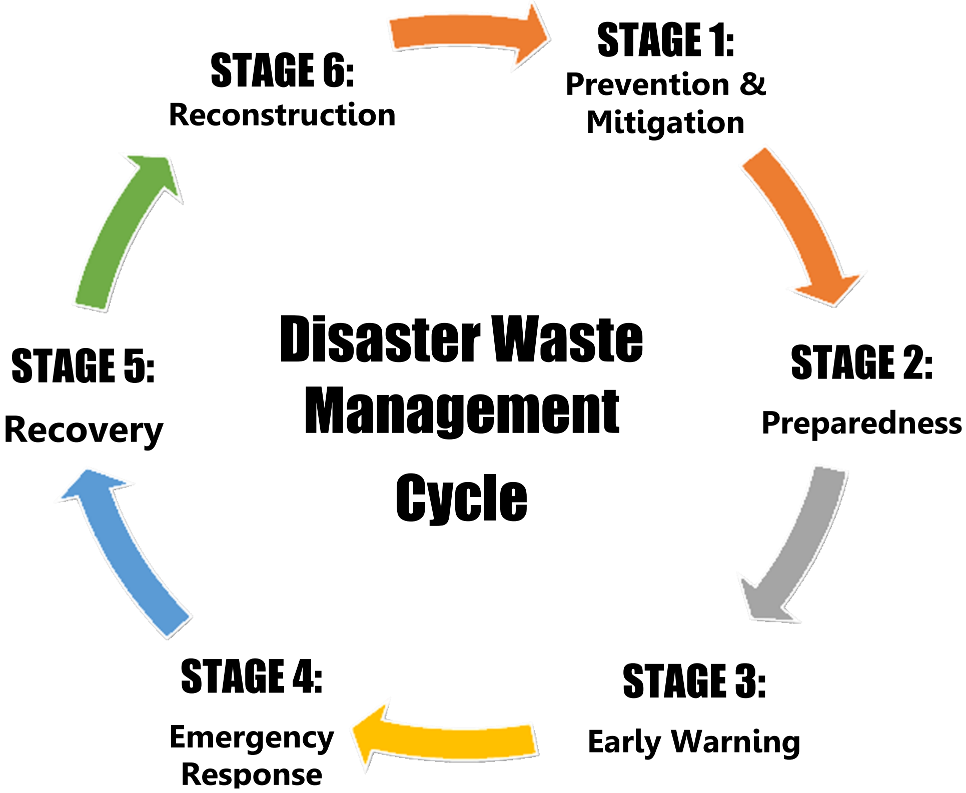
Fire

The result of such event can immediately create large quantities of waste, comprising organic waste, including biomass (e.g. vegetation) and contaminated soils, construction and demolition materials (e.g. bricks and concrete) and hazardous wastes (e.g. chemicals) that can disrupt the functioning of a community and create health and environmental safety risks. Disaster waste is typically intermittent and high in volume that needs to be cleared very quickly (PacWastePlus, 2019).

The Regional Disaster Waste Guideline launched by SPREP in 2019 summarise disaster wastes and associated issues as follows:

- overwhelming waste generated as a result of the impacts of extreme natural hazards to the surrounding natural environment, public infrastructure and facilities as well as people`s properties.
- Piles of waste on the roads when not quickly managed can delay emergency lifesaving operations.
- Hazardous materials like asbestos from building debris directly pose health risks to people.
- Piles of waste can become breeding sites for mosquitoes and rats.
- The consumption of contaminated food supplies from shops is a health risk.
- Leaked containers of waste oil and chemicals from existing businesses and storage facilities if not contained earlier is damaging to the environment.
- There is always a high cost to recover, collect, transport and dispose of safely the large quantities of disaster waste. This is especially for hazardous waste like asbestos and waste oil as well as large items like ships and boats washed on the coastlines.
- High cost of waste disposal sites management to accommodate the large amount of disaster waste during disasters.

The Regional Disaster Waste Guideline describe six stages of disaster management, each with its own management priorities and actions:



Stage 1, 2 and 3 focus more on waste issue assessment, immediate hazard reduction and the movement of waste to temporary storage sites. The use of waste management technologies to process the waste becomes more relevant in stages 4,5 and 6 of disaster management.

Technologies that are suitable for managing disaster waste include:

- Technologies that specifically address the different waste streams that emerge following a disaster, such as those outlined elsewhere in this document for healthcare waste (which could also help treat other biohazardous waste), e-waste, asbestos, recyclables, organic waste, bulky waste and wastewater impacted by solids.
- Technologies that are portable and can be rapidly deployed to a disaster-affected region.

Technologies that can be rapidly deployed are more common for waste streams that have lower tech, or smaller, modular options such as healthcare waste (e.g. low-tech incineration units), recyclables (e.g. low tech plastic recycling), organic waste (e.g. portable biochar facilities) and wastewater impacted by solids (e.g. portable wastewater treatment units). Less deployable technologies tend to be in the areas of e-waste and asbestos, and any waste streams that typically require higher-tech, larger scale facilities.

The Technology Providers List (Appendix A) provides examples of technologies identified for other waste streams that may have applicability for disaster waste management due to their portability. However, fixed waste management facilities also have a role to play when they can receive, stockpile and treat disaster waste.

BULKY WASTE

Overview

Bulky waste describes wastes that are too large to be accepted by regular waste collection services due to its size and nature.

Currently, waste collection authorities in the Pacific undertake separate collection for bulky wastes (a costly effort) or such wastes are disposed of in community dump sites. Due to this current management, bulky waste has the potential to contaminate soil and surrounding waterways, posing a threat to health and local communities.

Management of bulky wastes typically requires:

Collection:
haulage/transport vehicles for collection, or the option and accessibility for community to drop of larger items

Storage:
facilities that contain areas that are safe and secure including:

- containment (bunding) to hold toxic components within bulky wastes e.g. heavy metals and refrigerants within the site
- management of storage volumes at safe heights for large, heavy items

Processing:
equipment to manage larger size items and volumes of waste

Investigating options for collection and storage are beyond the scope of this investigation. Bulky waste typically contains recyclable components, including metals, plastics and glass that can be dismantled and separated for further processing and recycling. As bulky waste is varied and complex in nature, it does not generally have single dedicated technologies, but relies upon separate technologies for sorting/separating, shredding, recovery, and recycling. These technologies are typically the same as used for other waste streams such as recyclables, e-waste, asbestos, and wastewater impacted by solids (solvents and oils), as detailed elsewhere in this document. The Technology Providers List (Appendix A) provides examples of technologies identified for bulky waste, including tyres and the other waste streams that have applicability.

Wastewater

WASTEWATER

Overview

The PacWastePlus programme wastewater management priority encompasses waterways (surface and groundwaters) impacted by solid wastes from activities involving:

Landfill from the production of leachates

Mining and other industry

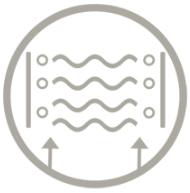
Contaminated soils, from water encountering soil impacted by oil spillage or debris from military operations e.g. explosives

Point source pollution from stormwater drains

The intention for managing wastewater impacted by solid wastes in the Pacific is to monitor and protect the receiving environment from waste facilities or solid waste handling activities. Environmental protection in the Pacific Islands is administered by the USEPA Region 9 Pacific Southwest. Treated wastewater returning back into the environment is managed under the National Pollutant Discharge Elimination System (NPDES), a program under the Clean Water Act (1972) to help address water pollution by regulating point sources that discharge pollutants to waters of the United States. The NPDS Program Areas include industrial (including mining, oil and gas) and municipal wastewaters and stormwater runoff. Wastewater treatment systems installed are regulated under this program. Refer to the Technology Providers List (Appendix A) for a list of example companies providing wastewater management and who were contacted for this literature review. Technologies that could treat water impacted by solid wastes are outlined below.

Gross pollutant traps

Gross Pollutant Traps (GPTs) are coarse filters to catch litter and silt from entering the environment through urban drainage systems. They can employ various methods to filter and separate solid waste from water (e.g. hydraulic treatment via vortex, or filtration sieve). GPTs are typically installed directly into the stormwater drainage systems to capture contaminants close to the surface including litter or debris. GPTs typically remove 99% of gross pollutants at the surface/point source (Enviroconcepts, 2020). GPTs can be sized to custom pit sizes and are typically, quick, and easy to install, requiring simple maintenance. Costs of this technology are dependent upon site conditions. Examples of companies providing this technology include SPEL stormwater and Environconcepts. More information about these providers are listed in the technology provider list in Appendix A.



Clarifiers/Dissolved Air Flotation

Clarifiers, such as dissolved air flotation (DAF) systems can remove solids and hydrocarbons, including fats, oils, and heavy metals. The process involves air bubbles being emitted to the wastewater which binds with the oils and fats and precipitates metals and suspended solids to increase their flotation ability. The result enables pollutants to float to the surface for easy removal by a mechanical scraper. Clarifiers, like DAFs are widely used in wastewater treatment in various settings; they can be used to treat wastewaters from petrochemical and chemical plants, food processing facilities, dairies, abattoirs and water from heavy equipment and machinery washdowns. They have the capacity to eliminate up to 95% of suspended solids, heavy metals, oil and grease from water and wastewater sources from mining operations (Enviroconcepts, 2020). This technology can be sized accordingly and generally requires some technical skills and knowledge of operation and general maintenance.

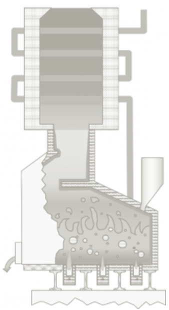
Filtration systems (media)

Filtration systems remove various particle sizes and suspended solids, and as a result can remove pollutants such as oils, metals, toxic chemicals in wastewater. There are many types of filtration materials of varying pore size including, micro filtration, ultra-filtration, multi-media, and cartridge filtration. Media filtration units can be used to remove iron, colour, and hydrocarbons. Making this technology suitable for treating water impacted by industry, including mining, and water that has been in contacted with contaminated soils. Examples of companies providing this technology include SPEL stormwater and Environconcepts, more information about these providers are listed in the technology provider list in Appendix A.

Sterilisation (Chemical/UV/Ozone)

Water requiring sterilsation requires the destruction of pathogens including bacteria, viruses, and cysts from wastewater. The use of chemicals such as chlorine, UV light and ozone can be used to remove pathogens (and metals) in wastewater, essentially destroying (or reducing to an acceptable level) bacteria, viruses, and cysts from wastewater, enabling discharge into a receiving environment or reuse of water that is fit for purpose. These systems can vary in size and cost, and performance is based on project specifications.

Submerged combustion technology



Submerged combustion technology is provided by BeneTerra Australia by their BeneVap plant. This technology can reduce the volume of wastewater or eliminate production water from oil and gas extraction, landfill leachate and industrial wastes. The BeneVap is proven technology used in US and Australia. The process employees blowing air to create hot gas bubbles into a liquid wastewater solution. The resulting water vapour that forms inside the liquid waste, essentially incinerates the dissolved and suspended solid wastes, separating the liquid, and forming a concentrate sludge. There are currently two models of this technology available (Model BV150 and BV300) offering a maximum evaporative capacity from 30,000 L/d (turndown rate 2:1) to 50,000 L/d (turndown rate 2:1). The cost range of the technology is AUD500,000 to 1,000,000, depending upon customisation, materials used, fuel supply booster, components, and communications package. The BeneVap process' high energy consumption could deter form its use unless regulation drives the project. The BeneVap machines can be operated by company staff or local personnel on-site with some mechanical and instrument knowledge. Remote access and monitoring allow for real-time remote operation, but requires internet connection, typically by cellular modem.

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Appendix A: Technology Provider List and Assessment Matrix

Please find matrix on the PacWastePlus website – https://www.sprep.org/pacwaste-plus

EUROPEAN UNION

SPREP
Secretariat of the Pacific Regional Environment Programme

PacWastePlus
PACIFIC WASTE MANAGEMENT