ENVIRONMENTALLY SUSTAINABLE TECHNOLOGIES (EST) FOR MSW ORGANIC WASTE FRACTIONS

FINAL REPORT

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1 Introduction

The amount of solid waste has been increasing by rapid population growth, improved technology, economic development and changing consumption habits. According to ***UNDP SWM Study Report 2007,*** the total organic fraction of municipal solid waste (OFMSW) from both councils (*Majlis Bandaraya Pulau Pinang and Majlis Perbandaran Seberang Perai*) comprises 71% of the total municipal solid waste in Penang. Rapid biodegradation of the organic fraction of municipal solid waste is of key importance to identify environmentally more responsible ways to process it rather than landfilling. Therefore, there is a need to apply other environmentally sound technologies before the desired result can be achieved.

Table 1: Composition of Municipal Wastes from Majlis Bandaraya Pulau Pinang and Majlis Perbandaran Seberang Perai, 2003[1]

Item	MPSP		MPPP	
	Tonnes	**%**	**Tonnes**	**%**
Food	605.84	50%	206.23	33%
Yard & Garden	148.99	12%	59.86	10%
Paper	54.12	5%	176.15	28%
Plastics	208.10	17%	89.89	15%
Textile/Rubber	38.48	3%	19.02	3%
Metal	43.36	4%	29.09	5%
Hazardous	2.69	0%	1.92	0%
Others	98.42	8%	37.74	6%
Total	**1,200.00**		**619.90**	

Source: Satang 2003, UNDP SWM Study Report 2007

In diverting the organic waste fraction of municipal solid waste from landfills in Penang, anaerobic digestion (AD) and composting are recommended to be the most appropriate alternatives for treating the waste stream since AD results in two valuable products, biogas and compost that may be utilised for electricity production and as soil fertilizers respectively while composting produce nutrient rich compost.

2 Composting

Composting is the natural process of decomposition of organic matter by microorganisms under controlled conditions. Raw materials such as crop residues, animal wastes, food garbage, some municipal wastes and suitable industrial wastes, enhance their suitability for application to the soil as fertiliser resources, after having undergone composting.

2.1 Benefits of Composting

Composting provides a variety of benefits as below: [16]

- Reduce or eliminate the need for chemical fertilizers.
- Promote higher yields of agricultural crops.
- Facilitate reforestation, wetlands restoration, and habitat revitalization efforts by amending contaminated, compacted, and marginal soils.
- Cost-effectively remediate soils contaminated by hazardous waste.
- Remove solids, oil, grease, and heavy metals from storm water runoff.
- Avoids Methane and leachate formulation in landfills.
- Capture and destroy 99.6 percent of industrial volatile organic chemicals (VOCs) in contaminated air.
- Provide cost savings of at least 50 percent over conventional soil, water, and air pollution remediation technologies, where applicable, reduces the need for water, fertilizers, and pesticides.
- Serves as a marketable commodity and is a low-cost alternative to standard landfill cover and artificial soil amendments.
- Extends municipal landfill life by diverting organic materials from landfills.

2.1.1 Process Description

During composting, microorganisms from the soil digest the organic (carbon containing) waste and break it down into its simplest parts. This produces a fibre-rich, carbon-containing **humus** with inorganic nutrients like nitrogen, phosphorus and potassium.

The aerobic composting process starts with the formation of the pile. In many cases, the temperature rises rapidly to 70-80 °C within the first couple of days. [17] First, mesophilic organisms (optimum growth temperature range = 20-45 °C) multiply rapidly on the readily available sugars and amino acids. They generate heat by their own metabolism and raise the temperature to a point where their own activities become suppressed. Then a few thermophilic fungi and several thermophilic bacteria (optimum growth temperature range = 50-70 °C or more) continue the process, raising the temperature of the material to 65 °C or higher. This peak heating phase is important for the quality of the compost as the heat kills pathogens and weed seeds.

The active composting stage is followed by a curing stage, and the pile temperature decreases gradually. The start of this phase is identified when turning no longer reheats the pile. At this stage, another group of thermophilic fungi starts to grow. These fungi bring about a major phase of decomposition of plant cell-wall materials such as cellulose and hemi-cellulose. Curing of the compost provides a safety net against the risks of using immature compost such as nitrogen (N) hunger, O deficiency, and toxic effects of organic acids on plants.

Eventually, the temperature declines to ambient temperature. By the time composting is completed, the pile becomes more uniform and less active biologically although mesophilic organisms recolonize the compost. The material becomes dark brown to black in colour. The particles reduce in size and become consistent and soil-like in texture. In the process, the amount of humus increases, the ratio of carbon to nitrogen (C: N) decreases, pH neutralizes, and the exchange capacity of the material increases.

The compost conditions must be balanced for efficient decomposition. There must be:

- **Plenty of air** - mixture should be turned daily or every other day
- **Adequate water** - mixture should be moist, but not soaking wet
- **Proper mix of carbon to nitrogen** - ratio should be about 30:1
- **Small particle size** - big pieces should be broken up, as smaller particles break down more rapidly
- **Adequate amount of soil** - should provide enough microorganisms for the process

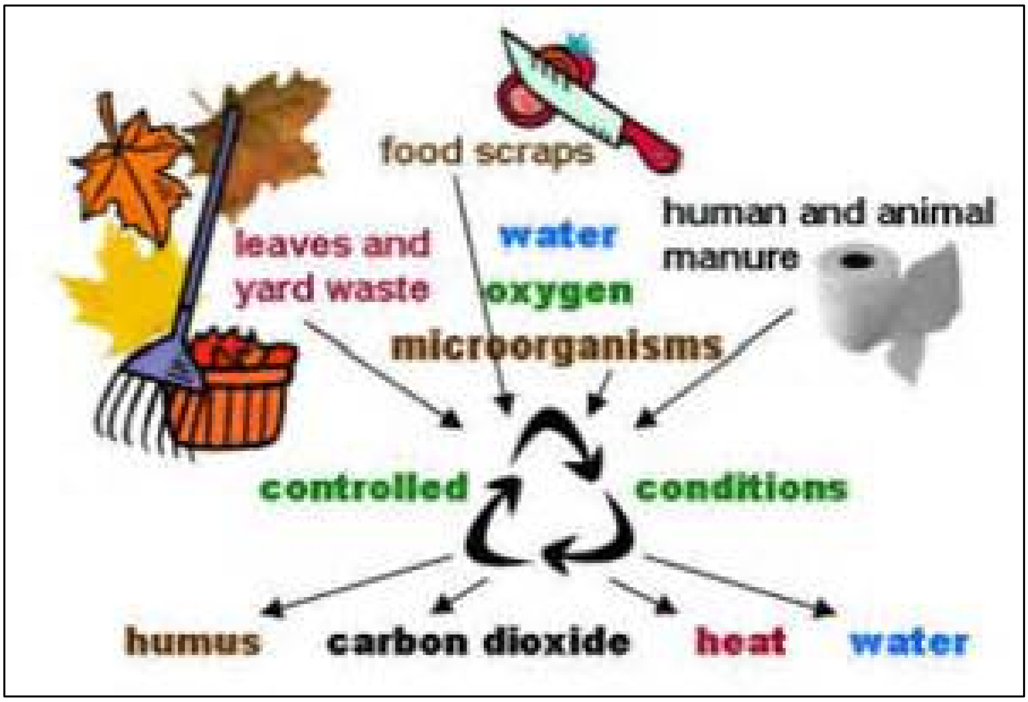


Figure 1: Composting Process

2.1.2 Important Process Parameters

The five important process parameters that must be "controlled" during composting process as below:

- **Feedstock and nutrient balance.** Controlled decomposition requires a proper balance of "green" organic materials (e.g., grass clippings, food scraps, manure), which contain large amounts of nitrogen, and "brown" organic materials (e.g., dry leaves, wood chips, branches), which contain large amounts of carbon but little nitrogen. Obtaining the right nutrient mix requires experimentation and patience and is part of the art and science of composting.

- **Particle size.** Grinding, chipping, and shredding materials increases the surface area on which the microorganism can feed. Smaller particles also produce a more homogeneous compost mixture and improve pile insulation to help maintain optimum temperatures. If the particles are too small, however, they mayprevent air from flowing freely through the pile.

- **Moisture content.** Microorganisms living in a compost pile need an adequate amount of moisture to survive. Water is the key element that helps transports substances within the compost pile and makes the nutrients in organic material accessible to the microbes. Organic material contains some moisture in varying amounts, but moisture also might come in the form of rainfall or intentional watering.

- **Oxygen flow.** Turning the pile, placing the pile on a series of pipes, or including bulking agents such as wood chips and shredded newspaper all help aerate the pile. Aerating the pile allows decomposition to occur at a faster rate than anaerobic conditions. Care must be taken, however, not to provide too much oxygen, which can dry out the pile and impede the composting process.

- **Temperature.** Microorganisms require a certain temperature range for optimal activity. Certain temperatures promote rapid composting and destroy pathogens and weed seeds. Microbial activity can raise the temperature of the pile's core to at least 60°C. If the temperature does not increase, anaerobic conditions (i.e., rotting) occur. Controlling the previous four factors can bring about the proper temperature.

2.1.3 Type of Composting

2.1.3.1 Backyard or Onsite Composting

Backyard or onsite composting can be conducted by residents and other small quantity generators of organic waste on their own property. [19]

Table 2: Backyard or Onsite Composting

	Item	Description
1.	Types of Waste and Waste Generators	Backyard or onsite composting is suitable for converting yard trimmings and food scraps into compost that can be applied on site.
2.	Climate or Seasonal Considerations	Climate and seasonal variations do not present major challenges to backyard or onsite composting because this method typically involves small quantities of organic waste. When conditions change-for example, if a rainy season approaches-the process can be adjusted accordingly without many complications.
3.	Environmental Concerns	Improper management of food scraps can cause odors and also might attract unwanted attention from insects or animals.
4.	Requirements	Backyard or onsite composting requires very little time or equipment. Education is the most critical aspect of backyard or onsite composting. Local communities might hold composting demonstrations and seminars to encourage homeowners or businesses to compost on their own properties.

5.	Results	The conversion of organic material to compost can take up to two years, but manual turning can hasten the process considerably (e.g., 3 to 6 months). The resulting natural fertilizer can be applied to lawns and gardens to help condition the soil and replenish nutrients. Compost, however, should not be used as potting soil for houseplants because of the presence of weed and grass seeds.

2.1.3.2 Vermicomposting

Vermicomposting is a process that relies on earthworms and microorganisms to help stabilize active organic materials and convert them to a valuable soil amendment and source of plant nutrients. Earthworms will consume most organic materials, including food preparation residuals and leftovers, scrap paper, animal manure, agricultural crop residues, organic by-products from industries, and yard trimmings.

Table 3: Vermicomposting Requirements

	Item	Description
1.	Types of Waste and Waste Generators	Worms will eat almost anything you would put in a typical compost pile (e.g., food scraps, paper, and plants). Worms eat only plant/vegetarian organic matter and not meat, acidic, oily or spicy food. Vermicomposting can be ideal for apartment dwellers or small offices that want to derive some of the benefits of composting and reduce solid waste. It is frequently used in schools to teach children conservation and recycling.
2.	Climate or Seasonal Considerations	Worms are sensitive to variations in climate. Extreme temperatures and direct sunlight are not healthy for the worms. The optimal temperatures for vermicomposting range from 13° C to 25° C. In hot, arid areas, the bin should be placed under the shade. By vermicomposting indoors, however, one can avoid many of the problems posed by hot or cold climates. The primary responsibility is to keep the worms alive and healthy by providing the proper conditions and sufficient food.
3.	Environmental Concerns	Extremely dry and hot weather may kill the worms and similarly with polluted water sources.

		Extremely wet weather may drown the worms in the compost pile if not covered up during heavy rainfall.
4.	Requirements	Vermicomposting has only a few basic requirements, among them: worms, worm bedding (e.g., shredded newspaper, cardboard), and a bin to contain the worms and organic matter. Maintenance procedures include preparing bedding, burying garbage, and separating worms from their castings.
5.	Results	One pound of mature worms (approximately 800-1,000 worms) can eat up to half a pound of organic material per day. It typically takes three to four months for these worms to produce harvestable castings, which can be used as potting soil. Vermicomposting also produces compost or “worm” tea, a high-quality liquid fertilizer for house plants or gardens.

2.1.3.3 Aerated Windrow Composting

Organic waste is formed into rows of long piles called “windrows” and aerated by turning the pile periodically by either manual or mechanical means. The ideal pile height, which is between 1 and 2.5 metres , allows for a pile large enough to generate sufficient heat and maintain temperatures, yet small enough to allow oxygen to flow to the windrow's core. The ideal pile width is between 4 and 5 metres.

Table 4: Aerated Windrow Composting Requirements

	Item	Description
1.	Types of Waste and Waste Generators	This method can accommodate large volumes of diverse wastes, including yard trimmings, grease, liquids, and animal byproducts (such as fish and poultry wastes), but only with frequent turning and careful monitoring. This method is suited for large quantities, such as that generated by entire communities and collected by local governments, and high volume food-processing businesses (e.g., restaurants, cafeterias, packing plants).

2.	Climate or Seasonal Considerations	In a warm, arid climate, windrows are sometimes covered or placed under a shelter to prevent water from evaporating. In rainy seasons, the shapes of the pile can be adjusted so that water runs off the top of the pile rather than being absorbed into the pile. Also, windrow composting can work in cold climates. Often the outside of the pile might freeze, but in its core, a windrow can reach 60° C.
3.	Environmental Concerns	Leachate is liquid released during the composting process. This can contaminate local ground-water and surface-water supplies and should be collected and treated. In addition, windrow composting is a large scale operation and might be subject to regulatory enforcement. Samples of the compost should be tested in a laboratory for bacterial and heavy metal content. Odors also need to be controlled. The public should be informed of the operation and have a method to address any complaints about animals or bad odors. Other concerns might include zoning and siting requirements.
4.	Requirements	Windrow composting often requires large tracts of land, sturdy equipment, a continual supply of labor to maintain and operate the facility, and patience to experiment with various materials mixtures and turning frequencies.
5.	Results	This method will yield significant amounts of compost, which might require assistance to market the end-product. Alternatively, local governments can make the compost available to residents for a low or no cost.

2.1.3.4 Aerated Static Pile Composting

Aerated Static Pile (ASP) composting, refers to any of a number of systems used to biodegrade organic material without physical manipulation during primary composting. The blended admixture is usually placed on perforated piping, providing air circulation for controlled aeration. It may be in windrows, open or covered, or in closed containers. [20] With regard to complexity and cost, aerated systems are most commonly used by larger, professionally managed composting facilities, although the technique may range from very small, simple systems to very large, capital intensive, industrial installations.

Table 5: Aerated Static Pile Composting

	Item	Description
1.	Types of Waste and Waste Generators	Aerated static piles are suitable for a relatively homogenous mix of organic waste and work well for larger quantity generators of yard trimmings and compostable municipal solid waste (e.g., food scraps, paper products), which might include local governments, landscapers, or farms. This method, however, does not work well for composting animal byproducts or grease from food processing industries.
2.	Climate or Seasonal Considerations	Like windrow composting, in a warm, arid climate, aerated static piles are sometimes covered or placed under a shelter to prevent water from evaporating. In the cold, the core of the pile will retain its warm temperature, but aeration might be more difficult in the cold because this method involves passive air flowing rather than active turning. Some aerated static piles are placed indoors with proper ventilation.
3.	Environmental Concerns	Since there is no physical turning, this method requires careful monitoring to ensure that the outside of the pile heats up as much as the core. One way to alleviate bad odors is to apply a thick layer of finished compost over the pile, which can help maintain high temperatures throughout the pile. Another way to deal with odor, provided that the air blower draws air out of the pile, is to filter this air through a biofilter made from finished compost.
4.	Requirements	This method typically requires equipment such as blowers, pipes, sensors, and fans, which might involve significant costs and technical assistance. Having a controlled supply of air enables construction of large piles, which require less land than the windrow method.
5.	Results	This method produces compost relatively quickly-within 3 to 6 months.

2.1.3.5 In-Vessel Composting

In-vessel composting generally describes a group of methods that which confine the composting materials within a building, container, or vessel. In-vessel composting systems can consist of metal or plastic tanks or concrete bunkers in which air flow and temperature can be controlled, using the principles of a "bioreactor".[21] Generally the air circulation is metered in via buried tubes that allow fresh air to be injected under pressure, with the exhaust being extracted through a biofilter, with temperature and moisture conditions monitored using probes in the mass to allow maintenance of optimum aerobic decomposition conditions.

Table 6: In-Vessel Composting

	Item	Description
1.	Types of Waste and Waste Generators	In-vessel composting can process large amounts of waste without taking up as much space as the windrow method. In addition, it can accommodate virtually any type of organic waste (e.g., meat, animal manure, biosolids, food scraps). Some in-vessel composters can fit into a school or restaurant kitchen while others can be as large as a school bus to accommodate large food processing plants.
2.	Climate or Seasonal Considerations	In-vessel composting can be used year-round in virtually any climate because the environment is carefully controlled, often by electronic means. This method can even be used in extremely cold weather if the equipment is insulated or the processing takes place indoors.
3.	Environmental Concerns	In-vessel composting produces very little odor and minimal leachate.
4.	Requirements	In-vessel composters are expensive and might require technical assistance to operate properly, but this method uses much less land and manual labor than windrow composting.

5.	Results	Conversion of organic material to compost can take as little as a few weeks. Once the compost comes out of the vessel, however, it still requires a few more weeks or months for the microbial activity to stabilize and the pile to cool.

2.1.3.6 Compost Processing and Application

Compost is a rich source of organic matter. Soil organic matter plays an important role in sustaining soil fertility, and hence in sustainable agricultural production. In addition to being a source of plant nutrient, it improves the physico-chemical and biological properties of the soil. As a result of these improvements, the soil: (i) becomes more resistant to stresses such as drought, diseases and toxicity; (ii) helps the crop in improved uptake of plant nutrients; and (iii) possesses an active nutrient cycling capacity because of vigorous microbial activity. These advantages manifest themselves in reduced cropping risks, higher yields and lower outlays on inorganic fertilizers for farmers.

2.1.3.7 Important Issues related to Composting Plant [18]

Important Issues related to Composting Plant are listed below:

- Inadequate attention to the biological process requirements
- Lack of vision and market plans for final compost product
- Poor feedstock which yields poor quality finished compost, for example heavy metal contamination
- Poor accounting practices which neglect that the economics of composting rely on externalities, such as reduced soil erosion, water contamination, climate change and avoided disposal costs
- Difficulties in securing finances since the revenue generated from the sale of compost will rarely cover processing, transportation and application costs
- Poor marketing experiences
- Poor integration with agricultural community
- Nuisance potential, such as odours and rats
- Inadequate attention to the biological process requirements
- Lack of vision and market plans for final compost product
- Poor feedstock which yields poor quality finished compost, for example heavy metal contamination
- Poor accounting practices which neglect that the economics of composting rely on externalities, such as reduced soil erosion, water contamination, climate change and avoided disposal costs

- Difficulties in securing finances since the revenue generated from the sale of compost will rarely cover processing, transportation and application costs
- Poor marketing experiences
- Poor integration with agricultural community
- Nuisance potential, such as odours and rats

2.1.3.8 Comparison of composting systems

The most appropriate composting system has to be selected based on its technological feasibility, economic costs and social and environmental impacts. Table 7 compares the main technological differences among the composting processes.

Table 7: Comparison of Composting Processes [18]

Item	Windrow	Aerated static pile	In-vessel
Capital costs	Generally low	Generally low in small system, can become high in large systems	Generally high
Operating costs	Generally low	High (in sludge systems)	Generally low where bulking agents are used.
Land requirements	high	high	Low, can increase if windrow drying or curing is required
Control of air	Limited unless forced aeration is used	complete	complete
Operational control	Turning frequency, amendment or compost recycle addition	Airflow rate	Airflow rate, agitation (dynamic), amendment, or compost recycle addition
Sensitivity to weather	Sensitive unless in housing	Demonstrated in cold and wet weather	Demonstrated in cold and wet weather
Control of odors	Depends on feedstock, potential large area	May be a large area source but can be controlled	Potentially good
Potential operating problems	Susceptible to adverse whether	Control of air supply is critical, potential for channeling or short circuit of air supply	Potential for short circuit of air supply, system may be mechanically complex

2.1.3.9 Mechanical Biological Treatment

A mechanical biological treatment system is a type of waste processing facility that combines a sorting facility with a form of biological treatment such as composting or anaerobic digestion. [22] It is a generic term for an integration of several processes commonly found in other waste management processes such as Materials Recovery Facilities (MRFs), Refuse Derived Fuel (RDF), solid recovered fuel/ specified recovered fuel (SRF), sorting and composting plant. The system enables the recovery of materials contained within the mixed waste and facilitate the stabilisation of the biodegradable component of the material.

2.1.3.9.1 Benefits of Mechanical Biological Treatment

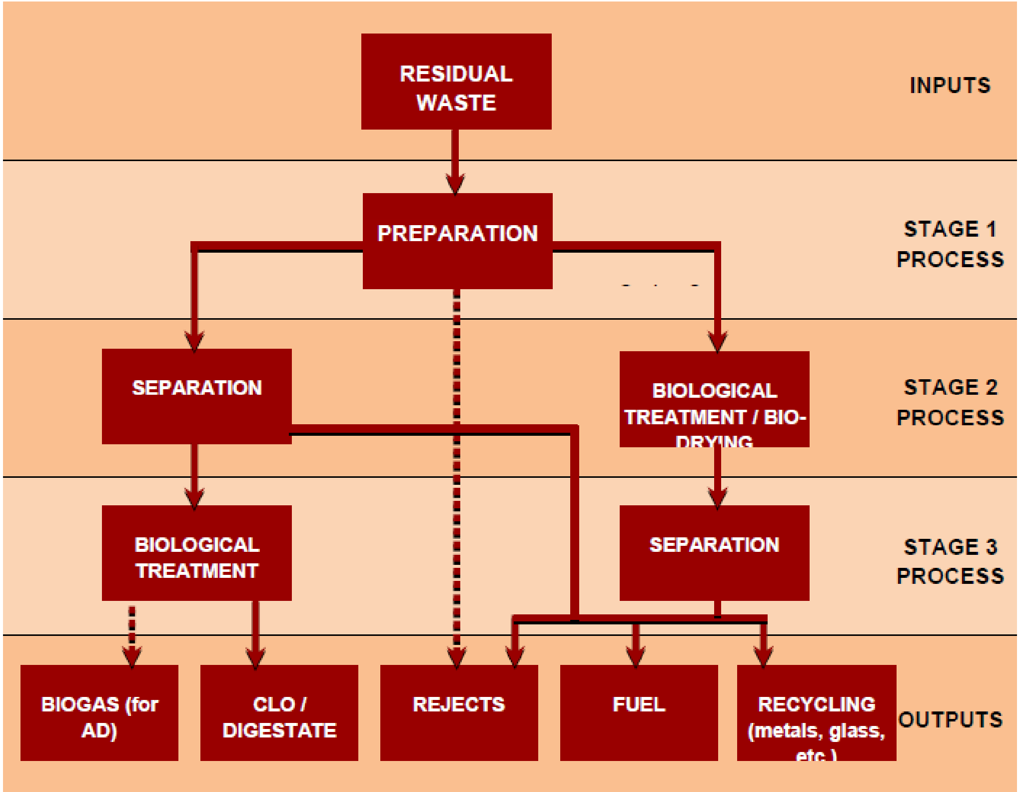
The benefits of Mechanical Biological Treatment are listed below:

- Pre-treatment of waste going to landfill
- Diversion of non-biodegradable and biodegradable municipal solid waste going to landfill through the mechanical sorting of municipal waste into recoverable materials for recycling and/or energy recovery as refuse derived fuel (RDF) [23] solid recovered fuel/ specified recovered fuel (SRF).
- Diversion of biodegradable municipal solid waste going to landfill
- Stabilization into compost-like output for use for soil improvement
- Conversion into combustible biogas for energy recovery
- Drying materials to produce a high calorific organic-rich fraction for use as refuse derived fuel (RDF).

2.1.3.9.2 Process Description

Mechanical Biological Treatment (MBT) plants may be configured in variety of ways to achieve required recycling and recovery of biodegradable municipal waste diversion performance. Figure 2 illustrates configurations for the MBT plant.

Figure 2: An Illustration of Potential Mechanical Biological Treatment Options



2.1.3.9.3 Process Output

Possible outputs of this system:

- Renewable fuel (biogas) leading to renewable power
- Recovered recyclable materials such as metals, paper, plastics, glass etc.
- Digestate - an organic fertiliser and soil improver
- Carbon credits – additional revenues
- High calorific fraction refuse derived fuel - Renewable fuel content dependent upon biological component
- Residual unusable materials prepared for their final safe treatment (e.g. incineration or gasification) and/or landfill

2.2 Locally Available Technologies in Penang

In Penang, several locally available technologies that are environmentally sustainable have been used by Penangites for composting at the household, community and community levels. Also available are technologies that uses machines and microbial decomposition.

2.2.1 Household & Community Composting

Local available technologies for composting that used at the household, community and community levels are listed below (Details please refer to Appendix A):

- Flower Pot composting
- Plastic Bag Composting
- Perforated Barrel
- Rotating Barrel
- Tower Tyre Composting
- Wire Hoop Composting
- Simple Pit Composting
- Heap Composting
- Small scale Windrow Composting
- Bottomless Bin Composting
- Vermiculture
- Community Shed
- Centralised Composting Plant
- Groundswell Static Fermentation Piles
- Green Waste Windrow composting

2.2.2 Other local available technology that use machine and microbial decomposition

- Bio-regen Food Waste Processing machine
    -
- Rotating in-vessel composting machine at:
    - Bagan Ajam Wet Market
    - Autocity, Juru.

3 Treatment Options for OMSW (Organic Fraction of Municipal Organic Waste) at Municipal Level

The environmental sound treatment options available for organic fraction of Municipal Solid Waste in developing and developed countries as below:

- Municipal Composting

  Municipal composting processes are similar to those described for community composting in the previous section but occur on a larger scale. E.g. of municipal composting of green waste in Penang are found at the Jelutong Dumpsite and the Ampang jajar Transfer Station in Seberang Perai.

- Anaerobic Digestion

Anaerobic Digestion (AD) and Composting are seen as the most favoured options to deal with OMSW in many developing and developed countries. Both treatment options reduce the environmental burden and enable the generation of a nutrient rich fertilizer. A number of other options for dealing with residual waste are now becoming more significant, one of these is a group of technologies called Mechanical Biological Treatment.

Over the past 20 years, Anaerobic digestion of municipal solid waste technology has advanced in Europe because of waste management policies enacted to reduce the long term health and environmental impacts of landfill disposal.[2] Composting of the OFMSW has increased significantly over the past 15 years, particularly for source-separated wastes.

3.1 Anaerobic Digestion (AD)

Anaerobic Digestion (AD) is a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. One of the end products is biogas, which is combusted to generate electricity and heat, or can be processed into renewable natural gas and transportation fuels.

The European market has shown a large preference for single stage over two stage digesters and a slight preference for dry digestion system over wet systems. However, the choice of anaerobic digestion technology depends on the composition of waste stream, co-product markets and other site specific requirements. The design of any new digester facility should be based on a thorough feasibility study and special attention should be paid to all aspects of the treatment process, including waste collection and transportation, pre-treatment processing, material handling, post-treatment processing, public education, and strategic siting of the system.

Anaerobic digestion systems for MSW include[3]:

- **Single-stage wet digesters:** Typically simpler to design, build, and operate and generally less expensive, the organic loading rate (OLR) of single-stage digesters is limited by the ability of methanogenic organisms to tolerate the sudden decline in pH that results from rapid acid production during hydrolysis.
- **Dry fermentation:** Type of single-stage digester, but distinctive from other AD categories because feedstocks are in a solid state that can be handled with a front-end loader and normally no additional water is added. Digestion takes place at 20-45% total solids, and can be done in either a batch or continuous mode. In batch mode, materials are loaded into chambers then inoculated and maintained until the end of the retention time. In continuous mode, fresh feedstock is continuously fed to the digester and digestate is continuously removed.
- **Two-stage digesters:** System separates the initial hydrolysis and acid-producing fermentation from methanogenesis, which allows for higher loading rates for high nitrogen containing materials but requires additional reactors and handling systems. Another important design parameter is the total solids (TS) concentration in the reactor, expressed as a fraction of the wet mass of the be handled prepared feedstock. The remainder of the wet mass is water by definition. Feedstock is typically diluted with process water to achieve the desirable solids content during the preparation stages.

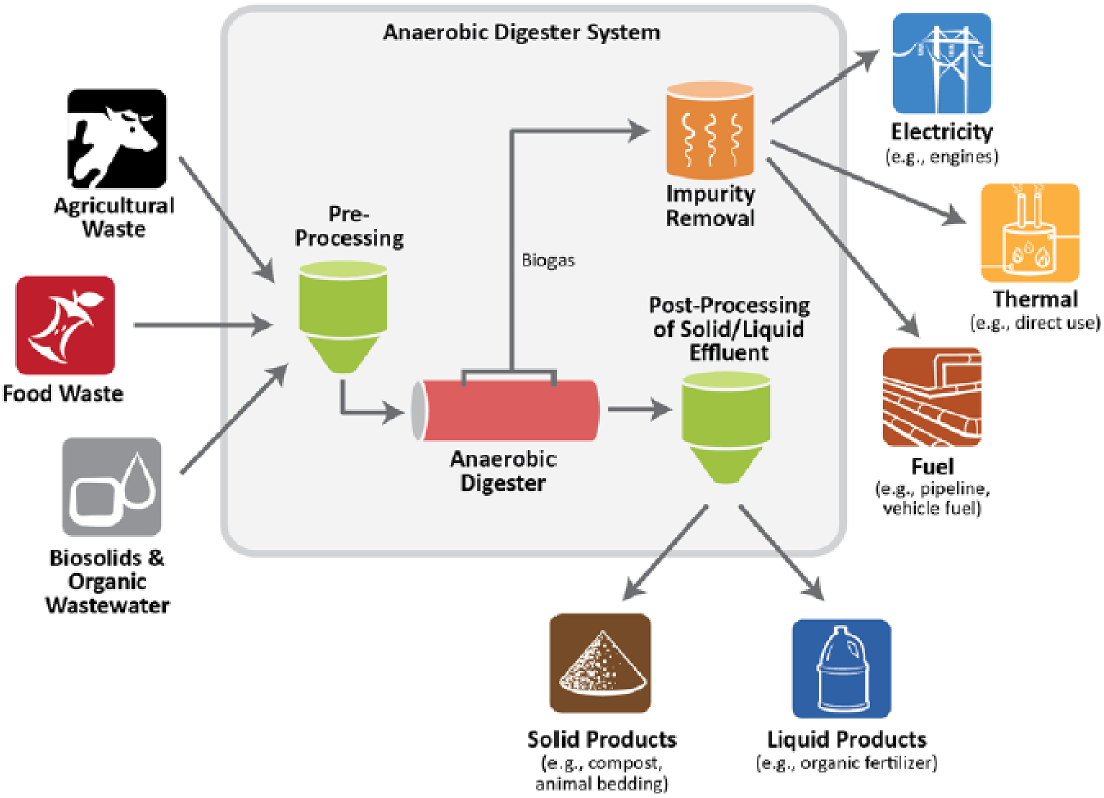


Figure 3: Successful Anaerobic Digestion across the World

3.1.1 Benefits of Anaerobic Digestion

Anaerobic digestion provides a variety of benefits which may be classified into three groups:

3.1.1.1 Environmental Benefits [5]

a. The application of anaerobic digestion reduces greenhouse gas emissions, which are causes of potential global warming.
b. Anaerobic digestion reduces the organic content of the waste, which results in a volume reduction for solid waste materials.
c. Anaerobic digestion removes and contains the biodegradable components of waste, which produce odour compounds.
d. The application of anaerobic digestion reduces the pathogen populations in the waste, which can enhance public health in the location of final waste disposition.
e. Anaerobic digestion removes mainly carbon, nutrients contained in the organic matter are conserved and mineralized to more soluble and biologically available forms.

3.1.1.2 Economic Benefits

a. Anaerobic digestion transforms waste liabilities into new profit centres.
b. Income can be obtained from the sale of organic fertilizer, carbon credits and sale of power.
c. Anaerobic digestion creates green jobs and contributes to growth in the local economy.

3.1.1.3 Energy Benefits

a. The production of biogas from waste material for use as a fuel energy source qualifies anaerobic digestion as a sustainable technology for renewable energy generation. However, energy production through anaerobic digestion alone may not always prove economically viable in a climate of low energy costs.
b. Energy conservation can be achieved by the application of anaerobic digestion instead of conventional aerobic processes. In order to supply oxygen for aerobic treatment, energy is consumed to compress air for aeration of wastewater or to turn and mix solid waste for aerobic composting.

3.2 Process Description

Anaerobic digestion is a process in which micro-organisms derive energy and grow by metabolising organic material in oxygen-free environment resulting in the production of methane. The anaerobic digestion of organic material is accomplished by a consortium of microorganisms working synergistically. The process of Anaerobic Digestion (AD) is generally carried out in four stages: hydrolysis, acidification; acetogenesis, and methanogenesis.

- **Hydrolysis** is the first step of anaerobic digestion in which insoluble complex molecules such as carbohydrates and fats are broken down to short sugars, fatty acids and amino acids.
- **Acidification** is the second step of aerobic digestion. Fermentation bacteria transform sugars and other monomeric organic products from hydrolysis into organic acids, alcohols, carbon dioxide, hydrogen and ammonia.
- **Acetogenesis** is the third step of anaerobic digestion. Products from fermentation (organic acids, alcohols) are converted into hydrogen, carbon dioxide and acetic acid.
- **Methanogenesisis** the fourth and final step of anaerobic digestion. Methanogenic bacteria, which are strictly anaerobic, transform the acetic acid, carbon dioxide and hydrogen into mixture of methane, carbon dioxide and vary quantities of nitrogen and other components.

A simplified schematic representation of anaerobic digestion of organic matter is provided in Figure 4. The pathways along with the stoichiometry of the overall chemical reactions are:

a. Acetotrophic methanogenisis: $4CH_3COOH \rightarrow 4CO_2 + 4CH_4$

b. Hydrogenotrophic methanogenisis: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

c. Methylotrophic methanogenisis: $4CH_3COOH \rightarrow 3CH_4 + 2H_2O$

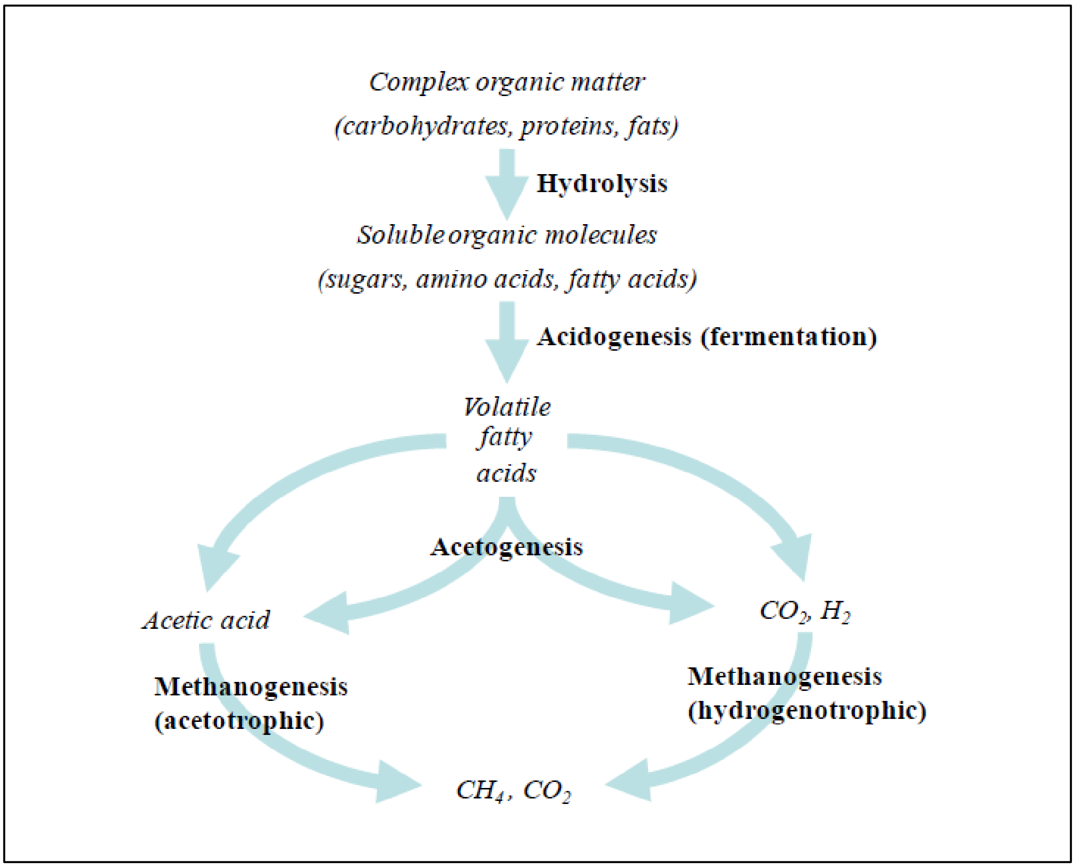


Figure 4: Anaerobic digestion Biochemical Conversion Pathway [2]

3.2.1 Important Process Parameters

For the digestion to be effective, it should operate as a finely balance and living system (carefully controlled and closely monitored) in order to create optimal conditions for the growth of the bacteria responsible for anaerobic digestion. Therefore, several parameter factors should be considered for design and processing of biogas treatment units. The most important of these parameters are described below:

- Mean Cell Residence Time [6]

  The mean cell residence time (MCRT) is the theoretical average time a bacterial cell remains in a digester. The shorter the MCRT, bacterial populations would need to reproduce faster to prevent being washed out of the digester. The MCRT is a key parameter that is used to control process stability and determine the required digester volume. Longer MCRTs general result in a more stable process and a higher degree of solid stabilization.

- Temperature

  They are mainly two temperature ranges that provide optimum digestion conditions for the production of methane, which are mesophilic and thermophilic ranges. The mesophilic range is between 20°C - 40°C and optimum temperature is considered to be 30°C - 35°C. The thermophilic temperature range is between 50°C - 65°C.[5] Thermophilic processes produce more biogas in shorter time but require higher input energy to obtain operation temperatures. Methane production can be increased at higher temperature, but also the generation of free ammonia, which can have an inhibitory effect on the digestion performance.[7]

- pH level

  Anaerobic bacteria, especially the methanogens are sensitive to the acid concentration in the digester and their growth can be inhibited by acidic conditions. The acid concentration in aqueous systems is expressed by the pH value. There are two groups of bacteria in terms of pH optima, namely acidogens and methanogens. The best pH range for acidogens is 5.5 – 6.5 and for methanogens is 7.8 – 8.2.[8] The operating pH tor combined cultures is 6.5 – 7.5.[9] Since methanogenesis is considered as a rate-limiting step, pH close to neutral is optimum.

- Carbon to Nitrogen Ratio

  The relationship between the amount of carbon and nitrogen in organic materials is represented by the Carbon:Nitrogen (C:N) Ratio. The C:N ratio is a measure of relative amounts of organic carbon and nitrogen present in the feedstock. The ideal substrate C:N ratio is 20-30:1.[10] A high C: N ratio is an indication of rapid consumption of nitrogen by methanogens, which the results in lower gas production. Low C: N ratio causes ammonia accumulation and pH values may exceed 8.5, which can betoxis to methanogenix bacteria. Optimum C: N ratio can be ensured by mixing difference feedstock material with high (e.g. organic solid waste) and low (e.g. sewage or animal manure) C: N ratios to achieve an ideal C: N ratio level.

- Mixing

  Mixing within the digester improves the contact between the microorganisms and substrate and improves the bacteria population's ability to obtain nutrients. Mixing also prevents the formation of scum and development of temperature gradients within the digester. However excessive mixing can disrupt the microorganisms and therefore slow mixing is preferred.

- Organic loading rate

  Organic loading rate is a measure of the biological conversion capacity of the anaerobic digestion system. It is expressed in kg Chemical Oxygen Demand (COD) or Volatile Solids per cubic meter of reactor. Feeding the system above its sustainable organic loading rate results in low biogas yield due to accumulation of inhibiting substances in digester slurry. The typical inhibitors are oxygen, hydrogen sulphide, organic acids, free ammonia, heavy metals and other hazardous substances such as disinfectants (from hospitals or industries), herbicides, insecticides (from agriculture, market, gardens, and households) and antibiotics.[11]

3.3 Type of Anaerobic Digestion Systems

Anaerobic digestion systems can be classified according to the **solid contents** of the feedstock, the **temperature** at which the digester operates, the number of stages involved in the process and whether the process is **batch or continuous**.

3.3.1 Wet versus Dry System

There are two ranges of solid matter concentration in anaerobic digestion systems, low solids and high solids. The low-solid system which usually operates with less than 10% total solids (TS) and can reach up to 20% TS is known as wet system. The high-solids system which operates with 20-40% TS sometimes even higher is described as a dry system.

A comparative analysis of low-solids and high solids Anaerobic Digestion processes for Organic Fraction Municipal Solid Waste is shown in Table 8.

Table 8: Comparison of wet and dry system of anaerobic digestion processes for the treatment of waste. [15]

Operation parameter	Low-Solids	High -Solids
Solids content	< 20%	>20%
Reactor volume	Larger	Smaller
Water addition	More	Less or none
Organic loading rate	Lower	Higher
Gas production rate	Lower	Higher
Mass removal rate	Lower	Higher
Equipment	Pumps of all types	High solids pumps, conveyor
Toxicity problems	Less severe	More severe
Leachate problem	More	Less
Effluent dewatering	More difficult, expensive	Easier, inexpensive
Digestate management	More difficult	Easier

Note: Project References (Details refer Appendix B)

- **Wet Systems:** Vasteras Case Study**,** Ludlow Case Study**,** Kahlenberg Case Study and Holsworthy Case Study.
- **Dry Systems:** Zurich Otefingen.

3.3.2 Mesophilic versus Thermophilic System

Anaerobic digesters are normally operated at either mesophilic temperatures (30-40^oC) or moderately thermophilic temperatures (50-60^oC), allowing optimal growth of the bacteria involved in the breakdown of the organic matter. [12]

3.3.2.1 Mesophilic Digestion Systems

Mesophilic bacteria have an optimal temperature for growth between 30-40^oC and consequently mesophilic digesters are usually operated at temperatures around 35^oC. It is essential for efficient operation to control temperature since reaction rates drop off considerably as temperature falls below 35°C and there is also a sharp drop off in activity at temperatures above 45^oC, as mesophilic bacteria become inhibited by the heat.

Mesophilic digestion systems are generally more stable than thermophilic systems due to the fact that a wider diversity of bacteria grow at mesophilic temperatures and these bacteria are generally more robust and adaptable to changing environmental conditions.

Case studies of operational mesophilic digestion systems can be seen from Vasteras, Kahlenberg, Greimel and Holsworthy project.

3.3.2.2 Thermophilic Digestion Systems

Thermophilic bacteria have an optimal temperature range of 50-60^oC. Thermophilic digesters are usually operated as close as possible to 55^oC. Thermophilic digestion offers the advantages of faster reaction rates compared to mesophilic digestion, leading to shorter retention times. Thermophilic digestion also provides better pathogen kill due to the higher temperatures, although this is less important if the waste stream is pasteurised as part of the treatment process.

Thermophilic systems are usually more expensive to operate as they require additional energy to maintain the higher operating temperatures. Another drawback of thermophilic systems is the greater sensitivity to operational and environmental conditions e.g. greater temperature control. For feedstocks rich in nitrogen where ammonium/ammonia can result in inhibition of the digestion process, thermophilic operation is less recommended.

Thermophilic systems can be of benefit where high solid content feedstock with optimal C: N ratios are available.

Case studies of operational thermophilic digestion systems can be seen from Zurich Otelfingen, Pohlsche Heide, and Lintrup project.

A comparative analysis of wet and high dry Anaerobic Digestion processes for Organic Fraction Municipal Solid Waste is shown in Table 9.

Table 9: Comparison of Mesophilic and Thermophilic Anaerobic Digestion Processes for the Treatment of Waste

Operation parameter	Mesophilic systems	Thermophilic systems
Temperature	35°C	55°C
Robustness	Higher	Lower
Loading rate	Lower	Higher
Retention time	Longer	Shorter
Gas production rate	Lower	Higher
Risk of inhibition	Lower	Higer
Pasteurisation	Yes	No
Handling of material	More difficult	Easier
Plant footprint	Larger	Smaller

3.3.3 Single-stage versus Multi-stage System

Anaerobic digestion system can be further categorized on the basis of whether they are single-stage or multi stage systems.

Single stage systems can come in many designs, including **continuously stirred tank reactor** (CSTR) and plug-flow digesters, each with different modes of operation and differences in design and operation.[13] In a single-stage system, the four different steps of the anaerobic process take place in one digester. Generally, single stage systems are simpler than two-stage systems, and cheaper to construct and operate.

In a multi-stage system, two or more reactors are used, so that hydrolysis and acetogenesis take place in the first stage and methanogenesis in the second stage, under different conditions. Another different of the multi-stage system is that it allows intermediate mixing, which homogenises the material and creates new surfaces for the microorganisms.

Advantages of Multi Stage Systems:

- Greater biological stability
- Greater ability to cope with fluctuating feedstock volume and quality
- Potentially higher throughputs due to optimal conditions

Disadvantages of Multi Stage Systems

- More complex control and operational requirements
- potentially higher capital costs

3.3.4 Batch versus Continuous System

Anaerobic digestion can be performed as batch process or a continuous process. If the flow is stopped and restarted it is a batch system and if the flow is continuous it is a continuous system. Generally, batch system is usually associated with high solids wastes of low volume, while the CSTR considers low solids wastes of high volume. [14]

In batch systems, the digesters are filled once with fresh feedstock, with or without addition of inoculate, and sealed for the complete retention time, after which it is opened and effluent removed.

In continuous systems, the feedstock is continuously or semi-continuously introduce in the digester, while the same time the digestate is removed from the digester.

3.3.4.1 Digestate Processing and Application

Digestate is the solid remnants of the original input material to the digesters that the microbes cannot use. It also consists of the mineralised remains of the dead bacteria from within the digesters. Dewatering separates the material into two fractions: a solid fraction (typically 25-35% dry matter) which can be used as a soil improver and a liquid fraction (typically ≤ 6% DM) that can be used as a liquid fertiliser.

The main advantages of dewatering digestate are to improve its manageability e.g. when using land injectors by avoiding blockages and to reduce transportation and storage costs. For example, dewatering produces an easily stackable fibrous fraction (potentially rich in phosphorus) and a liquid fraction (potentially rich in nitrogen and potassium). In many cases these digestates can be applied directly to farmland via traditional irrigation equipment. Another advantage of separating the liquor for use as a fertiliser is it will run easily from foliage leaving little residue.

Dewatering can be achieved using biological, mechanical processes, or thermal processesor a combination of these. Biological dewatering involves biodrying, which utilises the heat produced by the exothermic reactions in aerobic decomposition. Dewatering can also be performed through evaporation of the moisture. Mechanical dewatering devices for solid-liquid fraction separation can take the form of screw presses, belt presses and centrifuges.

Flocculants/polymers are often added to aid the efficiency of dewatering. The capital and running costs, throughput, energy requirements, and separation efficiency in terms of solid or mineral removal are important considerations when deciding which method of separation to employ.

As an alternative to direct land application, further stabilisation treatments e.g. composting can be carried out to improve the stability of the digestate. The resulting compost may then be applied to land. Other applications of digestates are currently being explored e.g. drying and pelletizing for use as a solid fuel.

3.3.4.2 Biogas Processing and Application

Biogas produced by anaerobic digestion is primarily composed of methane and carbon dioxide with smaller amount of hydrogen sulphide and ammonia. It can either be applied raw or upgraded, minimum it has to be cooled, drained and dried after production, and most likely it has to be cleaned for the content of hydrogen sulphide as well.[15]

There are various ways of biogas utilisation:

- Production of heat and/or steam
- Electricity production/combined heat and power production (CHP)
- Industrial energy source for heat, steam and/or electricity and cooling
- Vehicle fuel
- Fuel cells

3.3.5 Important Issues related to Anaerobic Digestion Plant

Important issues that related to Anaerobic Digestion Plant that should be considered are:

- Economics feasibility of the plant
    - Analysis especially on the cost and benefits of the plant.
- Feedstock quality
    - Purity of the feedstock is essential condition for the success of the anaerobic plant. The feedstock quality will affect the size and investment cost of the pre-treatment, quality of the final compost product and overall performance of the plant
- Quality of the final compost product
    - Ensuring the quality of the compost and the availability of compost market is of crucial importance in ensuring revenues from this product.
- Efficiency of the technologies installed
    - Efficiency of the technology installed for the plant in term of production of biogas, compost and electricity need to be monitored.
- Ari emissions control
    - Odour emitted from the plants is the problem that urges the public against the plants.

4 References

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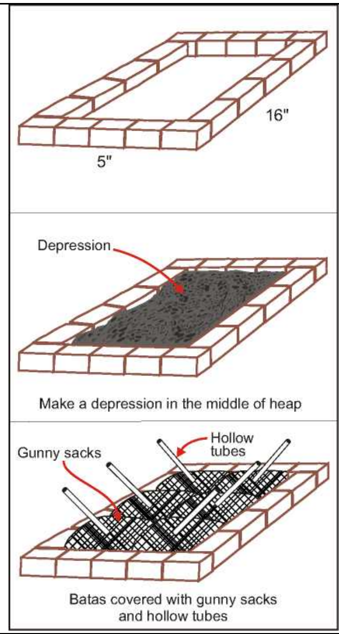
APPENDIX A: Locally Available Technologies in Penang

No.	Name	Feedstock	Method	Scale	Illustration
1	Flower Pot composting	Kitchen Waste, Soil or old Compost	Aerobic Composting layering method using flower pots and soil. Compost ready in about 4-5 weeks' time, and can be used as fertilizer for plants, trees or lawn.	Household	
2	Plastic Bag Composting	Kitchen Waste, Soil or old Compost	Aerobic Composting layering method using flower pots. Compost ready in about 4-5 weeks' time, and can be used as fertilizer for plants, trees or lawn.	Household	
3	Perforated Barrel	Kitchen Waste, Soil or old Compost	Aerobic Composting layering method using perforated drums and containers Compost ready in about 4-5 weeks' time, and can be used as fertilizer for plants, trees or lawn.	Household	

4	Rotating Barrel	Kitchen Waste, Soil or old Compost	Aerobic Composting layering method using perforated drums and containers Compost ready in about 4-5 weeks' time, and can be used as fertilizer for plants, trees or lawn.	Household	
5	Tower Tyre Composting	Kitchen Waste, Garden Waste, Soil or old Compost	Aerobic Composting layering method using stacked old tyres.	Household & Community	
6	Wire Hoop Composting	Garden Waste, Soil or old Compost	Aerobic Composting layering method using wire hoops Compost ready in about 4-5 weeks' time, and can be used as fertilizer for plants, trees or lawn	Household & Community	
7	Simple Pit Composting	Kitchen Waste, Garden Waste, Soil or old Compost	Aerobic Composting using layering and hole in the ground method. Compost ready in about 3-4 weeks' time, and can be used as fertilizer for plants, trees or lawn	Household & Community	

8	Heap composting	Garden Waste, Soil or old Compost	Aerobic Composting using layering method with upturned bins. Compost ready in about 12 months' time, and can be used as fertilizer for plants, trees or lawn	Household & Community	
9	Small scale Windrow Composting	Kitchen Waste, Garden Waste, Soil or old Compost	Compost ready in about 4-5 weeks' time, and can be used as fertilizer for plants, trees or lawn	Household & Community	
10	Bottomless Bin Composting	Kitchen Waste, Soil or old Compost	Aerobic Composting using layering method with upturned bins. Compost ready in about 4-5 weeks' time, and can be used as fertilizer for plants, trees or lawn	Household	

11	Vermiculture	Purely vegetable waste without meat.	Worms in worm bin. Vermicasts ready in about 1 months' time, and can be used as fertilizer for plants, trees or lawn	Household & Community	
12	Community Shed	Kitchen Waste, Soil or old Compost	Aerobic Composting using layering method with upturned bins. Compost ready in about 6-8 weeks' time, and can be used as fertilizer for plants, trees or lawn	Community	
13	Centralised Composting Plant	Food Waste, Market waste Fermentative Microbes	Rotating in-vessel with heat treatment. Compost ready in about 2 days' time, and can be used as fertilizer for plants, trees or lawn.	Community, Markets	
14	Centralised In - vessel Composter	Food Waste, Fermentative Microbes	Rotating in-vessel with heat treatment. Compost ready in about 5 days' time, and can be used as fertilizer for plants, trees or lawn.	Community, Markets, Restaurants, Food Courts	
15	Bio-regen Food Waste Processing machine	Food Waste, Market waste Fermentative Microbes	Grinder machine inoculated with microbial solution. Liquid soil amender ready in 28 days.	Community, Markets, Restaurants, Hotels, Schools, Factories	

18	Groundswell Static Fermentation Piles	Green Waste, Fermentative Microbes	Static windrow with microbes. Compost ready in about 6-8 months' time, and can be used as fertilizer for plants, trees or lawn.	Municipal Level	
17	Green Waste Windrow composting	Green Waste, Fermentative Microbes	Turned windrow with microbes. Compost ready in about 3 months' time, and can be used as fertilizer for plants, trees or lawn.	Municipal Level	

References:
Household Composting – a User's Manual 1st Edition, 2003
Household Composting – a User's Manual 2nd Edition, 2010

APPENDIX B: References for Foreign Anaerobic Digesters

No	Project Name	City or County	Feedstocks	Digestion Type	Status	Project Website
1.	Holsworthy Biogas Plant	UK	Food waste & Animal Waste	Wet	Operational	http://www.andigestion.co.uk/our-plants/holsworthy-devon
2	Cassington AD Facilities	Oxfordshire	Food Waste	Wet	Operational	http://www.agrivert.co.uk/products-and-services/case-studies/cassington-ad-plant
3.	Vasteras Biogas Plant	Sweden	Kitchen Waste & grease sludge	Wet	Operational	http://www.walesadcentre.org.uk/Controls/Document/Docs/Vasteras_comp__F.pdf
4.	South Shropshire Biowaste Digester at Ludlow	UK	Kitchen & green garden waste	Wet	Operational	http://www.walesadcentre.org.uk/Controls/Document/Docs/Ludlow_comp__F.pdf
5.	Rayong City Municipality	Rayong, Thailand	Organic portion of municipal solid waste	Wet	Operational	http://www.fao.org/nr/sustainability/food-loss-and-waste/database/projects-detail/en/c/210935/
6.	East Bay Municipal Utilities District	Oakland	Food, Biosolids, & fats, oils, and grease	Wet	Operational	http://www.ebmud.com/water-and-wastewater/environment/food-scraps-recycling

No	Project Name	City or County	Feedstocks	Digestion Type	Status	Project Website
7.	Inland Empire Utilities Agency -Environ	Chino	Food Waste	Wet	Operational	http://www.cce.csus.edu/conferences/CalRecycle/leatts11/docs/Presentations/31 13A AnaerobicMcNamara.pdf
8.	Kroger/Ralphs - Compton Distribution Center	Compton	Food Waste	Wet	Operational	http://www.triplepundit.com/2013/05/kroger-food-waste-power-southern-california-distribution-center/
9.	Central Marin Food to Energy	San Rafael	Food Waste	Wet	Operational	http://baywork.org/wp-content/uploads/2013/12/Central-Marin-Food-to-Waste.pdf http://www.casaweb.org/documents/casa_sop_and_exclusion_training_dow_cmsa_103014_0.pdf
10.	Sacramento Regional Sanitation	Elk Grove	Food waste, Biosolids, & fats, oils, and grease	Wet	Operational	http://www.regionalsan.com/biogas-enhancement-project
11.	North State Rendering	Oroville	Agricultural, food waste and grease	Wet	Operational	http://www.biogas-energy.com/
12.	Los Angeles Sanitation Districts AD Pilot	Carson	Food waste & Biosolids	Wet	Operational	http://www.calrecycle.ca.gov/Listservs/Archive/MessageDetail.aspx?ListPostingID=8200

No	Project Name	City or County	Feedstocks	Digestion Type	Status	Project Website
13.	Biocel plant	Netherlands	Vegetable, garden and fruit waste	Dry	Operational	http://attfile.konetic.or.kr/konetic/xml/use/31C3A0300618.pdf
14.	Kompogas Biowaste Treatment Plant-Otelfingen	Switzerland	Source segregated municipal biowaste	Dry	Operational	http://www.walesadcentre.org.uk/Controls/Document/Docs/Zurich%20-%20Otelfingen_comp__F.pdf
15.	Greimel Biogas Plant	Bavaria	Commercial and Industrial food waste	Dry	Operational	http://www.walesadcentre.org.uk/Controls/Document/Docs/Zurich%20-%20Otelfingen_comp__F.pdf
16.	ZWED-San Jose, California	San Jose, California	Green and Food waste	Dry	Operational	http://zerowasteenergy.com/what-we-do/our-projects/city-of-san-jose/
17.	Blue Line Zero Waste Energy	South San Francisco	Green and Food waste	Dry	Operational	http://zerowasteenergy.com/what-we-do/our-projects/south-san-francisco-scavengers-blueline/
18.	Monterey Regional Waste Management District – Marina, California	Marina, California	Organic Waste	Dry	Operational	http://zerowasteenergy.com/what-we-do/our-projects/monterey-regional-waste-management-district/
19.	ECOPARC 2/Montcada-Valorga	Spain	Vegetable waste, garden	Dry	Operational	http://lacitysan.org/solid_resources/strategic_programs/alternative_tec

No	Project Name	City or County	Feedstocks	Digestion Type	Status	Project Website
	Anaerobic Digestion Facility		waste and fruit waste			h/PDF/AnaerobicDigestionFacility_Spain.pdf
20.	Valorga Anaerobic Digestion Facility - Tilburg	Netherlands	Vegetable waste, garden waste and fruit waste	Dry	Operational	http://www.caddet-re.org/assets/no154.pdf
21.	Biomethan GmbH, Moosdorf (DE)	Germany	Organic municipal waste	Dry	Operational	http://www.schmack-biogas.com/en/System_Solutions/BIOFerm_Dry_AD/References/Moosdorf_Biogas_Plant.html

APPENDIX C: References for Foreign Composting Systems

	Project Name	City or County	Feedstocks	Digestion Type	Status	Project Website
1.	Ardley IVC Facility	Oxfordshire	Food Waste and Garden Waste	In-Vessel Composting	Operational	http://www.agrivert.co.uk/facilities/ardley-ivc-facility
2.	South Mimms IVC Facility	Hertfordshire	Food Waste and Green Garden Waste	Composting	Operational	http://www.agrivert.co.uk/facilities/south-mimms-ivc-facility
3.	Showell Composting Site	Oxford	Green Garden Waste	Composting	Operational	http://www.agrivert.co.uk/facilities/showell-composting-site
4.	Wallingford Composting Site	Wallingford	Green Waste	Composting	Operational	http://www.agrivert.co.uk/facilities/wallingford-composting-site
5.	Waste Composting plant in Dhaka	Dhaka, Bangladesh	Organic Waste	Composting	Operation	https://sustainabledevelopment.un.org/index.php?page=view&type=1006&menu=1348&nr=2200 http://www.wasteconcern.org/latestNews/unfccc_CERs%20issued.pdf
6.	Nangong composting plant	Beijing, China	Kitchen waste	composting	operation	http://www.ebeijing.gov.cn/BeijingInformation/BeijingNewsUpdate/t1096887.htm http://en.bmei.com/news-1.aspx?aid=63630

APPENDIX D: References for Mechanical Biological Treatment (MBT) Systems

	Project Name	City or County	Feedstocks	Digestion Type	Status	Project Website
1.	Kahlenberg (ZAK) MBT Plant	Germany	Residual waste (Municipal)	MBT	Operational	http://www.walesadcentre.org.uk/Controls/Document/Docs/Kahlenberg_Comp__F.pdf
2.	Pohlsche Heide (AML) MBT Plant	Denmark	Residual waste (Municipal)	MBT	Operational	http://www.walesadcentre.org.uk/Controls/Document/Docs/Pohlsche%20Heide_Comp__F.pdf
3.	Helibronn (U-Plus UmweltService AG) MBT Plant	Germany	Residual waste (Municipal)	MBT	Operational	http://www.walesadcentre.org.uk/Controls/Document/Docs/Heilbronn_Comp__F.pdf
4.	Phitsanulok Mechanical Biological Treatment Plant	Thailand	Residual waste (Municipal)	MBT	Operational	http://www.faculty.ait.asia/visu/pdfs/Activities/Participation/MBPC.pdf
5.	Canford Mechanical Biological Treatment Facility	UK	Residual waste (Municipal)	MBT	Operational	http://newearthsolutions.co.uk/wp-content/uploads/2011/08/case-study-Canford-email.pdf
6.	Ennigerloh Mechanical Biological Treatment Facility	Germany	Residual waste (Municipal)	MBT	Operational	http://www.ieabioenergytask36.org/Publications/2004-2006/Report%205_MBT_Ennigerloh.pdf

	Project Name	City or County	Feedstocks	Digestion Type	Status	Project Website
7.	Kadoma City Recycle Plaza Eco-park	Osaka, Japan	MSW	Others (sorting)	operational	http://www.jfe-eng.co.jp/en/products/environment/urban_environment/urb08.html
8.	Fukuyama City Clean Center	Hiroshima, Japan	MSW	Others (sorting)	operational	http://www.jfe-eng.co.jp/en/products/environment/urban_environment/urb08.html
9.	Akishima Kankyo Communication Center	Tokyo, Japan	MSW	Others (sorting)	operational	http://www.hitachizosen.co.jp/english/products/products002.html