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Decision Maker's Guides for Solid Waste Management Technologies

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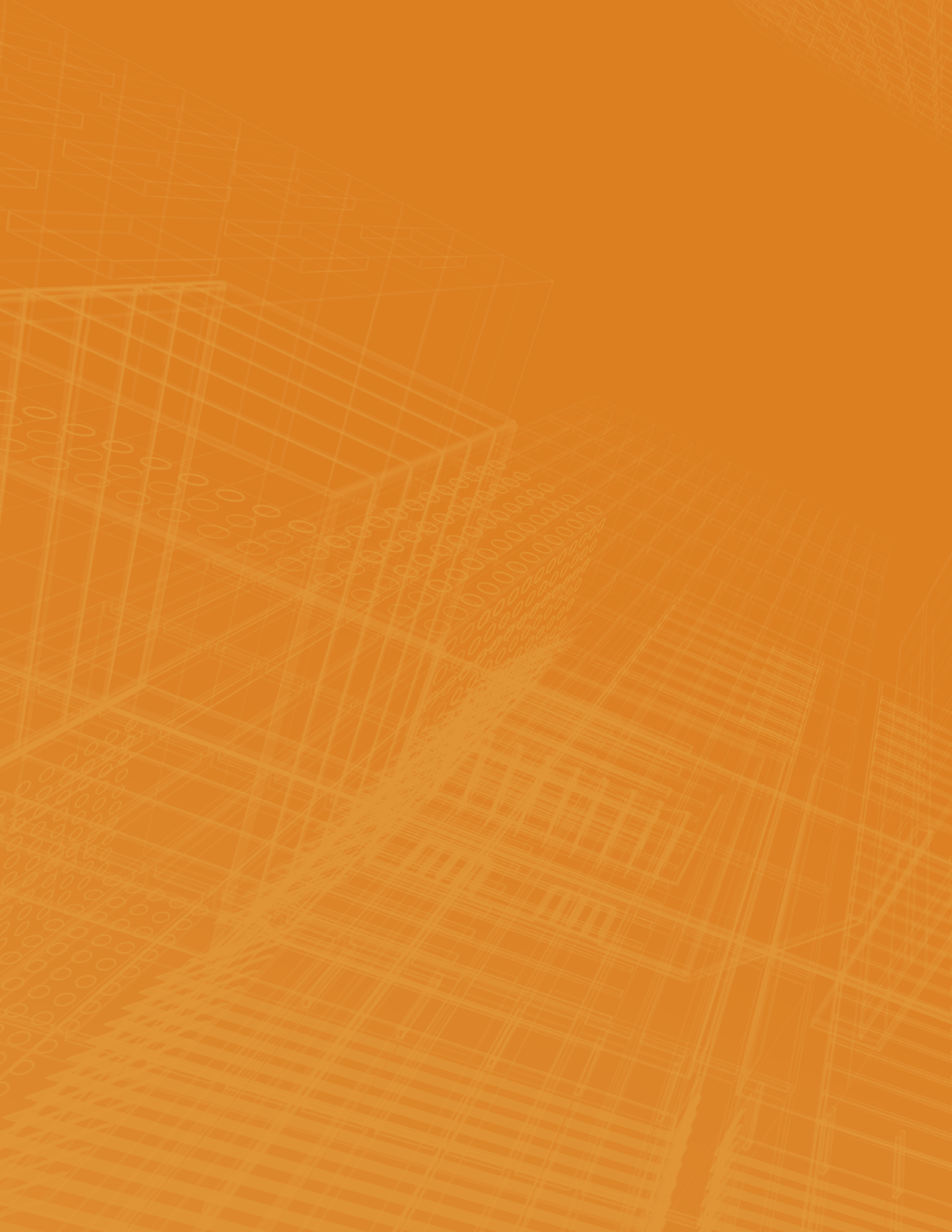

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Decision Maker's Guides for Solid Waste Management Technologies

Silpa Kaza and Perinaz Bhada-Tata
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Urban Development Series

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Introduction

The Decision Maker's Guides for Solid Waste Management Technologies were created to help mayors and decision makers understand the various technologies and when they would be appropriate based on local circumstances. Mayors are often approached by different solid waste management technology vendors and these guides aim to provide objective guidance and critical considerations. They offer insights into implementing environmentally sound treatment and disposal solutions.

The guides include:

- A basic description of what each technology is and how it works
- Key considerations when thinking about pursuing a specific technology
- Financial implications and suggestions for reducing and recovering costs
- Examples of where the technology has succeeded and failed
- Questions to ask the solid waste vendor to assess appropriateness of the technology and vendor for the local context

This is a compilation of guidance documents that are standalone and can be utilized independently as required. The documents included entail the following:

- Summary of key insights for decision makers to keep in mind for each technology
- Comparison table on key metrics for solid waste management technologies
- Guidance notes for sanitary landfills, composting, anaerobic digestion, incineration with energy recovery, and pyrolysis and gasification.

What Mayors Should Know

Sanitary Landfill	• Regardless of other waste disposal solutions, landfills are necessary for safe disposal of wastes that cannot be recovered/recycled and for residues from other treatment processes • If a landfill is not properly sited and constructed (with appropriate liner), maintained (monitoring surface and ground water and landfill gas generated) and operated (waste compacted and covered daily), it will quickly turn into a dumpsite and have significant adverse environmental and social impacts. • Financing for the entire landfill life, including post-closure monitoring (at least 30 years), should be accounted for from the beginning • Collecting and harnessing landfill gas before and after landfill closure can generate revenue and minimize greenhouse gas emissions • The organic fraction of waste can only be used once whether it is for landfill gas-to-energy, composting, or anaerobic digestion.
Composting	• Composting is a relatively low-cost option to convert organic waste into a fertilizer-like product while generating employment opportunities and environmental benefits • Uncontaminated organic waste (e.g. restaurant, vegetable market, or source-segregated waste) is necessary to produce a marketable product • Compost from separated household waste is unlikely to have high marketability but could be considered for other purposes (landscaping, landfill cover, residents' gardens) • In order to obtain revenues from compost sales, there needs to be a market or end use. A certification system could help build market confidence by demonstrating the quality of compost produced • Composting facilities can be operationally self-sufficient but tend to require support for capital costs
Anaerobic Digestion	• An anaerobic digester requires a largely uncontaminated organic waste stream (e.g. restaurant, vegetable market, or source segregated waste) at a consistent and sufficient volume to function properly. The process produces biogas and a liquid or, after drying, a solid fertilizer. The biogas can be used to generate heat and/or electricity • Large scale anaerobic digesters are high in capital and operating costs and require a high level of technical capacity to operate • Income can be generated by distributing the biogas directly to end-users, selling electricity generated from the biogas, and potentially selling the fertilizer to farms
Incineration	• Incineration requires a consistently high volume of dry, high energy content waste (i.e. <50% of organics and high proportions of combustible materials) and electricity price to operate cost-effectively • Incineration is typically used in contexts where there are land constraints, high tipping fees at landfills, high electricity prices, strong technical capacity, relatively high energy content waste, and robust environmental regulations • To date, incineration has not been widely used for treating municipal solid waste treatment in low-income countries • An incineration facility has high capital and operating costs and normally requires a long-term (25-30 year) contractual commitment from a municipality
Pyrolysis and Gasification	• Pyrolysis and gasification are emerging technologies that have not yet been demonstrated at large-scale for treating municipal solid waste • Both technologies require high capital and operating costs and technical capacity • They can generate a range of products, mostly a synthetic gas (that can be condensed to a liquid fuel) and a soil amendment

Comparison of Solid Waste Technologies

	Sanitary Landfill	Composting	Anaerobic Digestion	Incineration
Basic Process	Disposal	Biological treatment	Biological treatment	Thermal treatment
Ideal Types of Waste	Municipal solid waste, construction and demolition waste, wastewater sludge, non-hazardous industrial wastes	Food waste (including wastes from households, restaurants and markets), fats/ oils/ grease, paper and cardboard, landscaping and garden waste (e.g. hedge-clippings, leaves)	Food waste (including wastes from households, restaurants and markets), fats/ oils/grease, slaughterhouse waste (depending local regulations), and garden waste	Mixed municipal solid waste, medical waste, demolition wood, auto shredder residue, dried sewage sludge, and some industrial solid wastes
Waste to Avoid	Medical	Non-biodegradable wastes (plastic, glass, metal, inerts)	Non-biodegradable wastes (plastic, glass, metal, inerts), tree clippings	Yard leaves or source-separated food waste
Waste composition threshold for organic fraction or moisture content (%)	--	High as possible	>50%	<50%
Mass Reduction of Waste (%)	--	50%	50%	80-85%
Land Requirement (m2/tonne)	Generally large	0.065 – 10.8	1.61 – 6.45	Much smaller than that for landfill but ash must be disposed
Proven Technology/ Market Maturity	+++	++	++	++
Operational complexity	Requires specialized training, careful maintenance, and post-closure care	Proper training required	Proper training required	Technically complex, requires highly skilled training and careful maintenance
Pre-processing of Feedstock	No	Preferred	Yes	Yes
Average Range of Waste Throughput (tonnes/day)	50-10,000	2.5 - 300	0.5 - 500	5 – 1000 (common range is 200 – 700)
Primary output	Landfill gas (where recovered), leachate	Compost	Methane, digestate	Air and ash
Secondary output	Electricity and/or heat (where landfill gas is recovered)	--	Electricity and/or heat; liquid or solid fertilizer	Heat and sometimes electricity
Energy conversion efficiency (kWh/ tonne of municipal solid waste)	65 (landfill gas)	--	165 - 245	500 - 600

(continued)

Comparison of Solid Waste Technologies

(continued)

	Sanitary Landfill	Composting	Anaerobic Digestion	Incineration
Capital costs (US$/ annual tonne)	5 - 52 (US$/tonne over lifetime)	30 - 400	220 - 660	190 – 1000
Operating costs (US$/tonne)	7 – 30 (but can be as high as 120)	12 - 100	22 - 57	12- 55
Greenhouse Gas Emissions	Significant; can be captured by landfill gas recovery	Reduced	Significant; captured and used to generate energy	Considered renewable or climate-neutral
Carbon Finance potential	Yes (where landfill gas is recovered)	Yes	Yes (where biogas is recovered)	Yes (where energy is recovered)
CDM (Carbon finance methodology)	AMS-III.G.	AMS-III.F. AMS-III.AF.	AMS-III.A.O.	AMS-III.E.

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SANITARY LANDFILLS

SANITARY LANDFILLS

Landfills are an important part of any urban waste management system—regardless of other waste disposal solutions used. Even cities that recycle much of their waste or are heavily reliant on incineration need to landfill residual ash, wastes that cannot be recycled or combusted, and waste from other waste facilities when other disposal systems are not operating.

Around the world, nearly 40% of all waste discarded ends up in some type of a landfill. The rate is even higher in upper-middle income countries at 54%. Together with open dumping at 33%, landfills make up the most common form of waste disposal. Landfills require engineered design (as opposed to open dumps) and must be constructed and operated with care to ensure that they do not create problems that threaten human or eco-system health.

Sanitary landfills are a mature and proven waste management technique. Nevertheless, they are still fairly uncommon in low- and some middle-income countries due to the costs involved in infrastructure and operation and inadequate regulatory oversight. In these areas, it is more common to find uncontrolled or open dumps that lack basic environmental controls, putting public health and safety at risk.

LANDFILLING – THE BASICS

A properly designed sanitary landfill includes land area with an impermeable liner at the bottom. The liner prevents liquid contaminants (leachate) from coming into contact with groundwater (aquifers) and seeping into the soil. Leachate forms from moisture in the waste, or from rainwater that flows into the landfill and should be collected and treated. At a properly managed landfill, waste is compacted to conserve space; a cover material is applied over the waste on a regular basis to control odor, blowing litter, and other nuisances; and gas control systems are used to capture flammable landfill gas that forms as organic waste material decomposes within the landfill.

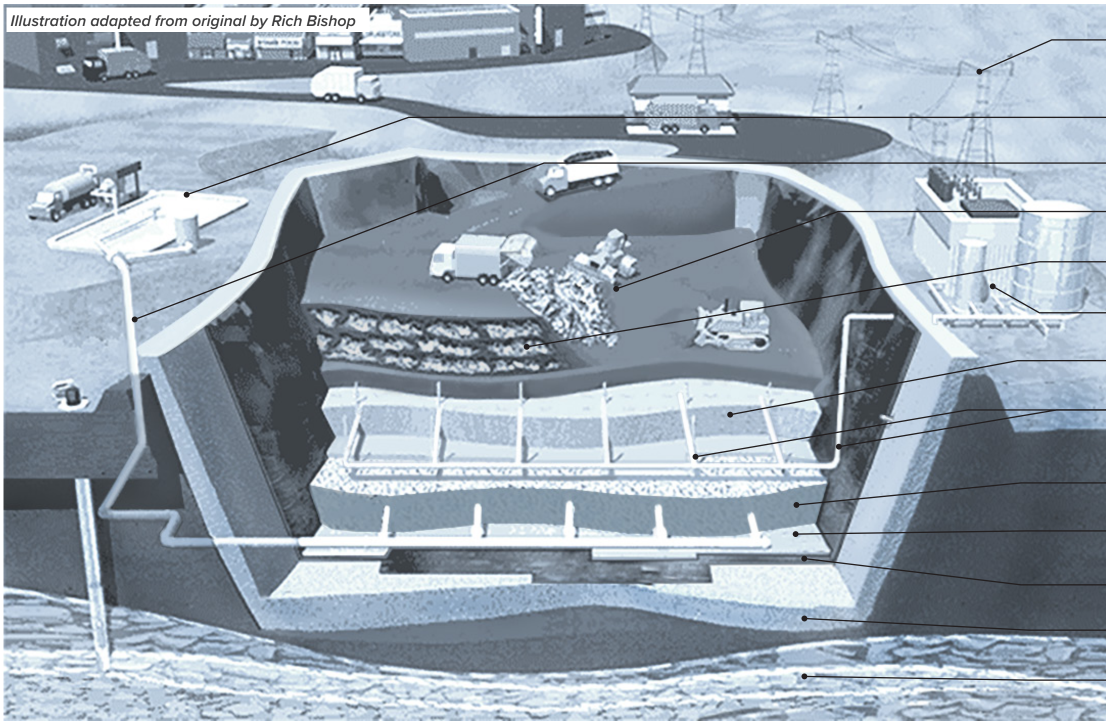
WHAT TO THINK ABOUT WHEN PURSUING A LANDFILL STRATEGY?

PRE-CONSTRUCTION

Landfill capacity: Landfills are usually built to last approximately 30 years; however, they should be sized to account for anticipated changes in local waste generation levels as the population grows or household income levels rise. Optimally, the plan should be to create and fill a cell every 18 months – 2 years before it is closed and utilized for landfill gas to energy.

Siting: A landfill is ideally geographically isolated from residential areas, airports, and drinking water aquifers. Depending on the area served by the landfill, proximity to rail lines or roads capable of handling heavy truck loads or volume may be necessary. The selected site should be assessed by engineers and geologists to ensure low risk for flooding, earthquakes, and landslides. Access to a regular supply of cover material is also critical. Communities near the selected site should be consulted to understand and address their concerns before the facility begins operation. Some communities may need to be resettled once a site is selected, and they should be compensated for any loss of land, livelihood, or cultural identity caused by the facility.

Recovery of valuable recyclable or reusable materials: Landfill life can be extended if recyclable and organic materials are removed or recovered before waste arrives at the landfill and will also likely result in lower costs. This could either be done at the community level, at a materials recovery facility, or at the landfill site itself. Landfill operators could benefit from partnering with waste pickers at the landfill site to ensure that these materials can be diverted and should ensure livelihoods are not displaced without making alternative provision for them.



Schematic diagram of a sanitary landfill

CONSTRUCTION AND OPERATIONS

Liner: The liner is an impermeable barrier (made of a low absorbing soil material such as clay and/or a synthetic material such as plastic) installed at the bottom of a landfill to prevent leachate from seeping into the groundwater or nearby waterways.

Leachate monitoring, collection, and treatment: The landfill should be designed with a network of pipes and synthetic material (drainage net) to collect the leachate from the bottom of the landfill. It can then be treated in a wastewater treatment plant or managed onsite in an evaporation pond.

Landfill gas collection: A landfill gas recovery system needs to be installed to capture the combustible gas resulting from the organic waste decomposition. If the landfill gas is not captured, there is a risk of explosion at the site. There is the secondary benefit of reducing greenhouse gas emissions.

Storm water management: A proper drainage system to divert water from landfills needs to be included in situations of excessive precipitation. A properly designed storm water management system reduces the quantity of leachate generated and, thus, the cost to treat the leachate.

Waste compaction: Waste should be compacted daily with specialized equipment to maximize the space available for disposal.

CLIMATE-PROOFING YOUR LANDFILL:

- Landfills in rainy regions are subject to erosion and landslides so the stability of steep slopes will have to be monitored. Heavy rains may also create the need for larger leachate fields to handle the extra water flow. Some equipment, including weighbridges, may need to be elevated for year-round use.
- Landfills should be sited away from waterways to ensure that flooding does not affect the facility.
- High temperatures and droughts could increase the risk of fire so proper covering is essential.

Cover: Landfills should be covered at the end of each day to prevent fires, scavengers, disease breeding, and litter. Typically, this entails a 6-inch soil layer; however, alternative materials can be used. These can include clean soil excavated from construction projects, vegetation and leaves, removable tarps, compost, mulch, construction and demolition waste, shredded tires, or spray-on slurry. Advantages of using alternative materials include saving landfill space, reducing costs of procuring, excavating, and transporting soil to the landfill, providing equal or better protection against odors and vermin than a 6-inch layer of soil, and slowing down the movement of landfill gas and leachate.

Monitoring: Monitoring wells should be installed nearby to guard against groundwater contamination and landfill gas leakage. Every facility should have an environmental monitoring plan that covers all phases of a landfill's life prior to commencing construction and operations.

CLOSURE AND POST-CLOSURE

Final cover: Landfill caps can be made with vegetative soil (suited for dry climates) or have a sophisticated multi-layer system of soil and geosynthetic material to divert water from entering the landfill (more appropriate for wet climates). A topsoil layer could be placed on top of any synthetic covers to support vegetative growth and to create opportunities for subsequent uses of the land.

Monitoring: Landfills must be monitored post-closure for methane gas formation and release, leachate problems, and to ensure the integrity of the landfill cover.

Post-closure use: Closed landfills pose some environmental and health risks, mainly from the potential escape of form of landfill gas; however, if planned and monitored properly, closed landfills can provide valuable space for recreation or even industrial use (including waste management, such as recycling or composting activities). Whatever the post-closure use, it is important the gas and leachate emissions are monitored and the associated risks mitigated.

Upfront Capital	Operations and Maintenance	Closure and Post-Closure
Costs vary considerably by size, region, regulations, design sophistication, etc. • Studies and design (e.g., site selection, topographic survey, social impact assessment) • Land acquisition • Preparation of the site • Closure of open dumps • Regulatory approval • Construction and equipment	• Labor • Safety equipment • Machinery and vehicles (e.g., compactors) • Venting of gases and drainage, leachate treatment • Monitoring equipment • Periodic changes to the site (e.g., roads, cell development and closures, excavations) • Power, fuel	Post-closure costs can continue for up to 30 years after landfill closure • Final closure (e.g., landfill cap) • Drainage system • Green cover and landscaping • Monitoring costs for landfill gas and groundwater contamination

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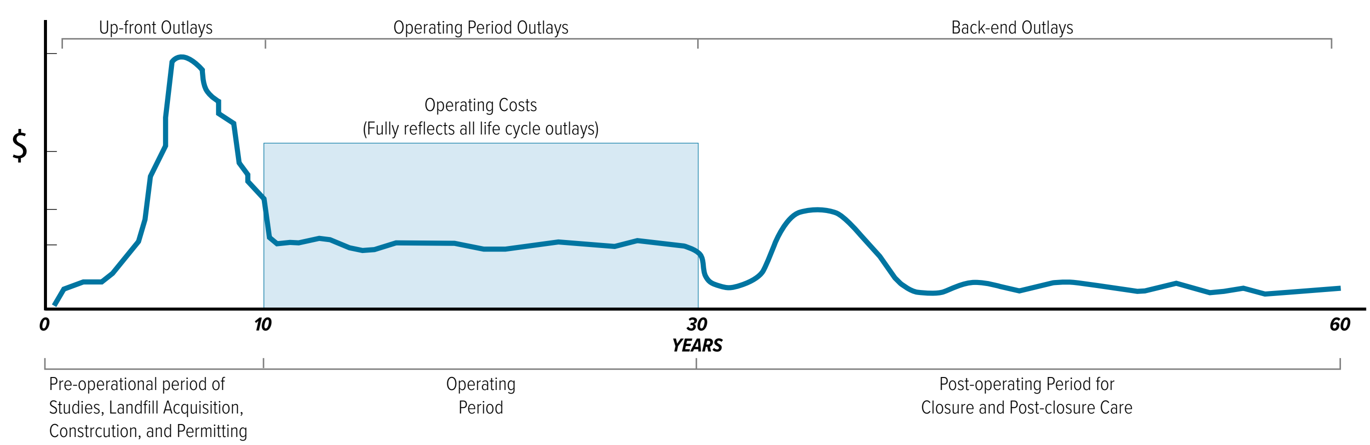

Landfill life-cycle costs and outlays
Source: US Environmental Protection Agency, 2014

HOW MUCH WILL A LANDFILL COST?

The costs of sanitary landfills do not vary widely between developed and developing countries as the technology required is not labor intensive. However, poor site selection may drive up costs considerably. Landfills have huge economies of scale. Generally, landfills that receive 400 tonnes/day or less of waste will have under-utilized equipment.

Costs for landfills can be divided into three components: (1) capital, (2) operations and maintenance, and (3) closure and post-closure.

(1) Capital costs are typically 25-50% of the total lifetime cost of a sanitary landfill. Total outlays could range from $1m to $50m for landfills with a processing capacity of 20,000 to 2,000,000 tonnes per year. A common industry benchmark is $1m per hectare over the lifetime of the landfill.

(2) Operating costs typically fall in the range of $7-30/tonne, and make up approximately 60-80% of landfill lifetime costs.

(3) Post-closure costs for the final cap are typically $80,000-$500,000 per acre and closure/post-closure costs can make up 10-15% of the lifetime landfill costs. Post-closure requires monitoring and performing necessary corrective actions for up to 30 years and should be accounted for through the creation of financial reserves set up while the facility is operational.

IS YOUR LANDFILL FACILITY TOO EXPENSIVE? THINK ABOUT…

Regional landfills: A landfill can be built and shared by several municipalities to take advantage of economies of scale.
Pooling or bundling landfills: If there are multiple landfills being designed nationally, then bundling the landfills together for financing could increase their attractiveness to investors.

Carbon finance: Landfill gas (primarily consisting of methane) can be captured at landfills and converted into electricity and/or heat, thus creating a steady revenue source. Depending on the size of the facility, it may be possible to access carbon finance or general climate financing to help pay for the cost of constructing the gas capture system.

Preferred tariffs for renewable energy: Governments may provide initiatives in the form of tax credits, preferential pricing, discounts, or other benefits to encourage electricity from renewable sources. This could be a potential revenue source if landfill gas is considered to be a renewable energy source in your jurisdiction.

Sale of byproducts or services: Landfill gas could be sold to power generators if a grid connection is available, recyclables could be sold if a market exists, and fees could be implemented for usage after closure (e.g. parking fees or entry fees for a recreational area)

Tipping fees: The landfill operator should charge a tipping fee (fee charged per tonne of material delivered to the landfill), which serves as a revenue source for landfills to cover operational costs and encourage households and municipalities to decrease the amount of waste sent to landfills. Such fee systems require a weigh station at the entrance to the facility as well as enforcement of fee collection (by securing the perimeter, proper record keeping, monitoring entry and exit, etc.).

Public-private partnerships: Municipalities should consider different models of public-private partnerships based on need. For example, a build-own-operate model allows a municipality to share costs with and leverage technical expertise from the private sector. A design-build-operate model would ensure that the operator optimizes the landfill facility design and operations for efficiency. The municipality could also procure contracts for design and construction and take on the operations themselves.

WHERE IS A GOOD SANITARY LANDFILL AND WHAT HAVE WE LEARNED?

Prior to 2000, the Northern West Bank was infamous for the poor quality of its waste collection system and improper disposal of waste at more than 85 unsanitary dumpsites. Open burning of waste was also a common practice. The local government had little financial and technical capacity to properly manage their solid waste. Between 2000 and 2009, the World Bank and other donors supported the closing of these dumpsites and construction of a new Zahrat al Finjan sanitary landfill in Jenin, West Bank to serve all municipal and village councils in the area. A joint council was established to coordinate solid waste management efforts across these communities. To ensure financial sustainability of waste collection and disposal, a household solid waste fee was implemented and collected with the assistance of the village and municipal councils. Most of the municipalities and villages collect the fee as a surcharge on household electricity bills and pay the joint council for the management of the disposal facility. In contrast, in many low and middle income countries, while there is an intention to operate a sanitary landfill, often the basic requirements (leachate management, landfill gas capture, daily cover, fencing, record-keeping, and plan for waste pickers) are not met. As a result, landfills end up being used as dumpsites and have an adverse social and environmental impact. Open fires are common across these sites, posing health risks to the waste pickers who operate there and the surrounding communities.

MAYOR'S CORNER: QUESTIONS TO ASK YOUR SOLID WASTE MANAGERS OR VENDORS WHO WANT TO CONSTRUCT AND OPERATE YOUR LANDFILL

1. Where would the landfill be sited? Do these areas meet siting requirements (e.g., geology, hydrology, seismology, storm water and groundwater impacts)?
2. What is your strategy to maximize the recovery of valuable recyclable commodities before they are buried in our landfill?
3. What would the disposal tipping fee be and does the fee fully cover our operating costs and enable you to deal with post-closure considerations? What other cost recovery mechanisms are you considering, if any?
4. How many local jobs will the facility create?
5. What is our health and safety strategy to protect workers at the landfill and minimize other nuisances (odors, fires, etc.)? What are you doing to ensure that the facility does not threaten local water supply aquifers, reduce the amount of landfill gas being vented into the atmosphere, and account for other environmental considerations?
6. Do you fully understand the waste disposal needs including the anticipated waste generation to determine the land area needed and the expected lifespan of the landfill?
7. How will climate change affect this landfill site, and what can you do to prepare for that?

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COMPOSTING

COMPOSTING

Composting is a process that optimizes the natural decomposition of food, garden, and agricultural wastes into a fertilizer-like product, called compost. It is a relatively low-cost strategy for converting the organic portion of the waste stream into a valuable material that can enrich the soil on farms, in parks and in household gardens.

44% of the municipal solid waste stream globally and 56% of waste in low-income countries could be readily composted, but less than 6%[2] of total waste generated worldwide is composted at present. Municipal composting is often not profitable unless capital expenditures are undertaken by another party such a government or an international organization. Composting on a municipal scale requires segregating the organic waste from other waste materials to ensure a high-quality end product. Composting differs from the natural decaying process because levels of oxygen, moisture, temperature, nutrients and the chemical environment are monitored and controlled at a facility. These conditions play a significant role in accelerating the decomposition process and determining the quality of the finished compost.

COMPOSTING - THE BASICS

The process of composting involves the breaking down of organic matter by microorganisms in the presence of oxygen. The volume of the organic waste can decrease by 60-90% as a result.

Various composting methods are available depending on the amount of available land, the volume of organic material to be composted, a community's available budget, and the technical ability of those working at the facility. Windrow composting is the cheapest and simplest process for municipal systems, where organic waste is placed in a large pile or row (known as a windrow) and periodically turned. The mixing process introduces oxygen into the pile to promote microbial activity. Specialized equipment known as windrow turners can be used for this purpose, but front-end loader tractors can suffice. More sophisticated windrow systems insert a perforated pipe into the middle of the compost pile and force air through the pile to promote increased microbial activity.

Another method is in-vessel composting, which is a mechanical solution that drastically speeds up the natural decomposition process by closely controlling the temperature and oxygen levels in a composting chamber. These systems generally include a mechanism to grind the waste into smaller pieces as well as to turn or agitate the material at periodic intervals to speed up the breakdown of waste. Once the organic material is processed, it must sit outside of the vessel to allow completion of the decomposition process. This maturation stage can take a few days or weeks depending on the system. Enclosed systems are much more expensive than windrow systems, but they require less land because of the faster processing time. If managed poorly, both types of systems can create odor problems that are a nuisance to neighbors of the facility.

	Windrow/Static Piles	In-Vessel
Scale of operation	Large/ regional/ municipal	Small/ neighborhood/ community
Processing capacity (tonnes per day)	1 – 1,000	20 – 350
Space/land requirement	High	Small, can increase for windrow drying or maturing of compost
Time required	Several weeks	Few days to weeks depending on the specifications of the unit. However, the compost might need to sit an additional 2-4 weeks prior to use
Odor	Can be significant if not well aerated	Air purification system confines odor to the vessel
Leachate production	Low	Minimal
Sensitivity to weather	If feedstock freezes, the decomposition process stalls	Functions in all climates
Capital cost (US$/tonne)	40-60	300-500
Operating cost (US$/tonne)	12	130

WHAT TO THINK ABOUT WHEN YOU ESTABLISH THE COMPOSTING FACILITY

Quality of input: The quality of the compost, and therefore its marketability, depends primarily on the quality of the feedstock. A single stream of organic waste, such as yard or garden waste, organic waste from produce markets or agricultural waste, rather than mixed municipal solid waste (MSW), creates higher quality compost and reduces the likelihood of contamination by chemical compounds. It is not advisable to attempt to produce a high quality marketable compost out of MSW, even if the waste contains a high volume of organic material. In order to make MSW-based compost marketable, there needs to be a strong source separation to minimize contaminants and build consumer confidence. A mechanical biological treatment (MBT) facility where organic waste is separated from MSW is likely to lead to compromised compost quality.

Types of input: The composting process occurs most rapidly if the material being composted has a carbon-to-nitrogen ratio of 30:1. Achieving this ratio generally involves balancing wetter, nitrogen-rich waste material (grass, food waste) with carbon-rich waste material (leaves, shredded wood, etc.). Clean paper and cardboard can also be composted if there are no good recycling options in a community.

Siting: Because of the odor potential, the question of where to site the facility is critical. Enclosed facilities can install a filtration system to eliminate most of the odor problems, but this adds to the system cost. Another option is to isolate the facility from residential or commercial areas or to co-locate the operation at a landfill or wastewater treatment site. Composting facilities should not be located in flood-prone areas as floodwaters will ruin the quality of the final compost. Proximity to the feedstock material is very important, since waste transportation can easily drive up system costs. Alternatively, if composting is only being used for reduced disposal volume, it could occur at the landfill facility.

Facility size: The size of the facility depends on the quantity of feedstock expected, the composting method selected, and the size of the compost market. An in-vessel composting operation typically requires a fraction of the space needed

Windrow/Static Piles

In-vessel composting

for windrow composting, but it still requires land where the compost can mature once the active in-vessel composting phase is complete. Regardless of the type of system selected, there should be sufficient space to accommodate at least four months of composted material. More space may be required for storage if the market for the finished compost is highly seasonal.

Storm water and leachate management: Leachate is liquid produced from the decomposing waste that could be potentially hazardous. It will be generated even in well-run facilities. Outdoor sites (without protective roofing) will generate large volumes of leachate when it rains. Paved flooring and a drainage system leading to a leachate tank or a wastewater treatment system can lessen this problem but they can dramatically increase the capital costs of a facility. Leachate can be reused on-site to maintain an appropriate moisture level in the pile or windrow. Poor leachate or storm water management can lead to water pollution, cause odors, and create a breeding ground for mosquitoes and other insects or pests.

Sensitivity to weather: During optimal composting, the decomposition process generates heat within the compost pile or chamber ranging from 30° to 60°C. Surrounding air temperatures do not affect the composting process as long as the ideal internal temperature range is maintained. Lower temperatures may slow down the decomposition process, while higher temperatures can kill the bacteria aiding the decomposition process.

Speed of composting process: Reducing the size of waste by chopping or grinding and frequently aerating will help break down waste more quickly and speed up the composting process.

Market for compost and product certification: Common consumers include farmers, landscapers and municipalities who can use the compost for agriculture, parks, schools, and public areas. Municipalities are the customers with the greatest control. Other small, high-end markets can also potentially exist. While no one will buy low-quality compost, good quality compost is not enough to guarantee a market. Attempting to sell poor quality compost can undermine attempts to create a market so it is important that careful consideration is given to quality control and marketing. Decision makers should be aware of negative attitudes towards compost produced from municipal solid waste because it is bulky and perceived as waste material or because the economic benefits to agriculture and sustainable land management are not well-known. Many operators offer compost quality assurance by having a third-party vendor or review system test the quality of the product and certify it to build trust.

CLIMATE-PROOFING COMPOSTING:

- Select a site away from waterways to prevent contaminated runoff from polluting waters during storms
- Ensure facility is sheltered from rain and extreme weather

CLIMATE-BENEFITS OF COMPOSTING:

- Composting avoids the generation of methane, which would have occurred if the organic waste had been landfilled instead
- Use of compost reduces the need for synthetic fertilizers (made from fossil fuels) and reduces the amount of water needed for irrigation (thus saving water as well as energy needed to pump and filter the water).

THINK YOU'RE SPENDING TOO MUCH ON YOUR ORGANIC WASTE MANAGEMENT PROGRAM?

Think in total system terms: The composting process reduces the volume of the waste by 60 to 90%, elongating your landfill life and often creating a new revenue source for your program. High quality compost can be used on local farmland, increasing the productivity of the land, or reducing municipal expenses for beautification efforts in parks or public spaces around the city.

Charge a fee for private sector access to your composting facility: Some cities ban organic waste from their landfill as a methane-prevention strategy, forcing private firms that collect food waste (or landscaping waste) from hotels or other commercial establishments to find a composting facility to accept this material. A small tipping (disposal) fee can be assessed on private businesses that bring organic waste to a municipal facility.

Offer related services: Composting facilities with self-sufficient operations often offer related services such a recycling or waste vocational training program.

Find a partner: Farmers or landscapers can also be the operator of composting plants, using the product for their own businesses. In such cases, some or all of the costs of composting can be amortized by the partnering business.

Share a regional facility: A composting facility can be built and shared by several municipalities in close proximity to one another to take advantage of economies of scale.

Pool or bundle facilities: If there are multiple composting facilities being designed nationally, then bundling the facilities together for financing could increase their attractiveness to investors.

Carbon finance: Composting avoids the generation of methane that would otherwise have formed in landfills. Composting facilities may be eligible for carbon finance, where "credits" from the reduction of emissions of greenhouse gases can be sold to offset the costs of a compost facility.

Encourage on-site composting: Home and business owners can be encouraged to compost material on their own property, cutting the need for municipal collection of organic waste and reducing the size of facility required. To support this strategy, many cities give away or sell "backyard" composting bins at low cost to the public.

Try a targeted approach: Many cities start their composting program by targeting high volume, uncontaminated organic waste generators (produce markets, restaurants, hotels, private landscaping firms), and build a program around these sources. This cuts collection costs, and is logistically much easier than trying to collect source-separated organic waste from every household or business on Day 1 of the program.

WHERE IS COMPOSTING BEING USED AND WHAT HAVE WE LEARNED?

South Africa is focusing on establishing an uncontaminated source of organic waste for composting and has met with success across several cities. Public awareness enables these cities to separate waste properly, enabling pure organic material for composting and maximizing the amount of waste diverted from landfills. Site managers, who receive training, are motivated to get a high-quality input and maintain the facilities to create compost of market value. Facilities that receive only yard and landscaping waste produce better quality compost than those that accept mixed municipal waste; regardless of the differences in quality, all sites are able to sell their compost to the local market (nurseries, households, landscapers).

A successful small-scale composting example involves small cities in Indonesia that adopted a two-pronged approach: enhancing the role of waste pickers by training them in composting techniques while stimulating the market by training intermediate buyers of compost to understand the physical and commercial benefits of compost. Offering training and support to a variety of stakeholders can benefit the overall community in the long run, and create an enduring market for the product.

In cases where municipal composting has not been successful, reasons include poor quality feedstock due to use of mixed MSW, failure to enforce guidelines, or poor estimation of revenue potential. The poor quality feedstock led to low-quality compost that farmers or other users rejected and potentially even harmed the environment with leaching of heavy metals into the ground. Improving waste separation and implementing strict guidelines for compost quality would mitigate the problem of low quality compost generation. A market study combined with the financing recommendations above could lead to a sustainable plan.

MAYOR'S CORNER: QUESTIONS TO ASK YOUR SOLID WASTE MANAGERS OR VENDORS WHO WANT TO OPERATE YOUR COMPOSTING PROGRAM

1. How much feedstock is available and what are the waste generation projections over the next 20-30 years? What is the seasonal variation of the feedstock as well as the moisture and carbon content? Does the size of the proposed composting facility make sense given the availability of the feedstock?
2. What systems are in place to ensure the quality as well as guaranteed supply of the feedstock?
3. What are the siting requirements for such a facility and have they been met? Have relevant site studies been conducted to make sure the facility will meet local and national regulations? What steps are planned to minimize any community opposition?
4. What's your odor strategy? Who else has relied on this strategy and what were the results? What is the plan to train the staff to ensure odor problems do not arise?
5. How many local jobs will the facility create?

MAYOR'S CORNER (CONTINUED)

6. What is the local market outlook for compost? What factors will influence what users are willing to pay (if anything)? What can the city do to build market demand and trust for locally-produced compost?
7. What are we doing to maximize the revenue potential and minimize costs from our composting program?
8. Can the facility access or benefit from carbon finance or other incentive programs?
9. How else is waste being treated? Are there complementary or competing disposal incentives in place?
10. How will climate change affect the composting site, and what can we do now to prepare?

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ANAEROBIC DIGESTION

ANAEROBIC DIGESTION

Anaerobic digestion (AD) refers to the biological process of converting food and outdoor green waste into two useable products — semi-solid fertilizer and biogas. The fertilizer can be used for landscaping or agricultural purposes and the biogas (primarily consisting of methane) can be used to generate electricity and/or heat.

AD is a proven technology that has been used for many years to treat animal waste and municipal and industrial wastewater. More recently, it is being used to convert the organic content of municipal solid waste (MSW) to useable products. Developing countries commonly use AD to treat waste from farms, while in Europe, the technology has been used to treat the organic fraction of MSW for over 20 years. The technology can break down any biodegradable matter and is most cost-effective when uncontaminated waste is readily available.

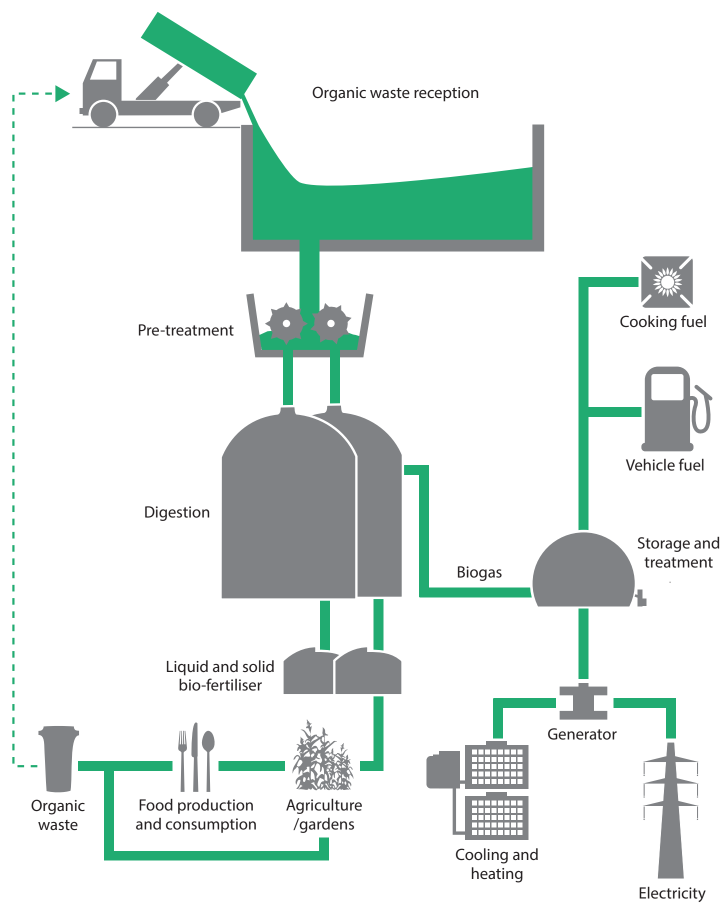
ANAEROBIC DIGESTION - THE BASICS

Anaerobic digestion occurs when naturally occurring microorganisms break down waste in the absence of oxygen (unlike composting which requires oxygen) and emit gases that are captured to generate electricity and heat. The fertilizer produced from anaerobic digestion is significantly moister than compost. It can be used directly or dried into a more solid form. As with composting, the solid residue may require some time outdoors in piles to finish the natural decomposition process.

The anaerobic digestion process typically decreases the solids content by 50-60% while conserving nutrients for soil and killing up to 95% of any disease-causing organisms. The fertilizer produced is a stable, low odor, high nutrient product that is suitable for land application.

The biogas created in this process can be used to generate electricity or can be refined and supplied to natural gas utilities. The typical amount of biogas generation is 100-200m^3 of total gas per tonne of organic MSW digested.

Anaerobic digestion models can vary based on 1) percent of solid content in the waste (low-solids waste has less than 20% solid concentration and high-solids waste has greater than 20%, ideally 20-50%), 2) preference of batch or continuous process, and 3) preference for a single or multi-stage process.



Schematic of fertilizer and energy generation from organic MSW in AD

A batch process (loading all organic waste at once) is lower cost, simpler to use, and requires less water than a continuous process (loading waste continuously as needed). Beyond that, the comparison of the remaining choices to be made are included in the table:

	Single-stage	Multi-stage
Low-solids waste	• Simple to design & operate • Less capital than multi-stage • Longer process • More sensitive	• Higher waste loading rates • Higher methane production • Higher capital costs • More stable
High-solids waste	• Biogas generation rate comparable to or greater than low-solids systems • Minimal pre-treatment (system tolerant of contaminants) • Low water needs • High capital costs	• Higher waste loading rates • Higher methane production • Minimal pre-treatment • High capital costs & operating costs • Low water needs • More expensive equipment

WHAT TO KEEP IN MIND WHEN PURSUING ANAEROBIC DIGESTION

Infrastructure: Digestion has to occur in a fully sealed vessel, in order to exclude oxygen and maintain optimal moisture and temperature levels.

Feedstock: The waste should either be a purely organic waste stream or, if sourced from MSW, it needs to be well-separated organic material that is free from contaminants. If the input contains other materials, such as plastic, metal, and glass, that are not removed beforehand, then the digesters run the risk of getting blocked and becoming inefficient. The contaminants will also reduce the fertilizer quality. Therefore, an effective source separation program is required if household organic waste is being considered.

Biogas production: To maximize biogas production, the feedstock should be entirely biodegradable, and the conditions in the digester should be moist (often achieved by adding water or wastewater) and maintained at a sufficiently high temperature as microorganisms are very sensitive to changes in these parameters. Note that the large quantity of biogas could be safety issue if not properly secured.

Biogas uses: Most anaerobic digestion plant, even small units, should generate sufficient biogas to be used as a fuel, either for creating heat (e.g. for heating or cooking) or to generate electricity using a generator. Excess biogas should be stored in a storage tank or balloon, or burnt (flared).

CLIMATE-PROOFING AN ANAEROBIC DIGESTER:

- May require a storm water management system to protect fertilizer from heavy runoff (if placed outdoors)
- Site away from waterways to prevent leachate contamination

CLIMATE-BENEFITS:

- Will result in reduced greenhouse gas emissions through capture and utilization of methane

MECHANICAL BIOLOGICAL TREATMENT SYSTEM:

- A Mechanical Biological Treatment System (MBT) is a Materials Recovery Facility, where sorting of waste occurs, that is combined with a biological treatment method such as composting or AD
- MBTs are used for processing mixed household
- Generally, the quality of output from composting and AD are lower from an MBT facility than when organics are sourced directly from restaurants, hotels, and markets due to contaminants

Cleaning of the biogas: A highly corrosive gas (hydrogen sulfide) is generated during AD and can be removed by two methods: 1) adding oxygen directly into the digester or storage tank, or 2) running the biogas through iron particles. Less cleanup is need for heat and electricity-use onsite than when the biogas is used for transport fuel or as a replacement for natural gas.

HOW MUCH WILL AN ANAEROBIC DIGESTION SYSTEM COST?

A financial analysis of using organic waste in an AD plant versus landfill should include the transportation cost of moving the organic waste to the AD plant as well as the transport of the resulting fertilizer to its destination.

- In resource-constrained communities, it may make sense to co-digest food waste and wastewater because the combination produces more biogas than stand-alone digestion, and one capital investment can manage both food waste and wastewater

Capital costs	
• Purchase/lease price of the land and equipment • Design and construction costs of the facility and related systems	• Connection to the grid (for electricity generation) • Permits and licensing • Training for operators

Capital costs: Capital costs can range from approximately $2,800 to $6,400 per kW of installed capacity. For AD plants accepting food waste, the biggest costs involve biomass feedstock preparation and handling and the converter system (to convert the gas into heat or electricity).

Operating costs: Generally, 20% of the income generated from an AD plant should be sufficient to cover maintenance and repairs. Operation and maintenance costs generally have two components: fixed and variable:

Fixed O&M costs	Variable O&M costs
• Include labor, maintenance, routine equipment replacement, etc. • Usually calculated as a percentage of capital costs • Range from 2.1 to 7% of installed cost of AD systems	• Include non-biomass fuel, unplanned maintenance and equipment replacement • Vary based on the output of the system and are usually expressed as a value per unit of output (e.g., $/kWh) • Approximately $4.2/MWh on average

Capital and operating costs in Europe and the United States are estimated in the table below:

	Anaerobic Digestion	
	Capital Expenditures (US$/annual tonne) *(1)*	Operational Expenditures (US$/tonne)
Europe	$345-600	$31-57
United States	$220-660	$22-55

(1) Annual tonne is the capital cost of the facility divided by the annual processing capacity

IS YOUR ANAEROBIC DIGESTION SYSTEM TOO EXPENSIVE? THINK ABOUT...

Total system terms: AD reduces the volume of the waste by 50-60%, elongates your landfill life and often creates a new revenue source for your program. High quality fertilizer can be used on local farmland, increasing the productivity of the land, or reduce municipal expenses for beautification efforts in parks or public spaces around the city.

Tipping fees: Like other waste disposal facilities, AD facilities also charge tipping fees per tonne of waste brought to the facility, which offset operational costs and sometimes even capital costs.

Sale of fertilizer: The fertilizer that is produced can be sold and would benefit from laboratory testing to provide product quality assurance.

Sale of biogas as an energy source: The biogas generated from the AD process could be used to generate electricity and/or heat and could be sold to nearby industries or to the grid, thus bringing in revenue. It could also be used on-site to reduce operating costs.

Preferred tariffs for renewable energy: Governments may provide initiatives in the form of tax credits, preferential pricing, discounts, or other benefits to encourage electricity from renewable sources.

Carbon finance: AD captures the methane that would otherwise have formed in landfills, and is thus a possible source for carbon finance, where "credits" from the reduction of emissions of greenhouse gases can be sold to offset the costs of the facility.

Public-private partnership: AD plants are specialized systems that are more difficult to design, construct and operate than landfills or traditional composting facilities. Municipalities normally work with a private sector developer for proper design, construction and operation of an AD plant to share costs and reduce operational risk

WHERE IS ANAEROBIC DIGESTION BEING USED AND WHAT HAVE WE LEARNED?

AD of MSW is commonplace in Europe and is increasingly economically attractive due to the widespread source separation of waste, high landfill tipping fees, and favorable energy prices. AD of other organic waste such as agricultural waste and wastewater is common throughout the developing world. Small-scale digestion of agricultural waste (e.g., manure) has been occurring in rural areas in China, India, and throughout the world, for hundreds of years. In Ningbo, China, there is an AD facility that primary processes restaurant waste. Recently, the government began including source-separated organic waste from households and is focusing on ensuring that incoming waste is uncontaminated. The municipality is providing a financial incentive to neighborhoods based on the quality and quantity of waste diverted, but still needs greater volume of waste and purer organic waste.

AD facilities have also faced problems, some to a point where they have had to shut down. Mechanical problems related to temperature control, mixing of the feedstock, appropriate liquid content; biological problems such as continuing viability of seed bacteria; and over-production of gases such as ammonia have been known to occur. Nevertheless, these issues can be alleviated with proper expertise, monitoring, and training. It is also important to remember that not only is financing important, but also siting and permitting issues, which have sometimes been the cause of halting projects.

MAYOR'S CORNER: QUESTIONS TO ASK SOLID WASTE MANAGERS OR VENDORS WHO WANT TO OPERATE THE ANAEROBIC DIGESTION FACILITY

1. How much feedstock is available and what are the waste generation projections over the next 20-30 years? Does the size of the proposed AD facility make sense given the availability of the feedstock?
2. What systems are in place to ensure the quality as well as guaranteed supply of the feedstock?
3. What is the market for the fertilizer and energy (electricity and/or heat) generated and the related costs for selling and transporting both? Can an AD facility be developed in conjunction with, or adjacent to, a factory that can use the energy (or produces organic waste which can be used in the AD process)?
4. Are there any other by-products that cannot be beneficially used? How would you dispose/treat them (whether solid, liquid, or gas)?
5. What are the siting requirements for the AD facility and have they been met? Have relevant site studies been conducted to make sure the facility will meet local and national regulations?
6. How many local jobs will the facility create?
7. What training and maintenance will be provided over the lifetime of the facility by the private developer? How can local capacity be fostered over time?
8. Can the facility access or benefit from feed-in tariffs, carbon finance, renewable energy tariff incentives, and other incentive programs?
9. Do you have a commercial facility like this in operation already? Where? What are the references?
10. How will climate change affect the facility, and what are you doing now to prepare for it?

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INCINERATION WITH ENERGY RECOVERY

INCINERATION WITH ENERGY RECOVERY

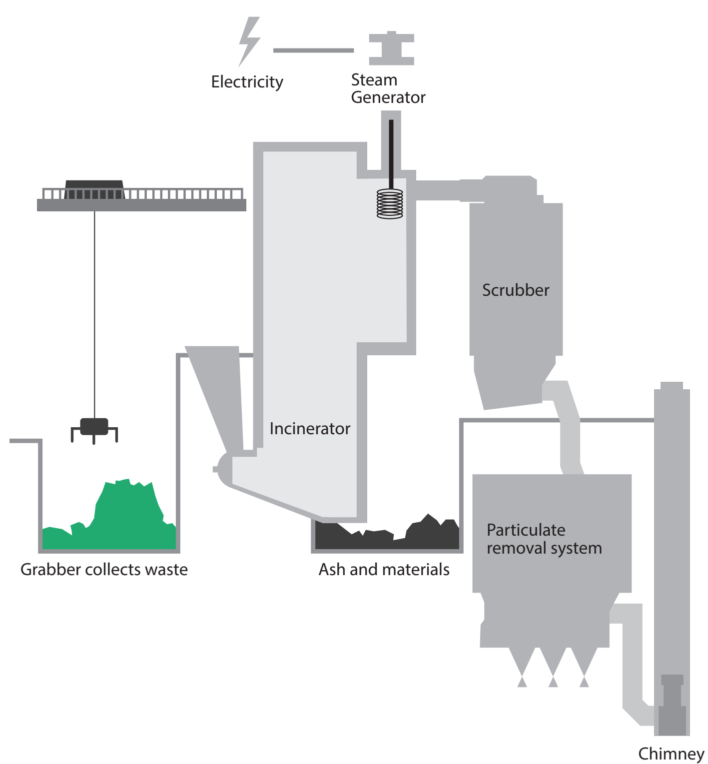
Incineration with energy recovery refers to the combustion of waste under controlled conditions to generate electricity and/or heat. The technology produces energy and heat, reduces the volume of municipal solid waste (MSW) that must be handled and destroys harmful substances, provided that the process includes highly advanced air pollution control (APC) equipment. The energy generated is considered to be partially renewable, due to the biogenic (plant-based) content of the waste, such as food and other organic waste, cardboard and wood. The fossil-fuel sourced components of the waste (e.g. plastic materials) are non-renewable. Incineration was often historically applied without energy recovery, but that is increasingly rare given the potential for the technology to be a source of energy in addition to a waste management solution.

Although incineration technology has matured over the last few decades, it is still relatively expensive, and thus primarily used in high-income countries. Incineration has been implemented successfully in jurisdictions with land (or landfill) scarcity, high technical capacity, significant financial resources, strong environmental regulations and typically a low or separated organic waste fraction. It is widely used in Japan where 80% of MSW was combusted in 2015. Around the world, approximately 11% of MSW is combusted, although the technology is most prevalent in high-income countries.

INCINERATION - THE BASICS

Modern incineration facilities consist of a storage area to sort and store the incoming waste, a crane for lifting the waste from the storage area into the combustion chamber, a heat recovery system that uses the heat from incineration to produce steam in a boiler for electricity generation, an ash handling system to capture non-toxic bottom ash (ash that collects at the bottom of the system), and an APC system, which captures toxic particles that rise with the gaseous emissions (fly ash) and treats harmful gasses prior to release into the air. The operational capacity of incineration facilities can range from 5 to over 1,000 tonnes per day of MSW; however, most facilities are in the range of 200 to 700 tonnes per day.

The main difference between incineration and open or uncontrolled burning is that the combustion in incineration occurs at a very high temperature in a contained plant which reduces the generation of harmful air pollutants. An incinerator can also capture and utilize heat and steam for electricity. Open burning occurs at a much lower temperature while exposed to the atmosphere.



Schematic diagram of incineration facility

Comparison of incineration and open burning

	Incineration	Open burning
Control of burning	Strict controls on volume and types of waste included as well as temperature of furnace	No control
Energy Recovery	Electricity and/or heat potential	No potential
Toxic Emissions Pollution	Low due to high temperature combustion, advanced APC equipment and typically strict government emission regulations	Can be 45 times higher than emissions from incineration. They are not captured but rather released into the atmosphere

WHAT TO KEEP IN MIND WHEN PURSUING INCINERATION

Feedstock requirements: The MSW should contain a sufficient amount of dry, combustible waste (paper, unrecyclable plastics, etc.), and be available at a consistent volume, that varies by less than 20%, to enable effective combustion and a minimum level of electricity and/or heat generation. Waste with a low organics fraction (<50%) is easier for combustion. The feedstock does not need to be homogenous and can include municipal, medical and hazardous waste. Waste that should be avoided includes those with high sulfur or chlorine contents, organic salts, or radioactive materials.

Siting: Assuming multiple sites are available close to the municipality, siting close to industrial plants would benefit both parties by reducing the cost of transportation of waste to the incinerator as well as the distribution cost of electricity and/or heat. If the ash is to be landfilled, siting the facility near a landfill would reduce transportation costs.

Air pollution control: The APC system is a sophisticated and key part of the incineration plant. It ensures that air emissions are kept below harmful levels. The APC system normally comprises a bag filter system in the flue (chimney) to capture the fine particles of the toxic fly ash and also a chemical-based system to capture other harmful gaseous compounds in the flue gas. Emissions are typically monitored continuously for regulatory compliance. Monitoring data is often made publicly available to demonstrate that emissions are below harmful limits.

Ash disposal: The non-toxic bottom ash normally comprises 10-25% by weight of the MSW processed. It can be treated and recycled as construction material or used in the production of cement. If such use is not possible, it must be disposed of in a landfill. Toxic fly ash (ranges from 3-5% by weight) is a hazardous material due to an often high content of heavy metals. It can be disposed of in a hazardous waste landfill (common in Europe) or can be mixed with bottom ash (common in the US) to be disposed of in a sanitary landfill or used as landfill cover.

Electricity and heat generation: A feedstock with suitable characteristics would generate net electricity of 500-600 kWh/tonne of MSW. In the European Union, it is common for both electricity (500 kWh/tonne) and heat (1000 kWh/tonne) to be generated, with the latter used in providing industrial or district heating. This approach is termed 'co-generation'.

Public perception: The lingering criticism of local incinerators from the 1960s and '70s makes incineration a highly contentious subject among many communities. Decision makers need to include the public in the decision-making process, by providing accurate information, and siting facilities away from residential areas.

Contract duration: Due to the very high capital costs of these plants, contracts for incineration are normally 25-30 years in duration. This is the typical time-period that allows the developer (and its financial backers) to recoup the substantial investment made in the capital equipment. It is important to properly assess possible changes in waste quantities, composition and other related factors over the long term so as to ensure that the municipality is not bound into a contract that prevents waste prevention or discourages recycling or composting initiatives to be developed.

Contractual requirements for waste quantities and composition: Successful incineration plants require a consistent flow of waste feedstock and a consistent composition, with a calorific value between defined levels. The developer and operator of an incinerator will typically insist on a minimum quantity and composition of waste as part of any waste treatment contract with a municipality. Small waste quantities are likely to make the facility too costly due to the high upfront capital investments. If the agreed quantity and composition of waste is not provided by the municipality then the incinerator operator will normally apply a financial penalty to compensate for the effect that the lower quantity or change in composition will have on the plant's operation.

Informal waste pickers: the contractual requirements of an incinerator-based waste treatment contract could result in pressure to collect as much waste as possible for delivery to the incinerator. In cities where there are major waste picking activities, waste pickers and informal recyclers may lose access to waste materials, their main source of income. It is essential to consider the issues carefully before engaging in an incinerator-based waste treatment contract. A social assessment must be done with measures in place to mitigate these risks. Policies could be developed as part of an integrated waste management strategy to integrate waste pickers as part of the new system.

Integrated solid waste policy: An incineration facility should be planned as part of an integrated, long-term strategy that also considers waste prevention, reuse, and recycling and composting activities. Recycling and incineration can complement each other if there is sufficient waste volume and the interactions between different initiatives are assessed in detail.

HOW MUCH WILL AN INCINERATION FACILITY COST?

- Costs vary by facility according to the combustion technology chosen since each has unique design characteristics, variations in equipment costs, capacity, site-specific waste characteristics, space requirements, and regulatory requirements.
- On a per tonne basis, capital costs for incineration plants range from US$190-1000 per annual tonne, while operating costs range from US$12-55/tonne. This makes incineration generally more expensive than landfilling, composting, and anaerobic digestion, but cheaper than pyrolysis and gasification.
- Below are a few examples of operational expenditures and capital expenditures for incineration facilities (per tonne of waste processed):

	Incineration Expenditures	
	Capital Expenditures *(1)* (US$/annual tonne) *(2)*	Operational Expenditures *(3)* (US$/tonne) *(4)*
Europe	$600-1000	$25-30
United States	$600-830	$44-55
China	$190-400	$12-22

(1) In Europe and US, predominantly mass-burn/moving grate technology is used for waste incinerator with energy recovery (waste-to-energy). In China many incinerators use circulating fluidized bed (CFB) technology which reflects the lower end of investment cost although moving grate incinerators are also becoming more common.

(2) Annual tonne is the capital cost of the facility divided by the annual processing capacity of the facility

(3) Operating costs without accounting for revenues range between $100-200/tonne. The figures presented in the table are typical operating costs (net gate fees) taking into account revenues for electricity and/or heat sales and other revenues. In the EU, also including subsidies to energy from waste in some countries, these revenues are typically about $100/tonne, hence the resulting operating costs. In US feed-in tariffs for electricity are typically lower, below $50/MWh.

(4) Mixed waste in the US and the EU is relatively low in organics and water content and hence high in calorific value. As a consequence, operating costs for waste with high organics often seen in lower income countries could substantially increase operating costs due to lower revenues

- The high costs of incineration facilities can be heavily offset by revenues earned from operations, as long as the facilities are operated at full processing capacity and optimized technically.
- APC equipment costs are roughly equal to that of the rest of the facility. Thus, the costs and importance of APC technology should be clearly understood.
- There are significant potential economies of scale for incineration, especially when the cost of APC equipment is factored in. Hence, if there is sufficient demand for waste treatment or if a plant can serve a whole region, there may be a clear financial benefit.
- In general, maintenance and other consumable costs are estimated to be 3% and 1%, respectively, of capital costs.

Capital Costs	
• Land and buildings acquisitions • Design and construction of the facility and related systems (steam turbine, APC, etc.) • Environmental and social impact assessments	• Approvals and licensing • Machinery and equipment • Training and monitoring equipment

REVENUE OPPORTUNITY

Revenues can be obtained from tipping fees, sale of electricity, metals recovery, and carbon finance.

Costs are sometimes also calculated based on the per kilo-watt generation electricity from the facility. Comparative costs of thermal treatment options are shown below ($/kW for a 15 MW output)

Incineration with energy recovery	$7,000-10,000
Gasification (conventional)	$7,500-11,000
Gasification (plasma arc)	$8,000-11,500
Pyrolysis	$8,000-11,500

HOW TO RECOVER COSTS OF IMPLEMENTING THESE TECHNOLOGIES

Think in total system terms: Incineration reduces the volume of the waste, elongating your landfill life and often creating a new revenue source for your program. The average lifespan of incineration facilities is about 25 years.

Tipping fees: A major source of income at an incineration facility is tipping fees, which is the fee charged to waste haulers or the municipality per tonne of waste brought to the facility. This can offset capital and operating costs. Larger facilities would have slightly lower tipping fees due to small economies of scale.

Sale of electricity and/or heat generated: The electricity and/or heat generated that is not used in running the facility itself could be sold to nearby industries, to the electric grid, or to district heating systems.

Generation efficiency: Incinerators that generate both heat and electricity are significant more energy-efficient (in terms of the using the energy context of the waste feedstock) than those that generate electricity only. Generating electricity is a common challenge and should not be solely relied on. Locating an incinerator adjacent to, or as part of, an industrial facility/area that can use the heat is an effective way of maximizing the use of the available energy. Alternatively, a district heating system can be developed in conjunction with an incinerator.

Preferred tariffs for renewable energy: Governments may provide incentives in the form of tax credits, preferential pricing, discounts, or other benefits to encourage electricity from renewable sources. In the US and Europe, incineration is considered to be a renewable source of energy because the major portion of carbon in the waste does not increase the total amount of atmospheric carbon

Carbon finance: Incineration facilities can be possible candidates for carbon finance where "credits" from the reduction of emissions of greenhouse gases can be sold to offset costs. Incineration facilities prevent the generation of methane in landfills that could have occurred, and generate electricity and/or heat that might otherwise have been generated from fossil fuels.

Materials recovery: The separation of recyclables, particularly high-value metals, prior to combustion can be a significant source of revenue for incineration facilities.

WHERE IS INCINERATION BEING USED AND WHAT HAVE WE LEARNED?

Incineration facilities have been successful in places like Japan and the European Union where space for landfilling is diminishing and the costs of landfilling are increasing. Other factors that have driven the growth of incineration include improved pollution and emissions controls, legally-binding regulations mandating energy generation from renewable sources, targets for reduction in greenhouse gas emissions, and eligibility for carbon credits and other financial and tax incentives. Decision makers and incineration operators have succeeded in gaining public acceptance by including incineration as a key part of their environmental and waste strategies, encouraging recycling, and using waste as a source of energy.

Incineration has been challenged in some low and middle-income countries where facilities built decades ago without proper waste characterization studies and lack of air pollution control equipment resulted in insufficient and low-quality feedstock, inefficient incineration, and high levels of air pollution. The facilities were not profitable due to lack of revenue generation from electricity, and instead resulted in strong public opposition to the technology due to the resulting high costs and pollution.

CLIMATE CONSIDERATIONS:

- Combusting one tonne of waste in an incineration plant prevents one tonne of CO_2e from being emitted through alternative waste treatment methods
- Incineration offsets fossil fuels by generating sustainable energy

[4] *Assuming 5-year average conversion rate of 1.5139 USD per British pound and 1.18 USD per Euro*

MAYOR'S CORNER: QUESTIONS TO ASK YOUR SOLID WASTE MANAGER OR VENDOR WHO WANT TO CONSTRUCT AND OPERATE THE INCINERATION FACILITY

1. Is the technology appropriate given the local waste composition (organics should be <50% unless government is willing to procure extra treatment equipment), quantity generated, and seasonal variation? What are the waste generation projections over the next 20-30 years? Does the size of the proposed incineration facility make sense given the availability of the feedstock?
2. What systems are in place to ensure the quality as well as a guaranteed supply of the feedstock?
3. Is it financially sustainable? What will the tipping cost be and what cost recovery mechanisms will be put in place?
4. Is there a market for the sale of electricity and/or heat generated from the incineration facility? Is there preferential pricing for waste-derived electricity? Can the incinerator be developed in conjunction with an industrial or residential development or be connected to a grid that can use the electricity and heat?
5. Can land for the facility be readily obtained? What are the siting requirements for such a facility and have they been met? Have relevant site studies been conducted to make sure the facility will meet local and national regulations?
6. How many local jobs will the facility create?
7. What training and maintenance will be provided over the life of the facility by the private developer? How can local capacity be fostered over time?
8. Does the project developer have prior experience in undertaking complex technical and financial projects with sufficient technical knowledge?
9. Does the technology provider already have an existing facility in operation, operating at a similar scale, with a similar feedstock? Can the vendor provide operational and performance data, including emissions and costs, for at least several months, if not longer, of continuous operation?
10. Does the vendor have proof of adhering to the local standards set by solid waste and air pollution regulations?
11. What opportunities exist to put the physical by-products of incineration (e.g., bottom ash) to productive use, such as in road construction or as a component of cement?

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PYROLYSIS AND GASIFICATION

PYROLYSIS AND GASIFICATION

Pyrolysis and gasification, two technologies referred to as Advanced Thermal Treatment (ATT) technologies, convert waste primarily into a synthetic gas or fuel. ATT technologies have been widely applied to industrial and hazardous waste streams for a number of years but only recently been applied to the treatment of municipal solid waste, mainly in Japan.

Both ATT technologies burn waste in a zero- or low-oxygen environment and provide several waste management benefits: (1) quick and large reduction in mass and volume of waste, thus prolonging landfill life; (2) destruction of toxic substances; and (3) energy production. Unlike incineration, where the energy is used on-site to create electricity and/ or heat, pyrolysis and gasification generate fuel that can be transported for use at other locations.

PYROLYSIS AND GASIFICATION - THE BASICS

Pyrolysis involves heating the waste to high temperatures in an enclosed container without oxygen, producing (1) a synthetic gas (syngas) that can be used as liquid fuel, (2) tar, and (3) char, a solid material consisting of the remaining burned waste that can be used as a soil amendment. The temperature at which the waste is burned affects the composition of the output: higher temperatures (>760°C) lead to more gas production, while lower temperatures (450-730°C) favor the production of both liquid fuel and gas.

Gasification involves heating the waste at high temperatures (typically above 700°C) with some oxygen but less than the amount required for incineration, producing syngas and char.

Plasma arc is a heating method that can be used with both technologies. For gasification, it treats waste with very high heat (1,000-1,500°C), producing syngas and a glass-like inert material that may be reused or safely disposed.

Most pyrolysis and gasification plants follow four basic stages:

1. PRE-TREATMENT OF WASTE
   - Dry
   - Sterilize
   - Separate out recyclables

2. HEATING REMAINING WASTE
   - Mainly organic waste
   - Produce syngas, solids

3. 'SCRUBBING' THE SYNGAS
   - Clean syngas to remove particles, soluble substances
   - Produce a 'clean' gas

4. GENERATE ELEC-TRICITY AND/ OR HEAT
   - Use 'scrubbed' gas to generate electricity and/or heat recyclables

	Pyrolysis	Gasification	Incineration with energy recovery
Air Supply	Total absence of oxygen	Low oxygen	Significant oxygen
Temperature Range (°C)	300-800	>750	>850
External heat source	Required	Required	Not required
Pre-treatment of Feedstock	Required (removal of glass, metals, inerts)	Required (removal of glass, metals, inerts)	Not required unless waste has organic fraction to be dried
Products	Syngas, char, tar	Syngas, char, ash	Steam, gas, ash
Outputs	Syngas converted to liquid fuel to produce electricity, heat, or use in a gas engine or as a chemical feedstock	Syngas converted to liquid fuel to produce electricity, heat, or use in a gas engine or as a chemical feedstock	Heat, electricity
Scale of application	Range from small scale (30,000 tonnes/year) to large scale (500,000 tonnes/year)	Range from small scale (30,000 tonnes/year) to large scale (500,000 tonnes/year)	Generally large scale (73,000+ tonnes/year)
Efficiency of energy conversion to a steam boiler	10-20%	10-20%	19-24%

Table 1: Comparison of gasification, pyrolysis, and incineration

WHAT TO THINK ABOUT WHEN PURSUING PYROLYSIS AND GASIFICATION

Energy: ATT technologies require high amounts of energy for operations due to the need for external heating and to clean the syngas. If the gasification process uses pure oxygen, as opposed to air, more energy would be required. In plasma arc gasification, the process is viewed more as a waste disposal option rather than as a fuel source option, because a considerable amount of the energy generated from the process is consumed to operate the plasma torches.

Feedstock: The feedstock can be heterogeneous, but both the amount of energy required to run the facility and the amount generated would depend on 1) the moisture of the waste (if too high, waste would need to be dried in advance), 2) the reactor temperature (higher temperature requires more energy), and 3) quantity of air introduced. Upstream separation of waste is recommended to secure a constant waste composition.

Controlled facility: The facility needs to contain the syngas because the gas itself is toxic and explosive. Syngas is also costly to clean and prepare for use as an energy source.

Flexible capacity: Generally, the ATT technology plants are modular and made up of small units that can be added or removed as waste generation changes, making them more flexible than incineration facilities. They can also be operational in the span of a few months.

Siting: Locate ATT facilities in areas that are planned for industrial activities or near recycling stations and landfills to transport the residual wastes. The electricity and/or heat generated can be used by neighboring industrial plants, thus reducing the cost to both parties. Residential areas are generally avoided but if appropriate, communities should be involved in the decision-making process to avoid opposition.

Enclosed facility: Dust and odor are possible issues and can be controlled within an enclosed building. Waste facilities are generally designed to operate under negative pressure, which minimizes the dust and odor that leaves the building.

Residual waste disposal: If the waste is sorted to remove recyclables at the ATT facility, the recyclables could be sent for further processing. Residual waste should be sent to a landfill for final disposal. An integrated plan should be established during the design phase.

Air pollution control: An air pollution control system is essential to monitor and prevent harmful emissions from entering the air.

HOW MUCH WILL PYROLYSIS AND GASIFICATION COST?

Capital costs for ATT technologies range between $15-80 million for facilities that receive 25-100 kilo-tonnes per annum of MSW. Cost estimates are difficult given the limited number of full-scale operations. Cost data should be treated with a high degree of caution as prices may vary dramatically among technology vendors and may not be fully inclusive.

Costs for pyrolysis and gasification average at $699/tonne for capital expenditures and $6.6 million for annual operations and maintenance expenses. These costs assume an average electricity generation of 8MW.

Air pollution control costs are generally lower for ATT technologies than incineration due to the lower volume of air and energy required for the process.

Capital Costs	
• Land acquisition • Design and construction of the facility and related systems • Environmental and social impact assessments	• Approvals and licensing • Machinery and equipment • Training and monitoring equipment

Operating costs can vary from $3-3.7 million (roughly $35/tonne) for a 100,000 tonne/year facility. These generally have a lower impact on the overall costs of the facility as compared to capital costs and are mainly a function of the amount of waste processed.

Operating Costs	
• Repair and maintenance • Labor (salaries, insurance) • Insurance for the facility	• Sorting/pre-processing • Taxes • Facility operations

THINK YOUR PYROLYSIS OR GASIFICATION FACILITY IS TOO EXPENSIVE? CONSIDER...

Think in total system terms: The ATT technologies reduce the volume of the waste, elongating your landfill life and often creating a new revenue source for your program. The average lifespan of ATT facilities is approximately 30 years.

Sale of electricity and/or heat generated: The electricity and/or heat generated that is not used in running the facility itself could be sold to nearby industries or to the electric grid or district heating system.

Tipping fees: Facilities can be paid a fee per tonne of waste accepted from waste haulers/municipalities. Fees are typically considered to be the main source of revenue for ATT technology facilities. Larger facilities would have slightly lower tipping fees due to small economies of scale.

Sale of recyclables: Facilities that segregate recyclables can earn revenues from the sale of metals, plastic, and other recyclables

Renewable energy credits: Governments may provide incentives in the form of tax credits, preferential pricing, discounts, or other benefits to encourage electricity from renewable sources

Carbon finance: ATT could be a possible candidate for carbon finance, where "credits" from the reduction of emissions of greenhouse gases can be sold to offset the costs of the facility.

Private sector partnership: A way to overcome the lack of capacity to operate and finance could be to work with the private sector under a public-private partnership. A design-build-operate model could be considered with the caveat that there is a higher financial risk to the municipality and less for the developer.

CLIMATE BENEFITS OF ADVANCED THERMAL TREATMENT TECHNOLOGIES:

- ATT avoids the generation of methane by diverting waste from landfills
- Char benefits soil fertility and long-term carbon sequestration
- Compared to landfilling, gasification reduces CO2-eq emissions by 0.3-0.6 tonnes per tonne of MSW; the reduction for pyrolysis is 0.15-0.25 tonnes CO2-eq per tonne of MSW (WMW 2012)

WHERE ARE PYROLYSIS AND GASIFICATION BEING USED AND WHAT HAVE WE LEARNED?

Given the relative newness of applying these technologies to MSW treatment, the need for advanced technical knowledge, and the expense required, there are only a handful of full-scale operations in Europe and Japan. Most facilities were constructed in the late 1990's or early 2000's. A number of these facilities handle relatively homogeneous and dry waste, thus more research is required on whether pyrolysis and gasification would be suited for all kinds of MSW.

Europe, in particular, provides a number of enabling conditions through government regulations and public support that encourage the development of ATT technologies. There are regulations that support the generation of electricity and heat from renewable energy sources as well as a market for renewable fuels (with a willingness to pay higher prices). The stringent environmental regulations have encouraged improvements in air pollution control technology to such an extent that emissions into the atmosphere are significantly lower than emission standards, thus gaining public acceptance for these technologies. These are in combination with high recyclable content with high caloric value, strong local technical capacity, and the ability to fund significant capital investments and operations and maintenance costs. Finally, the lack of space for landfills provides motivation to advance technologies that reduce the amount of final waste that needs to be disposed.

MAYOR'S CORNER: QUESTIONS TO ASK YOUR SOLID WASTE MANAGER OR VENDOR WHO WANT TO OPERATE THE PYROLYSIS OR GASIFICATION FACILITY

1. Is the technology appropriate given the local waste composition and quantity generated? What systems are in place to ensure the quality as well as guaranteed supply of the feedstock?
2. Does the municipality have prior experience in undertaking complex technical and financial projects with sufficient technical knowledge?
3. Is sustainable financing possible? What cost recovery mechanisms will be put in place? Is there a market for the end products?
4. Is there preferential pricing for waste-derived electricity, or at least an easy mechanism by which to sell electricity to the electric grid or heat to neighboring industries?
5. Can land for the facility be readily obtained? What are the siting requirements for such a facility and have they been met? Have relevant site studies been conducted to make sure the facility will meet local and national regulations?
6. What are the local or national air pollution regulations applicable for ATTs? Does the vendor have proof of adhering to the local standards set by solid waste and air pollution regulations in past projects?
7. Does the technology provider already have an existing facility in operation, operating at a similar scale, with a similar feedstock? Can the vendor provide operational and performance data, including emissions and costs, for at least several months, if not longer, of continuous operation? If syngas is to be used as an electricity source, does the vendor have the syngas already operating on an electricity production device (engine, turbine, etc.)?
8. How many local jobs will the facility create?
9. What training and maintenance will be provided over the life of the facility by the private developer? How can local capacity be fostered over time?
10. Is there a local source of expertise to operate the likely imported ATT technology or a private firm that has the technical and operational capabilities?

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