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Secretariat of the Pacific Regional Environment Programme

PacWastePlus
PACIFIC WASTE MANAGEMENT

This initiative is supported by **PacWastePlus**-a 72 month project funded by the European Union (**EU**) and implemented by the Secretariat of the Pacific Regional Environment Programme (**SPREP**) **to sustainably and cost effectively improve regional management of waste and pollution.**

WASTE-to-ENERGY
Information Booklet

November 2021

Further information is provided in a full Advanced Waste Technology Research Report, with this Information Booklet providing a high-level summary. The full Research Report provides more context for waste generation and renewable energy targets, along with case studies and examples of each type of technology viewed as applicable to the Pacific region and Timor Leste.

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Our vision: A resilient Pacific environment sustaining our livelihoods and natural heritage in harmony with our cultures.

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Contents

Acronyms

3Rs	Reduce, Reuse, Recycle
AD	Anaerobic Digestion
CSTR	Continuous Stirred Tank Reactor
EIA	Environmental Impact Assessment
FOG	Fats, Oils, and Grease
GHG	Greenhouse Gas
H_2	Hydrogen
HCFCs	Hydrochlorofluorocarbons
HRT	Hydraulic Retention Time
MSW	Municipal Solid Waste
PESTLE	Political, Environmental, Social, Technological, Legal and Economic
PICs	Pacific Island Countries
PPP	Public Private Partnership
RNG	Renewable Natural Gas
SPREP	Secretariat of the Pacific Regional Environment Programme
SWM	Solid Waste Management
UASB	Upflow Anaerobic Sludge Blanket
UNEP	United Nations Environment Programme
WTE	Waste to Energy

PacWastePlus Programme

The Pacific – European Union (EU) Waste Management Programme, PacWastePlus, is a 72-month programme funded by the EU and implemented by the Secretariat of the Pacific Regional Environment Programme (SPREP) to improve regional management of waste and pollution sustainably and cost-effectively.

About PacWastePlus

The impact of waste and pollution is taking its toll on the health of communities, degrading natural ecosystems, threatening food security, impeding resilience to climate change, and adversely impacting social and economic development of countries in the region. The PacWastePlus programme will generate improved economic, social, health, and environmental benefits by enhancing existing activities and building capacity and sustainability into waste management practices for all participating countries.

Countries participating in the PacWastePlus programme are: *Cook Islands, Democratic Republic of Timor-Leste, Federated States of Micronesia, Fiji, Kiribati, Nauru, Niue, Palau, Papua New Guinea, Republic of Marshall Islands, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu*.

KEY OBJECTIVES

Outcomes & Key Result Areas

The overall objective of PacWastePlus is “to generate improved economic, social, health and environmental benefits arising from stronger regional economic integration and the sustainable management of natural resources and the environment”.

The specific objective is “to ensure the safe and sustainable management of waste with due regard for the conservation of biodiversity, health and wellbeing of Pacific Island communities and climate change mitigation and adaptation requirements”.

Key Result Areas

- **Improved data collection, information sharing, and education awareness**
- **Policy & Regulation** - Policies and regulatory frameworks developed and implemented.
- **Best Practices** - Enhanced private sector engagement and infrastructure development implemented
- **Human Capacity** - Enhanced human capacity

Learn more about the PacWastePlus programme by visiting

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PacWastePlus
PACIFIC WASTE MANAGEMENT

https://pacwasteplus.org/

Background

The *Cleaner Pacific 2025: Pacific Regional Waste and Pollution Management Strategy 2016–2025* was developed for and in consultation with the Pacific islands. By addressing waste, chemicals and pollutants, the Strategy aims to reduce associated threats to sustainable development of the region.

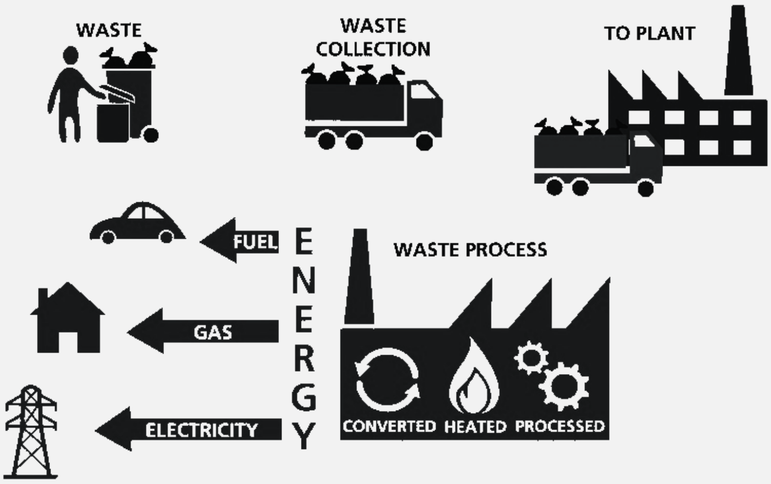
Within the Strategy, there is acknowledgement of the growing interest among Pacific Island countries (PICs) to explore municipal waste-to-energy (WTE) options that reduce the need for landfills and dependence on diesel importation for electricity generation. The promotion of proprietary waste to energy technology by international companies is highlighted in the Strategy as a driver, with concerns that long-term affordability and sustainability are not always taken fully into account in these discussions. The Strategy raises key risks and recommends rigorous investigation of the suitability and constraints of WTE approaches for PICs.

It is often difficult to determine the applicability of advanced waste technologies for countries with lower populations and limited financial resources for operational costs. This research is timely for PICs, providing advice on the most applicable options for more detailed feasibility analysis. Up to date and relevant information will inform options for investment in future waste management, using a technology-agnostic approach to short-list applicable technologies while acknowledging constraints and risks.

Further information is provided in a full *Advanced Waste Technology Research Report*, with this Information Booklet providing a high-level summary. The full Research Report provides more context for waste generation and renewable energy targets, along with case studies and examples of each type of technology viewed as applicable to the Pacific region and Timor-Leste.

What is Waste-to-Energy?

Waste-to-Energy (WTE) technologies are also known as an Advanced Waste Technologies. These are technologies to improve the management of waste and harness the energy within materials that are traditionally viewed as rubbish. The promise of WTE is that it turns a problem into a resource, reducing greenhouse gas emissions by effectively using waste to replace fossil fuel energy sources, and reducing the need for landfills. There are several options that can be broadly grouped into thermal, biological, and mechanical processes.



This Information Booklet cannot provide a detailed investigation of all technologies on the marketplace. Technologies are rapidly developing, with many plants still in the design and commissioning phase. The options reviewed use municipal solid waste (MSW) as a resource to produce an energy output.

The technologies range from household or community scale bio-digesters through to high-tech pyrolysis thermal technologies. These technologies have been established for several years in parts of the world such as Europe and Singapore, but are they the right solution for the Pacific region and Timor-Leste?

Understanding the Challenges

Drivers for Change

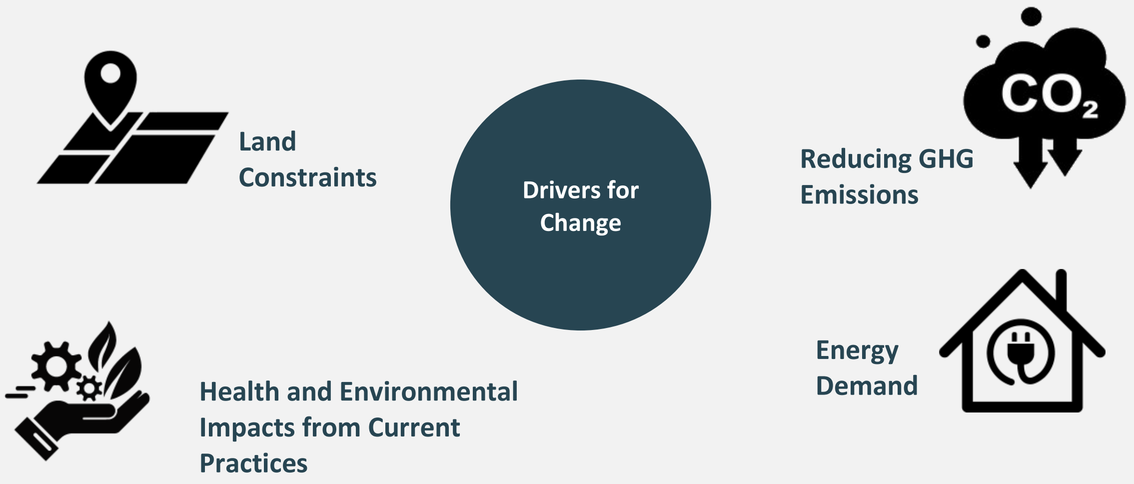


Figure 1 Global Drivers for Adopting Advanced Waste Technologies

There are several drivers for change, which have led many to consider WTE, such as:

- Lack of land availability for landfill expansion and development of new disposal sites
- Changing lifestyle and consumer choices leading to increased volumes of waste generation
- Risk of pollution of land and water through uncontrolled or unlined landfills, particularly for atoll countries
- Distance to market for recycling commodities and lack of economy of scale
- Increasing presence of plastic marine debris
- The moral imperative to demonstrate that low emission countries are also playing a part in reducing GHG emissions, replacing fossil fuel energy sources with renewable energy
- Limited energy security due to reliance on imported fuels

Key Constraints

Even though the drivers promote a keen interest in alternative approaches to landfill, broader waste management constraints must be kept in mind, including:

- Limited reliability and efficiency in waste collection services
- Low awareness or engagement in improved waste management
- Limited willingness to pay for waste services and infrastructure
- High-wear coastal environments combined with lack of funding or capacity for vehicle and equipment maintenance
- Insufficient government priority and political support for action
- Relatively small population sizes
- High population density in some urban centres or countries with limited land
- Unplanned urban sprawl
- Fluctuating visitor arrival numbers generating waste

Considering WTE Technologies

With a greater focus on improved waste management by donors, the regional community, national decision makers, and communities; waste management has improved over the last decades. This includes improvements to laws and infrastructure, increasing awareness, and progress in initiatives like recycling and composting.

Landfill may not always be the best option for residual waste, particularly in countries with atoll islands, or limited land availability. The other key factor is energy. Converting waste into energy is viewed in many jurisdictions as a critical component of a circular economy (after waste reduction, reuse, and recycling).

Compared to landfill, advanced waste technologies can reduce greenhouse gas emissions, which is a key driver for change in many countries. As part of this bigger picture, advanced waste technologies can play an anchoring role within a carefully planned integrated waste management system.

Any appraisal of technologies should be informed by locally specific feasibility work, ensuring technologies are in line with local priorities. Experience elsewhere demonstrates that thorough planning and appraisal without a bias towards a particular technology or company, are fundamental to sound decision making.

Summary of Technologies Applicable to the Pacific Region

Technology Summary

WTE technologies are rapidly developing, with many options that vary in feedstock requirements, scale, complexity, and outputs. There are several technologies that are inappropriate for the Pacific Island and Timor-Leste context.

The following technologies are those that may be applicable in the Pacific and Timor-Leste.

Combustion

Inciner8 combustion reactor in Kiribati, Tonga, Tuvalu, and Vanuatu for medical waste (note this is combustion only, without energy generation) Image Source: Inciner8, 2016

Waste is placed in a furnace where it is combusted at high temperatures to recover energy and sometimes heat. Combustion reduces most wastes by up to 85% of their original volume.

High temperatures can destroy toxins and pathogens in clinical and hazardous wastes.

Incinerator types include rotary kilns, fluidised beds, and moving or sloping grate incinerators. Waste is burnt to produce heat, leaving materials such as recoverable metals, bottom ash, flue gases and particulates. Gases pass through air pollution abatement equipment.

Residual flue ash and bottom ash need to be disposed in a specialised hazardous waste landfill. The most robust and proven combustion technology is categorised as moving grate, mass burn technology.

This does not require pre-treatment or sorting of MSW, giving it flexibility to accommodate large quantities and variations in waste composition and calorific value.

Pyrolysis

PacPyro pyrolysis plant in Somersby, Australia
Image Source: WasteMINZ, 2011

Nufuels Limited small-scale pyrolysis system in the Solomon Islands
Image Source: WasteMINZ, 2011

Pyrolysis is the thermal decomposition of material with no oxygen present. Feedstock must be first dried and crushed. Heat is applied indirectly, more like an oven than a burn chamber. There are three main types of pyrolysis technology - slow, fast, and flash.

There is also microwave-assisted pyrolysis. All types produce varying amounts of outputs (biochar, bio-oil, and syngas) with yields dependent on the technology selection.

All types of pyrolysis can be carried out as either a batch process or a continuous process. Pyrolysis typically consists of a reactor, a cyclone for the fly ash, and a condenser to condense the pyrolysis oil.

The different reactor types include fixed bed reactor, circulating fluidised bed reactor (bubbling bed), rotating cone reactor, entrained flow reactor, ablative (plate or rotary), auger reactor, and more.

There are some examples of small-scale pyrolysis technologies treating MSW, including modular systems that can be expanded with increased waste generation.

Depending on the type of pyrolysis and the scale, ease of operation of a pyrolysis plant varies significantly. Pyrolysis reactors can use their own energy produced to power the system as well as to dry the feedstock, without requiring further energy inputs.

The output of pyrolysis oil, known as bio-oil, is toxic without further treatment (such as hydrogenation and distillation).

Gasification

Afolau gasification plant in Samoa - commissioned Nov 2020
Image Source: *UNDP, 2021*

Waste is broken down in a low oxygen atmosphere, and generally operates at higher temperatures of above 700 ºC. Like pyrolysis, the process also results in the production of a char and a syngas, which can be used to generate energy. There are many different types of gasification reactors available, including fixed bed, circulating fluidised bed, entrained bed, as well as supercritical water gasifiers.

The main product is syngas – which usually needs to go through a cleaning process at the end. Additionally, a solid char is produced as a by-product, and heat is also produced.

Plug-flow Anaerobic Digestion

Smartferm Plug Flow Dry Anaerobic Digestion Technology, Monterey (U.S.)
Image Source: *Zero Waste Energy, 2013*

Anaerobic digestion (AD) is a biological treatment that generates energy as an output. Unlike thermal treatment that favours dry, high calorific wastes as feedstock, anaerobic digestion generally prefers wet, putrescible material with high organic biodegradable content. Anaerobic microorganisms decompose organic wastes in closed anaerobic reactors to produce biogas and digestate. The biogas can then be used to produce electricity, cleaned, and upgraded into renewable natural gas (RNG) or be used as a direct fuel in furnaces or boilers.

AD facilities typically process source separated organics (such as household food and garden waste) animal manure, fats, oils, and grease (FOG), agricultural residuals, and food processing residuals. In an AD facility, feedstock is received in a building, deposited onto a tipping floor or pit where the material is then transported to pre-processing equipment to prepare material for digestion. Feedstock is pre-processed to remove contaminants (such as plastics, metals, glass, packaging, bones, and other non-organic items), and then turned into a slurry that feeds the digestion tank, while the other material is removed as contamination.

Plug flow AD reactors are the most adaptable in treating mixed feedstock with high solids content, such as food waste or the organic fraction of MSW. Their primary objective is inclined more for waste management rather than biogas yield. They are elongated reactors with widely spaced paddle arms to slowly move the contents forward as a plug while creating a minimal amount of mixing. This provides for a more flexible operation that allows for longer retention times and reduces the risk of sudden imbalances brought on by inconsistent feedstock quality or quantity.

Co-Digestion

Hermitage Municipal Authority Wastewater Treatment Plant Co-Digestion Food Waste
Image Source: *Waste Management World, 2016*

Co-digestion utilises more than one feedstock. This technique combines feedstocks to achieve a complementary nutrient and/or moisture balance and enhance biological processes.

Co-digestion of wastewater treatment sludge with source separated organics is increasingly considered as a method to boost biogas yields and use excess digester capacity.

However, this approach requires careful regulation of feedstocks to optimise or maintain reactor performance. There is significant research ongoing in co-digestion, with co-digestion principles being applied to existing facilities and in the design of new facilities to optimise waste management outcomes and enhance biogas yields.

Small Scale Biogas Reactor

Community Biogas Reactor in Samoa – Site Preparation, Tank Modules, Biodigestion Bags, Gas Equipment
Image Source: *Ward and Rucks, 2013*

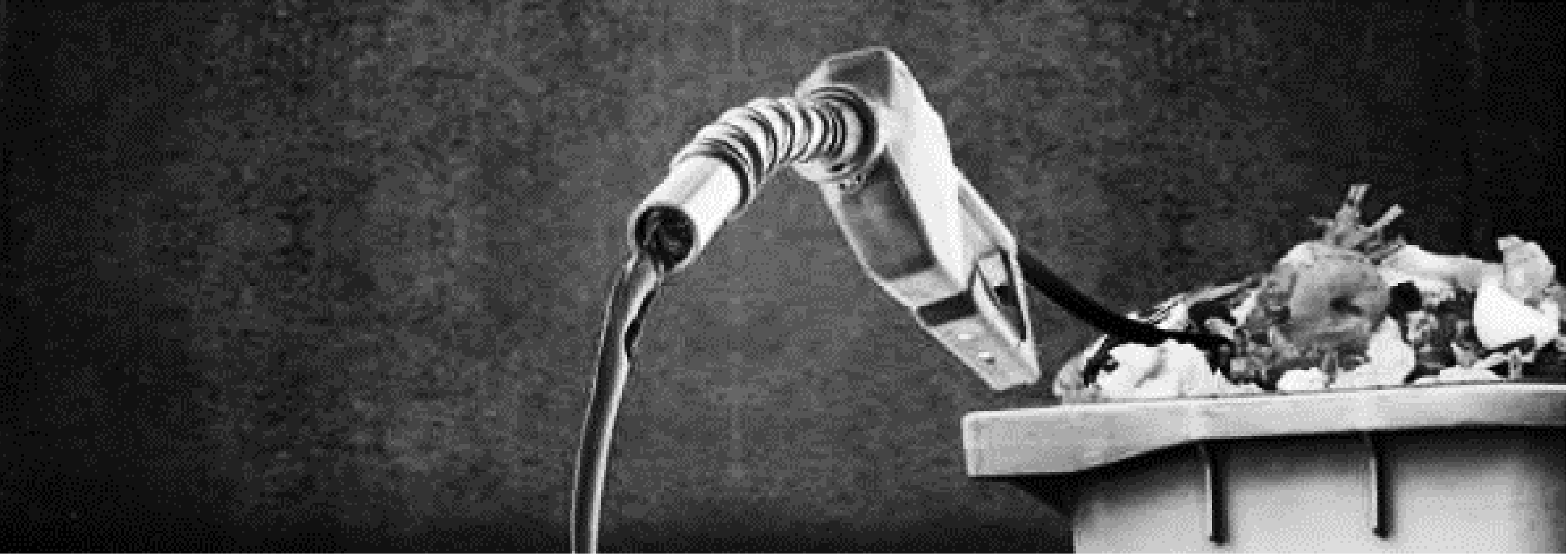
Small-scale biodigestion plants are AD plants that are smaller, less expensive, and easy to maintain. These units can be used on farms, or at a small community scale or at individual households to capture and create a source of clean energy from organic waste.

This produces biogas, with production units typically below 80 kW. The scale of this type of AD facility varies with a feedstock of 200 to 5000 tonnes of organic waste per year.

Feedstock is typically animal manures, food waste, industrial waste such as abattoir waste, or sewage sludge.

Small, fixed dome digesters consist of an inlet trough, a lower fermenting reservoir with a rigid, immovable collection dome capping it, and some type of overflow relief.

Most are constructed underground, with biogas collected and utilised on-site. The gas pressure is subject to fluctuations, requiring a regulating device.



Advantages, Disadvantages, and Risks

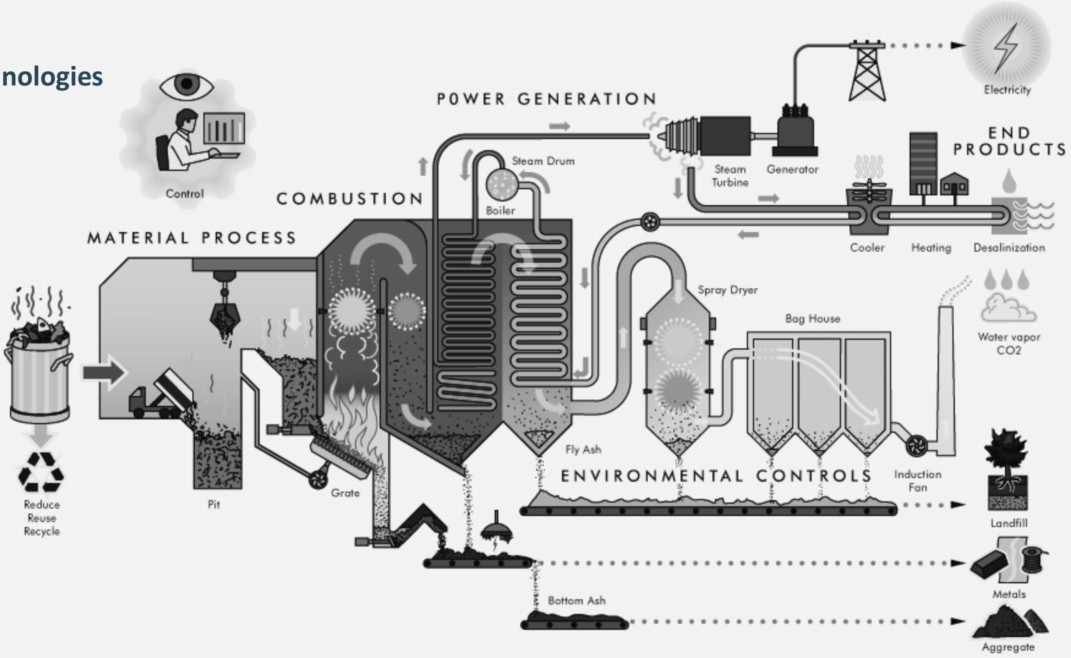
A critical issue for all advanced waste technologies are the requirements for operational capacity and ongoing maintenance, except for small-scale biogas reactors. Each of the technologies will have different requirements, but all require a degree of operational expertise and ongoing support as a pre-requisite for success.

Maintenance requirements must be carefully planned, with servicing, repairs and potential refurbishment factored in from the outset.

Long term operational support, training, and maintenance contracts should be considered. Several countries in the region do not have adequate technical skills in-country, or strong institutional cultures of proactive repairs and maintenance, a situation exacerbated by harsh coastal environments. As such, longer term partnership models may provide a sound option.

Thermal Technologies

Combustion



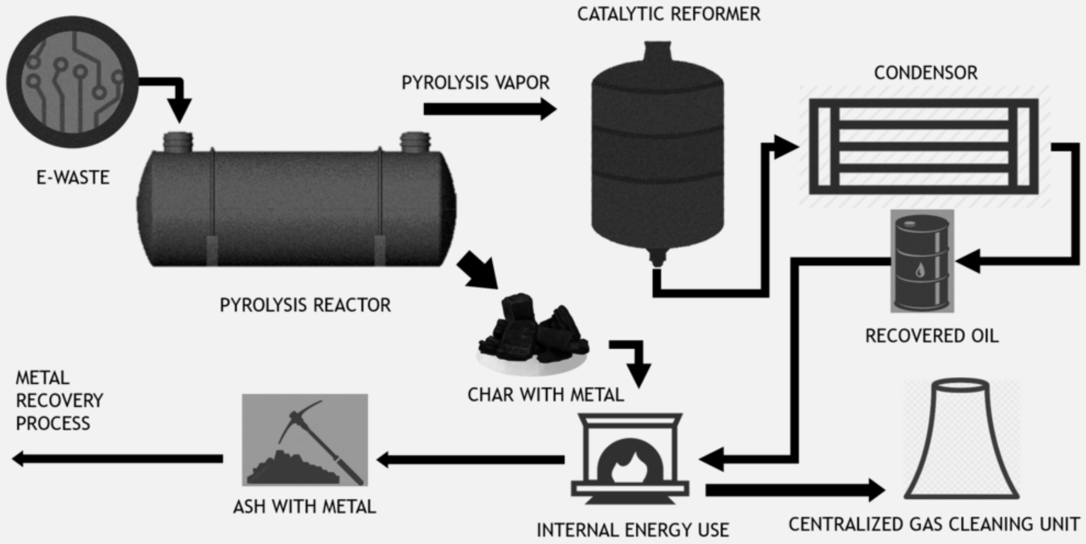
Advantages

- Reduces waste (up to 85%) whilst providing a useful energy output at the same time. Economic advantage with regarding operating costs when using waste as feedstock.
- Less pre-treatment of waste feedstock required compared to pyrolysis and gasification.
- Generally lower operating temperatures compared to gasification, resulting in reduced operating costs and a reduced safety risk. However, combustion has higher operating temperatures than pyrolysis.
- Relatively simple to operate and transport due to modular units available. Additionally, this makes them easy to scale up or down by simply adding more units.
- Mature technology, even for conversion of municipal solid waste to energy.
- Effective energy capture. The heat produced in the process is converted to steam to run turbines and generate electricity. Some incinerators can also capture the heat given off and feed it back into communities for general heating, hot water supply and other uses. A typical electricity only combustion system can operate at electrical efficiencies from 14% to 24% with a maximum efficiency of approximately 27% for the most modern facilities.
- Proven technology with many case studies of varying scale and approaches.

Disadvantages

- Excess GHG emissions. The emissions produced through combustion of waste are far greater than those produced through other thermal technologies such as pyrolysis and gasification. This is due to the excess oxygen environment.
- Limited range of products compared to pyrolysis and gasification. Only steam is produced as a useful product, but it can be converted to electricity.
- Potentially difficult to gain required consent and other specific legal requirements and sign off due to nature of technology – it has a negative reputation as it is seen as “burning rubbish”. Older technologies with less rigorous pollution control led to releases of dioxins and heavy metals, adding to negative perceptions of the technology, despite improvements in emission controls.
- Results in a higher amount of ash requiring further contained disposal such as landfilling compared to that of pyrolysis technologies.
- Emissions are less contained compared to pyrolysis and gasification technologies. Relies a lot on flue stack pollution mitigation technologies to be failsafe.
- Longer residence times, compared to pyrolysis and gasification.
- Some models require a priming fluid for start-up, adding operational costs.

Pyrolysis



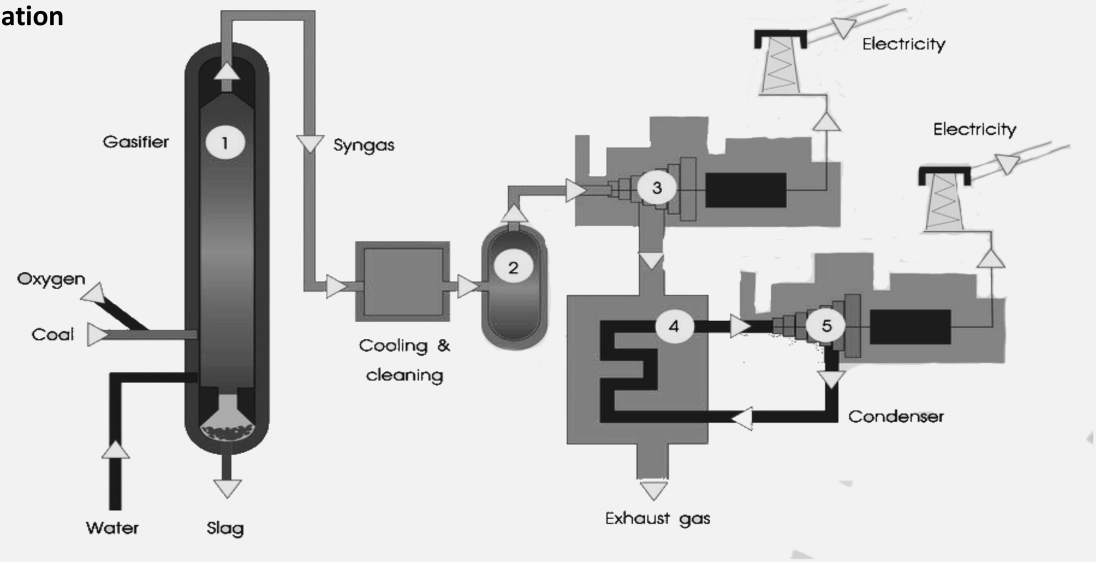
Advantages

- Reduces waste whilst providing a useful energy output at the same time. Economic advantage with regarding operating costs when using waste as feedstock.
- Low air pollution. The oxygen starved environment means no dioxins nor ultrafine particulate matter is produced (or at least very minimal amounts).
- Range of products. The different types of pyrolysis and operating conditions allow different products to be produced with different applications, whether that be solid biochar, liquid bio-oil, or syngas.
- Controlled emissions. All emissions are easily captured within the syngas, providing easy removal through syngas cleaning, allowing better containment of contaminants.
- Efficient. Pyrolysis is a very efficient process with high conversion of feedstock to products (e.g., high bio-oil yield). Although, if electricity is the desired product, pyrolysis efficiency is lower, similar to that of combustion technologies.
- Easy to operate and transport due to modular units available. Additionally, this makes them easy to scale up or down by simply adding more units.
- Liquid products have a similar heating value compared to fossil fuels.
- Can be used to convert a wide range of waste streams.

Disadvantages

- Unwanted by-products produced. Inert bottom ash is produced which requires contained disposal such as landfill.
- Most pyrolysis types require some form of pre-treatment of feedstock. This includes crushing and drying the MSW before entering the pyrolysis reactor.
- Elevated temperatures. The required elevated operating temperatures are a disadvantage from both a safety and an operating cost perspective.

Gasification



Advantages

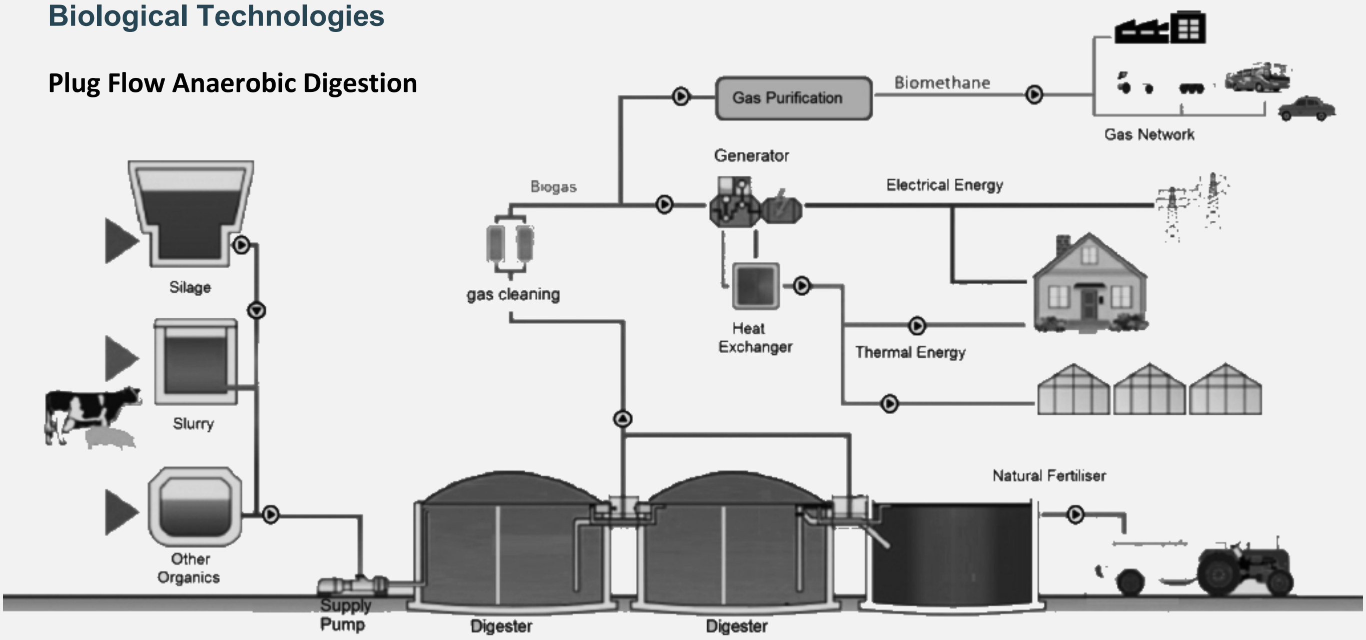
- Low air pollution. Similar to pyrolysis, gasification takes place in a low oxygen environment, which limits the formation of dioxins and SOx and NOx.
- Operated at or near atmospheric pressure. This is an advantage with respect to operating energy requirements and therefore operating costs, as well as an advantage with respect to safety.
- Reduces waste whilst providing a useful energy output at the same time. Economic advantage with regards to operating costs when using waste as feedstock.
- Range of products. The different types of gasification and their operating conditions allow different products to be produced with different applications, whether that be liquid bio-oil, or syngas.
- Controlled emissions. All emissions are easily captured within the syngas, providing easy removal through syngas cleaning, allowing containment of contaminants.
- Efficient. Gasification is a very efficient process with high conversion of feedstock to products (e.g., high bio-oil yield), especially when compared to combustion technologies.
- Easy to operate and transport due to modular units available. Additionally, this makes them easy to scale up or down by simply adding more units.
- Mature technology, even for conversion of municipal solid waste to energy and can be used to convert a wide range of waste streams.

Disadvantages

- Elevated temperatures. The required elevated operating temperatures are a disadvantage from both a safety and an operating cost perspective.
- Potentially difficult to gain required consent and other specific legal requirements and sign off due to nature of technology – it has a negative reputation as it is seen as “burning rubbish”.
- Significant financial capital expenditure, especially compared to combustion technology, however, this was not viewed as a fatal flaw given the potential for externally funding (providing it meets donor or lender criteria).
- Longer residence times compared to pyrolysis; however, gasification is faster than combustion technology.
- Results in a higher amount of ash requiring further contained disposal such as landfilling compared to that of pyrolysis technologies.

Biological Technologies

Plug Flow Anaerobic Digestion



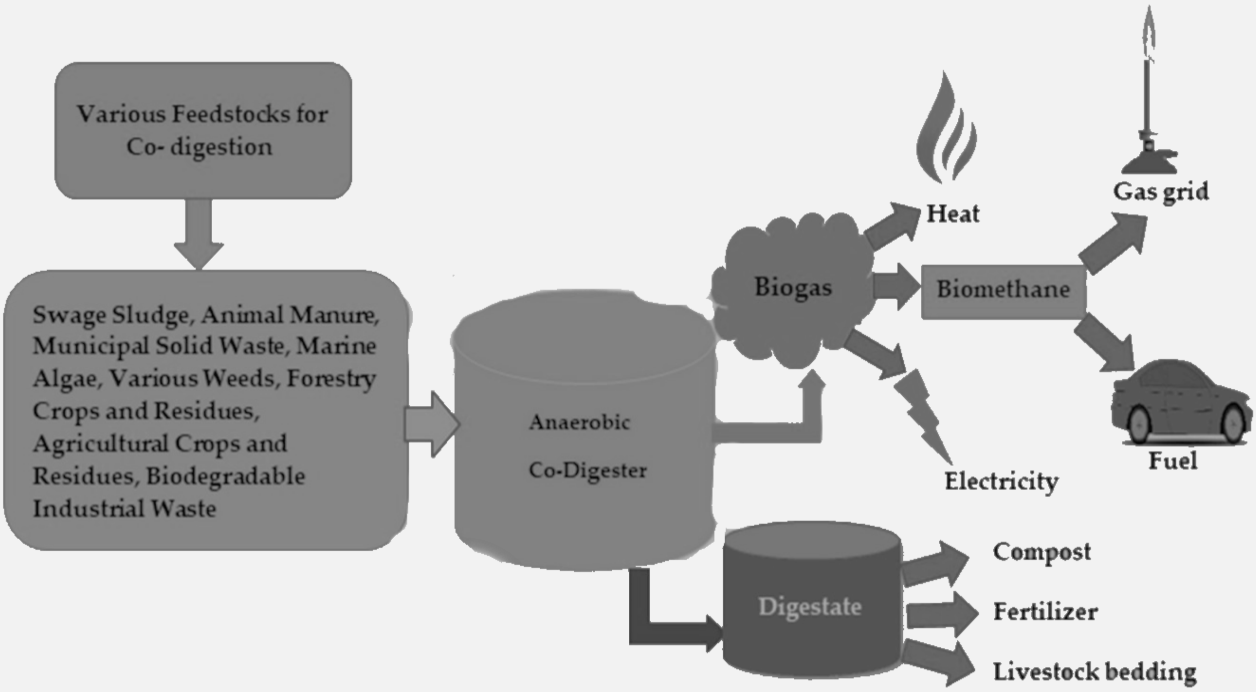
Advantages

- Less water consumption as the system can operate with low water inputs or without liquid addition.
- The flexibility to operate under drier conditions allows for a higher volume load of organic material per cubic meter of digester volume.
- It is sufficient to use smaller dewatering equipment considering that a drier digestate and less effluent volume is produced.
- Plug flow requires a longer time for substrate to pass through the reactor, improving sterilisation process of the output.

Disadvantages

- The anaerobic fermentation is slower and retention time longer than other AD systems.
- Having a long narrow design increases susceptibility to dead zones (where there is no microorganism activity) usually near corners, which can affect process performance.
- Requires more robust pumps and secondary equipment (to prevent dead zones), thus adding further costs.
- The drier process means less water is available to dilute the salts within the mix, presenting higher risk for salt concentration reaching toxic levels unless managed carefully.

Co-Digestion



Advantages

- The combination of different feedstocks can help improve nutrient balance and digester performance leading to higher biogas generation.

- The digestibility of feedstock with poor characteristics e.g., floating wastes, wastes with inhibiting components etc., can be compensated by other materials that instead complements and rectifies the shortcomings of the main material.

- Ability to target high-value feedstock that allows for higher biogas production.

Disadvantages

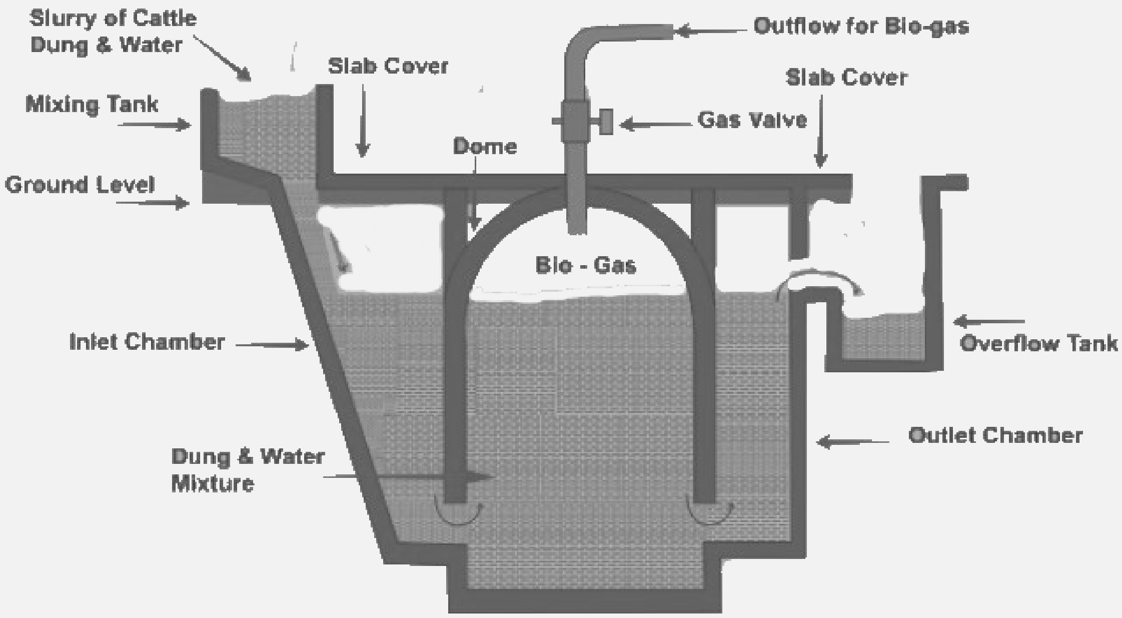
- The variable feedstock quality and quantity increases the risk of introducing fluctuating organic loading and inhibitory substances e.g., antibiotics, copper etc.

- Increased mixing and pre-treatment are required to prepare the different substrates into one homogenise and compatible feedstock.

- Likely presence of pathogens derived from certain feedstock mixtures (e.g., with manure or food waste addition), would require hygienisation compliance and the associated additional permits, infrastructure, and management.

- Restrictions of land use for produced digestate.

Small Scale Biogas Reactor



Advantages

- Simple, basic, compact design requiring minimal initial cost.
- Viable where land is scarce, especially if digesters are built underground.
- Easier system for community to maintain because the procedures to improve mixing or heating are nonessential with these digesters.
- Offers a two-pronged solution in waste disposal and energy demand for underprivileged communities through a cheap, viable and renewable method.
- Can provide accessible clean technology at a grass root level and improve living conditions.
- Can reduce odours from animal manures, particularly in built up or crowded areas.

Disadvantages

- Strong technical skill is required to ensure gas-tight construction as the design and construction needs to be properly sealed and waterproofed.
- In case of leakage, the underground digester makes repair work difficult.
- Concerns with feedstock availability being the limiting factor and the lack of a large and consistent feedstock volume within a community could hinder its adoption.
- Government or other agency support is usually required to initiate and finance community biogas projects.
- Capacity to operate and maintain the system can be challenging given the household or community nature of the infrastructure.

Key Considerations at a National Level

Broad Overview of PESTLE Analysis

PESTLE Analysis of Advanced Waste Technologies

	Pyrolysis	Gasification	Combustion	Anaerobic Digestion	Biodigesters
Political					
Political Drivers	Any of these options may be supported politically if it can demonstrate tangible benefit to the people. This will include considerations of affordability, which can be problematic in areas with no user fees for poor waste services, as willingness to pay may be low, which risks becoming a political debate. Political will to resolve waste management issues is a pre-requisite for change, with waste gradually being seen as a more pressing issue in the Pacific.				
Consultation with Government Stakeholders	This is a pre-requisite for implementation of any advanced waste technology, as it will need support across sectors, including waste, energy, and agriculture. It will also require consultation across the planning, infrastructure, and financial sectors, and be prioritised in national infrastructure investment planning.				
Media Attention	There is a risk that negative media attention can draw criticism or politicise technology choice. Transparent and open communication from the start is required to minimise this risk, ensuring that accurate information is provided to the media.				
Governance Arrangements	Governance arrangements are fundamental to investing in advanced waste technologies. The roles of operator and regulator need to be clearly articulated. If the facility is a public private partnership, support for establishing and managing transparent and effective contracts will provide the best results for the Government and the community, whilst avoiding politicisation of roles. Ongoing communication of risks and mitigation are an essential component of sound governance.				
Environmental					
Human Health	Effects on human health were considered and pyrolysis, gasification and combustion technologies were found to have the potential of negatively affecting the operator's health, if there were an accident / explosion. There is also the potential for health impacts from air pollution, particularly from combustion technologies.			There are limited risks to human health from AD.	There are limited risks to human health from biodigesters, provided they are constructed well, and are maintained to avoid leakage, particularly if household sanitation waste is being treated.

	Pyrolysis	Gasification	Combustion	Anaerobic Digestion	Biodigesters
Pollution (Air, Water, Or Land)	Pollution effects have been considered and pyrolysis was found to have very minimal effects to all land, air, and water environments, due to the high conversion efficiency of the waste feedstock, along with the pollution controls in place. The same applies to gasification technologies. For combustion, pollution control components must meet relevant standards to ensure release of dioxins and other toxins are avoided. Monitoring is also essential.			There are limited environmental risks provided the facility is not releasing leachate. Facilities are enclosed to avoid air pollution or odour. Leachate disposal can be problematic, particularly if it contains microplastics	As above.
Visual Amenity	Protection of visual amenity is dependent on scale of the facility and siting. This must be carefully managed to avoid impacts.			AD facilities are enclosed and can be screened to protect visual amenity.	Limited risk as they are usually buried in the ground and sited away from high amenity areas.
Noise	All thermal technologies have noise emissions particularly in the pre-treatment of waste (e.g., grinding). Enclosed facilities and siting away from sensitive receptors is critical to avoid impacts.			AD facilities are enclosed to minimise noise and sited away from sensitive receptors.	No noise emissions.
Traffic	Traffic impacts will depend on the scale of the facility, and the siting. This will need to be addressed in the EIA process.				No traffic impacts.
Climate Change	All technologies are mitigation measures, reducing GHG emissions from landfilling, and utilising the waste resource to produce a renewable energy to replace fossil fuel based energy sources.				
Local Natural Resources	No impact on local resources. If biomass is to be included as a feedstock, it needs to be from waste products.				
Local Flora and Fauna	Impact would only occur due to poor siting in an area with rich biodiversity. This will be assessed as a component of the EIA.				No impact.
Local Ecosystems	As above.				No impact.
Energy	All technologies produce a form of energy. However, energy inputs need to be considered as part of the feasibility work.				Produces local source of sustainable energy at household or community scale.

	Pyrolysis	Gasification	Combustion	Anaerobic Digestion	Biodigesters
Land Use and Agriculture	Impacts related to siting and potential loss of agricultural land, or conflicts with other land uses such as tourism. This will need to be considered in the EIA.				Unlikely to have any impact.
Natural Hazards	Natural hazards must be considered as a component of detailed feasibility work and siting. Sea level rise and increasing natural disasters are a significant risk for facilities. Design and construction must take this into account.				Limited risk as construction is within the ground.
Environmental Targets	All advanced waste technologies align with renewable energy targets, with varying impacts depending on the technology energy outputs and scale. An important consideration is how the proposed technology aligns with any waste avoidance, reuse or recycling targets. There is a risk that some thermal technologies with minimum feedstock requirements may provide a disincentive for the 3Rs.				
Social					
Consultation with Community Groups	Social licence is critical, particularly with thermal technologies, where there may be fears of health or pollution impacts. Consultation from the outset is critical, ensuring stakeholders understand the challenges, and constraints. For small-scale biodigestion, the community and or recipients need to be willing participants, and understand the work involved.				
Community Suitability or Applicability	This is a risk with all advanced waste technologies, with some potentially viewed as incompatible with current community priorities. Any increased costs must be discussed, without over-stating the financial returns from energy sale. The proposed technology needs to be viewed as an appropriate solution.				Attitudes need to be understood, as the technology will fail if it is not culturally favoured.
Cultural Heritage and Local Traditions	Unlikely to have impact, but siting must consider cultural heritage as part of the EIA process.				Impacts unlikely, although any cultural barriers must be openly discussed.
Technological					
Fit for Purpose	Being fit for purpose is a core aspect of the detailed feasibility assessment. There will be a number of options, and technologies available, but fit for purpose must inform decision making. Having successful plants in similar settings is an advantage and fit for the feedstock readily available must be ensured.				
Applicability in Pacific Context	OPEX, maintenance, availability of spares, skill level required for maintenance, who is paying for maintenance etc				
Build and Installation	These technologies will be internationally sourced. Those that come in modular or containerised systems should be viewed favourably. Technical support for build, operate (initially) and maintain functions need to be explored. Installation must consider the harsh coastal environment, and the need for protection from the elements.				Simple to build using local labour.

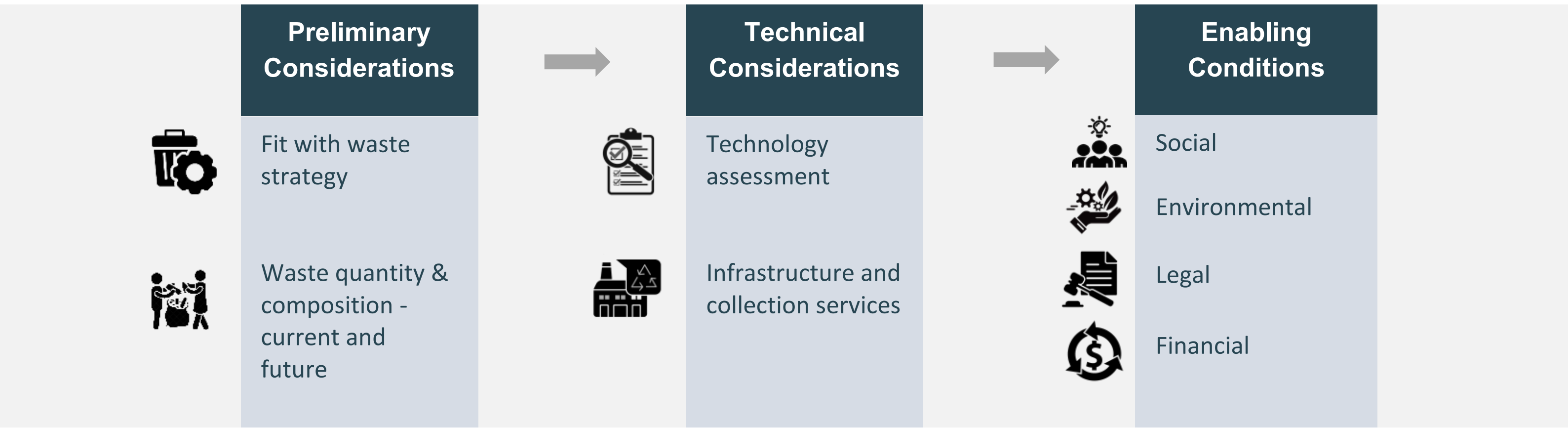
	Pyrolysis	Gasification	Combustion	Anaerobic Digestion	Biodigesters
Operation and Maintenance	Operation and maintenance are a risk given limited local capacity in a number of PacWastePlus countries. As such, the contract model must consider initial operations and long-term maintenance contracts as a core component of sustainability. This is the case for many donor funded equipment installations over relatively short term project lifespans, and the lesson consistently learned is that operation and maintenance is a fundamental sustainability issue.				Training must be provided, or longer-term support.
Upgrades	Upgrades are an unlikely aspect of these technologies, as the aim would be to gain utilisation of the infrastructure over the projected life of the asset. Minor upgrades, such as improved pollution control additions may be possible, but upgrades are generally not considered likely. This is another reason why the feasibility work must be undertaken with rigour.				
Decommissioning	All options must consider decommissioning as a part of the feasibility process. Importantly, thermal processes still require landfill for disposal of ash, and AD processes will still need landfill for residuals from the inorganic fraction of the waste. The planning for longer term operations and decommissioning are an essential component of planning.				Decommissioning is a consideration, but not viewed as a significant risk.
Legal					
Legislations, Regulations and Policies	A key risk for advanced waste technologies is adequacy of regulatory oversight. Emission monitoring needs to be built into contracts, with regular reporting to national ministries with the mandate for environmental protection. The technology must be aligned with national policies, including commitments to renewable energy, and to waste reduction, reuse, and recycling.				Need to ensure the building code and planning regulations are open to bio-generators, and that pollution control legislation is considered.
Other Countries	The Waigani and Basel Conventions must be considered if there is any transboundary transport of waste (although this is considered unlikely unless for hazardous wastes).				Not applicable.
Economic					
Commercial Viability	Advanced waste technologies are developed through public private partnerships, which will require commercial viability through disposal fees and energy revenue. Viability may not be a core consideration of technology feasibility assessment but will be the core aspect once the step of Expressions of Interest and tendering for partners is undertaken. Any partnership will need to closely consider viability, balanced with affordability for communities.				At a small-scale level, this is not so much a commercial consideration, but one of reducing household or community costs.
Cost-Benefit Analysis	A cost benefit analysis is relevant for all advanced waste technologies. This will consider the drivers for change, the benefits (including environmental and social), and the costs. Given the long-term application of this type of investment, cost-benefit analysis will need to provide clarity for decision makers, with assumptions clearly articulated.				

	Pyrolysis	Gasification	Combustion	Anaerobic Digestion	Biodigesters
Other Financial Impacts	User fees required as a basis for the technology must be analysed in terms of capacity to pay, and potential unintended consequences. If waste service fees rise significantly, will this create a response of increased illegal dumping and burning due to limited capacity to pay.				
Wider Economic Benefits	Pacific Islands and Timor-Leste, to varying degrees, have vibrant tourism economies. A key threat to this is visible poor waste management, including marine plastics, illegal dumping, littering, and burning of waste. Other wider economic benefits include health and environmental benefits from improved waste management, although this must be balanced with any potential impacts to consider from the proposed advanced waste technology.				
Financial Governance	Clearly articulated contracts in any PPP arrangement must spell out financial governance to ensure costs are projected accurately, and communities are protected from price shocks.				Needs oversight during implementation but is best managed over the longer term as a household or community asset, providing incentives to continue to maintain and operate.

The Decision-Making Process

The key steps to reviewing and considering advanced waste technologies are outlined following.

Figure 2 Considerations for Advanced Waste Technologies



Preliminary Considerations

Understanding the unique challenges within the local context provides an important baseline. For example, the Cayman Islands selected a WTE facility due to shortage of suitable land for landfilling waste, increasing volumes of waste particularly from the tourism industry, and impacts to the tourism industry from the growing visibility of the landfill site. Whilst the solution has increased disposal costs considerably, the drivers for change were centred on improving a system with unsustainable landfill practices in a country with limited options for new landfills.

An assessment of the current waste management system performance is required. The key message is that advanced waste technologies should only be considered as part of a broader strategy to minimise and manage waste and pollution.

Once the key drivers for change are well understood, and advanced waste technology is viewed as a sound option, there needs to be further detailed preliminary investigations, namely:

- Detailed waste characterisation data
- Waste flows – population numbers and locations, collection services, transport routes, distances, and waste composition / generation data
- Potential facility locations
- Clarity about requirements – what wastes need to be treated, and what outcomes are sought
- Demand for end-products
- Local infrastructure and waste service analysis, including areas of waste generation and transport routes

Technical Considerations

Once the feedstock and existing waste infrastructure is understood, a full technical assessment of advanced waste technology options must be undertaken.

Key considerations include:

- What technologies are suitable to the scale and composition of the waste to be treated
- Technologies that are appropriate to the region, including ease of use, low maintenance requirements, and simplicity of repairs
- The type of energy to be generated and how applicable this is at a local level, including demand
- Availability of a controlled landfill for residual disposal such as ash and flue residues
- Cost – capital and operational. What technologies provide the best value?
- Requirements for the waste segregation and/or collection system
- Local capacity for regulatory oversight

The technology analysis must be based on an 'agnostic' viewpoint. For example, in countries where the organic waste fraction is large, alternative WTE technologies such as anaerobic digestion could be more effective than thermal WTE for treating waste. A holistic assessment of all WTE options should always be undertaken, aligning with national waste management policy objectives.

Enabling Conditions

A life cycle assessment that includes a cost benefit analysis of thermal WTE and other potential WTE technologies would be beneficial to compare technology options, particularly costs. The social, economic, and environmental impacts and co-benefits of a WTE plant throughout its life cycle should be considered.

Siting of the proposed facility is also a critical aspect. A full Environmental Impact Assessment provides a clear assessment of alternatives. The EIA must also assess the GHG emissions, and the potential for impacts from emissions during operations.

The following legislative considerations must be undertaken:

- Laws that provide clarity on emissions standards, including flue gas and residual ash disposal (aligned with appropriate international standards)
- Plant decommissioning needs to be clear
- Integration of the advanced waste technology into the national waste strategy, and how it interacts with waste avoidance, reuse, and recycling

Financial elements are an integral component of the enabling environment, considering

- Projected costs and revenues
- Analysis of costs over the life cycle of the technology
- Inclusion of additional pre-requisite costs, such as improvements to the waste collection system or implementation of source segregation

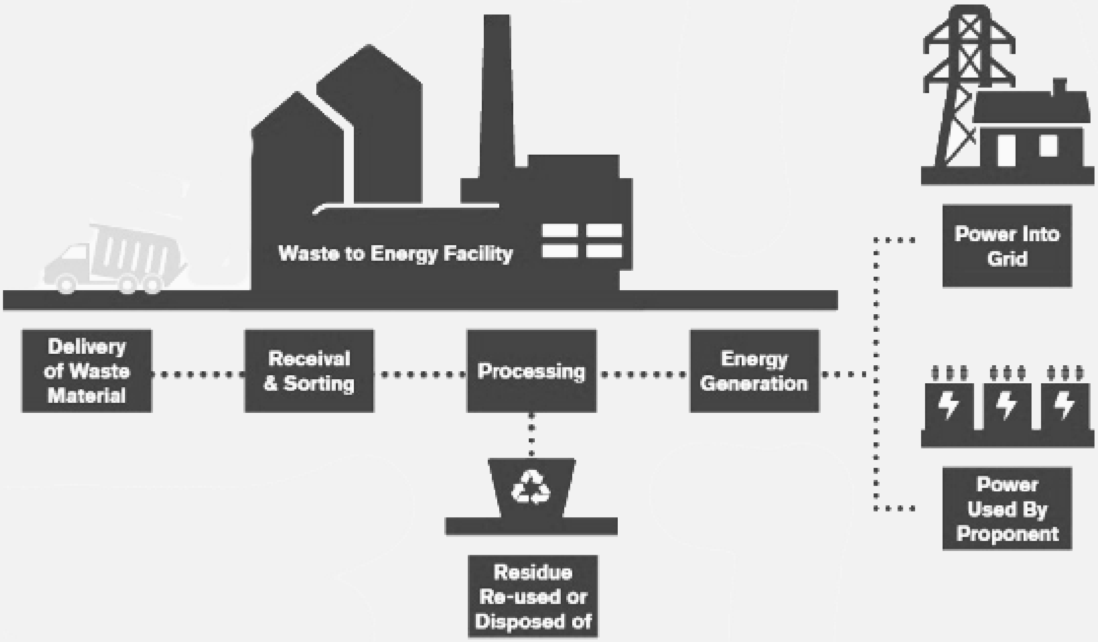
Advanced waste technologies are a large investment for developing countries. Investment sources can include:

- Donor funds
- Government subsidies
- Private sector investments
- Revenue from carbon credits
- User fees
- Energy sale revenue

In a typical PPP structure for WTE projects, the developer undertakes the development of the project under the Design-Build-Own-Operate (DBOO) model. To ensure sustainability, long term maintenance contracts are likely to be a minimal requirement for technology providers, along with support for operational functions.

The final component of the enabling environment is stakeholder acceptance. Providing opportunities for robust discussion, transparent information sharing, and collective problem solving will create a more robust enabling environment.

Without this, the technology cannot provide an effective solution to the immediate and long-term challenges of improved waste management in the Pacific Islands and Timor-Leste.



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