Part 5 –
Factsheets

DIRECT ANIMAL FEED

Input materials	Pre-condition/Pre-treatment	Operation & maintenance needs	Objectives / Key features	Key technical parameters
Suitable organic waste: – Food leftovers – Vegetables/fruit peels **Unsuitable waste:** – Wood, branches – Leaves – Animal manure	Segregate and ensure purity of specific organic waste types that are considered suitable feed for the type of animals considered	Low operation & maintenance required	Use specific organic waste as animal feed for animal breeding purposes. For instance pigs are omnivorous and can eat various organic waste materials.	Process time: - Mass reduction: - Space: -
Outputs / products	**Technical complexity**	**Maturity level**	**Educational aspect**	
Farmed animals that themselves or their products are used	Very easy to do No particular skills required No infrastructure required	Widespread practice	**Topics:** Animal growth, Nutrients recycling **Practical exercises:** Feeding animals (if done onsite)	

Organic waste can be used for feeding animals either inside or outside the school compound. Care should be taken to provide only pure organic waste to animal (i.e. segregated at source and without any plastic or contaminating material in it).

Using organic waste as animal feed is a very-well established option to recover the nutrients contained in the waste. Humans have beenfeeding biowaste to animals since the beginning of animal domestication [1]. This process works very well for swine breeding as omnivorous animals. Other animals can also be fed with organic waste but a selection of specific organic waste types suitable as feed for the targeted animals must be considered.

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Applicability: Small or large-scale operation is possible, and animal feeding can happen in the school or outside the school. If no animals are bred onsite, it is possible to ask nearby farmers if they are interested in collecting food leftovers and vegetable/fruit peels from the school to feed their animals.

Technical considerations: Using organic waste as animal feed is very easy to do and does not require any particular skill, knowledge or infrastructure if done at small scale. Yet it is very important to make sure that the waste given as animal feed is pure and free of any pathogen. For that, segregating the waste at source and making sure that no substances that are toxic to the animal are present in the waste is key. Also, be aware of the risk of bioaccumulation of heavy metals, PAHs, organochlorine pesticides [1].

Materials needed: Specific recipients for collecting pure organic waste are needed.

Technical operation & maintenance: Recipients should be washed regularly to avoid any contamination.

Health and safety: Make sure to properly wash hands after handling organic waste. If organic waste is not properly handled and free of pathogen, there is a risk of diseases transmission.

Costs: -

Social, legal, and environmental considerations: Using organic waste to feed animal might be restricted by law to avoid diseases transmission. Revise the local legislation and regulation framework.

Strengths and weaknesses:

- (+) Largely practiced
- (+) Easy process
- (−) Pure organic waste free is needed to avoid diseases transmission

> References and further reading

1. Lohri, C.R., et al., Treatment technologies for urban solid biowaste to create value products: a review with focus on low- and middle-income settings. Reviews in Environmental Science and Bio-Technology, 2017. 16(1): p. 81-130.

COMPOSTING

<table>
<tr>
<td>Input materials

Suitable organic waste:
– Garden trimmings
– Vegetables/fruit peels
– Animal manure

Unsuitable waste:
– Big chunk of woody materials
– Food-leftovers not preferred (risk of attracting pests and rodents)</td>
<td>Pre-condition/Pre-treatment

Waste segregation at source

Optional: shredding</td>
<td>Operation & maintenance needs

Regular low operation and maintenance required.</td>
<td>Objectives / Key features

Aerobic degradation of waste producing compost which can be used as soil-amendment.</td>
<td>Key technical parameters

Process time: 3-6 months

Mass reduction: 35-40%

Space: 180 - 300 m2/t*d</td>
</tr>
<tr>
<td>Outputs / products

Compost, soil amendment

Compost is a stable dark-brown, soil-like material with earthy smell.</td>
<td>Technical complexity

Limited infrastructure required (covered area)

Low-level skill required for construction

Medium-level skills required on composting process for appropriate operation and maintenance</td>
<td>Maturity level

Proven technology globally</td>
<td colspan="2">Educational aspect

Topics: Microbiology, Organic degradation, Nutrients recovery, Plant growth

Practical exercises: Observing degradation process, Monitoring composting heap, Investigation on crops yield with compost</td>
</tr>
</table>

Composting involves the controlled aerobic decomposition of organic matter that results in a soil like material called compost. This process occurs as a result of microbial activity under aerobic conditions (in presence of oxygen). Use of compost improves soil structure and increases the nutrients availability in the soil.

Composting is an ancient and widespread practice worldwide. Composting of organic matter is driven by a diverse population of microorganisms and invertebrates who break down organic matter and produce carbon dioxide, water and heat.

Controlling the process implies that the predominant parameters such as organic material composition (carbon–nitrogen ratio), particle size, free air space, aeration, temperature, moisture, or pH are managed, controlled and adjusted to achieve fast degradation and good compost quality [1].

A typically feature of a well-functioning composting process is a high temperature phase (50-70°C). The high temperature contributes to the hygienization of the material by partially eliminating pathogens and weed seeds. The end of the composting process is reached when the inner temperature of the pile is similar to ambient temperature and the oxygen concentration in the air cavities within the pile remains (10–15%) for several days [2].

Under ideal operating conditions, compost can be produced within 3 months. When conditions are not optimal, the process may be slower or may be hindered [3].

The main output product from composting is compost, a stable dark-brown, soil-like material, with dark color and earthy smell. The quality of the input material and key biological and physical operating parameters have a major influence on the quality of the final compost.

Applicability: Composting can be conducted at different scale and with different use of technology mechanization. Small-scale home-composting is most frequently conducted in bins or open heaps and rely on passive aeration process, while medium and large-scale rely on mechanization with regular turnings or active aeration, either with open windrow, bins, or in-vessel composting reactor [3].

Design considerations: Key components in the design of a composting facility include space for waste separation and preparation, fo the composting heaps or units, for screening the compost and storage of produced compost as well as space for a buffer zone. Depending on the climate and available space, the facility (at least the area of the composting heaps or units) may need to be covered in order to better control moisture. The facility should be fenced to avoid animals entering and should be located close to organic waste sources to minimize transport efforts and costs. Robust grinders can be used for shredding large pieces of organic waste before composting [4].

Materials needed: Composting facilities can be constructed with locally available material. The compost pad can be made out of concrete or well-compressed clay. Cover/roof can be made from local materials such as bamboo, grass matting, wood, plastic or metal sheet. Prefabricated composting vessels of different sizes are available on the market.

Operation & maintenance: A good mixture of carbon and nitrogen in the waste is required to allow composting. This is expressed by the C/N ratio. Moisture is also highly relevant. Depending on the moisture content of the feedstock used in composting and the climate, the addition of water may be necessary at the beginning or during the process to ensure sufficient moisture for microbial activity. Periodic turning of the composting pile ensures sufficient aeration. This can be done by hand using a pitch fork or shovel.

Health and safety: While composting is not an inherently dangerous activity, precautions are necessary to protect against injury [5].

Costs: Costs of building a composting facility vary depending on the method chosen and the cost of local materials and if machinery is included or not in the design.

Social, legal, and environmental considerations: Composting can create leachate at the beginning of the composting process. Leachate should be collected and used to water the composting pile when the moisture content decreases. When composting is not performed in a controlled way, may attract rodents and flies. Furthermore, if too wet, anaerobic degradation may occur (i.e. organic waste starts to rot) generating bad smells and greenhouse gases (GHG). Bad smells from uncontrolled composting process can decrease social acceptance for composting. Ensuring that the compost product conforms to local guidelines/standards is necessary prerequisites.

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Strengths and weaknesses:

- ⊕ Proven, effective treatment method
- ⊕ Can be built and maintained with locally available materials
- ⊕ Low capital and operating costs
- ⊕ No electrical energy required
- ⊕ Easy to link with education purposes
- ⊖ Requires a large, well located land area
- ⊖ Long treatment time
- ⊖ Requires skills and knowledge on composting process and dedicated person to control the process

> References and further reading

1. Zabaleta, I., et al., Selecting Organic Waste Treatment Technologies. SOWATT, Eawag, Editor. 2020.
2. Cooperband, L., The Art and Science of Composting - A resource for farmers and compost producers, C.f.I.A. Systems, Editor. 2002.
3. Lohri, C.R., et al., Treatment technologies for urban solid biowaste to create value products: a review with focus on low- and middle-income settings. Reviews in Environmental Science and Bio-Technology, 2017. 16(1): p. 81-130.
4. Gensch, R., et al., Compendium of Sanitation Technologies in Emergencies. 2018.
5. Rynk, R., M. Van De Kamp, and G.B. Willson, On-farm Composting Handbook. 1992.

CCAC, ISWA. A handbook for schools on organic waste management. 2015

Rothenberger et al. Decentralized composting for cities in low- and middle-income countries. 2006

MOOC Youtube videos:

- *MOOC Mod.3.2 Science of composting*
- *MOOC Mod. 3.4 Operating the Composting Process*

VERMICOMPOSTING

Input materials	**Pre-condition/Pre-treatment**	**Operation & maintenance needs**	**Objectives / Key features**	**Key technical parameters**
Suitable organic waste: – Garden trimmings – Vegetables/fruit peels – Animal manure **Unsuitable waste:** – Big chunk of woody materials – Food leftovers (especially dairy product, meat and fish waste, salty and vinegary food)	Waste segregation at source Pre-composting (2 weeks) Optional: shredding	Regular low operation and maintenance required. ! Make sure to have pure organic waste!	Biological process where organic matter is digested by worms and microorganisms to produce vermi-compost.	Process time: 1.5-2.5 months Mass reduction: 40-80% Space: 300-580 m2/t*d
Outputs / products	**Technical complexity**	**Maturity level**	**Educational aspect**	
Vermicompost Worms (animal feed) Worm tea	Medium-level skills required on appropriate vermicomposting technique Limited infrastructure required (covered area)	Proven technology globally	**Topics:** Microbiology, Biology, Organic degradation, Nutrients recovery, Plant growth **Practical exercises:** Observing degradation process, Investigation on crops yield with vermicompost	

Vermicomposting is a biological process where organic matter is digested by worms and microorganisms. The products are vermicompost or wormcompost, a stable soil amendment which has higher level of nutrients than compost and the worms themselves.

Vermicomposting depends on the interaction between microorganisms and earthworms. Microorganisms in the waste prepare the waste for the earthworms through a first step of aerobic degradation [1].

Appropriate earthworm species for vermicomposting are surface worms that have high adaptability to different waste types and conditions, rapid feeding and digestion, and fast growth and reproductive rate. Among these, *Eisenia fetida* is the most frequently used species besides *Lumbricus rubellus, Eisenia andrei, Perionyx excavatus and Eudrilus eugeniae* which is popular in tropical and subtropical countries [1].

Earthworms are able to process a broad range of organic waste but they do not tolerate food waste such as meat and fish waste, grease and oils, salty and vinegary foods. They also do not like onions and spicy peppers.

It is important to provide the waste as feed for eathworms in shallow layers placed into bins or beds and fed at least weekly. Thick layers will result in increase of the temperature in the waste layer or anaerobic conditions; both situations are unfavorable for the worms.

Vermicompost is a mineralized, nutrient-rich, microbiologically active organic amendment [2]. In some contexts, worms can also be used as high-protein animal feed or even for their medicinal properties. Another by-product is worm tea, the leachate from the worm bins. This can used as liquid fertilizer.

Applicability: Vermicomposting can be conducted at different scale, from household scale to large-scale facility. Vermicomposting usually takes place in worm bins or beds.

Design considerations: The size of the bin or bed will depend on the amount of organic waste available. Holes or mesh are needed for aeration. Spout or holes in the bottom can be added to drain the excess liquid (i.e. worm tea) into a tray for collection [2]. Darkness should be maintained; cover the bins to keep them shaded and protected. To save space, bins can be stacked up. But make sure to also allow fresh air circulation. Roofing for shading and rain protection is recommended but a walled enclosure is not required.

Materials needed: Vermicomposting bins and beds are most commonly constructed with plastic (recycled PET, PP) or wood. Plastic bins will require more drainage than wooden ones, however, wooden bins will eventually decay and need to be replaced. Styrofoam and metal materials should be avoided, as well as cedar wood containing resinous oils [2].

Bedding material like shredded papers, cartons, moss, straw should be added to hold moisture and create structure to allow air exchange [2].

It is better to identify locally available earthworms species to introduce foreign species that can be harmful to the local ecology [3].

Operation & maintenance: The worms can process waste up to their body weight per day. From that amount, around 50% is converted in vermicompost. A feeding rate of 50% of worm mass per day is adequate for a good operation. Layer of waste should not be above 10cm to avoid heating pile and anaerobic conditions.

Feeding worms should happen once a week and water added if the bedding dries up. If the bedding gets too wet, add dry material such as paper strips [3].

Moisture should be always kept between 70 and 85%. The pH should be neutral or slightly above neutral and aerobic conditions maintained in the entire bin. Therefore it is important to not feed fresh waste (acidic) but rather precomposted waste.

Health and safety: Vermicomposting is generally a safe activity. Health risks can be minimised if workers adopt basic precautions and hygienic practices and wear personal protective equipment.

Costs: Costs of building a vermicomposting facility vary depending the cost of local materials and earthworms but costs are generally low.

Social, legal, and environmental considerations: Before considering a vermicomposting system, the concept needs to be discussed with the school community beforehand. If the community has experience with separating organic waste and composting this can be a facilitating factor. Seeing and studying the lifecycle of the worms can be exciting lesson and experience for students.

Strengths and weaknesses:

- (+) Simple technology
- (+) Can be built and maintained with locally available materials
- (+) Relatively low capital costs
- (+) No electrical energy required
- (+) High value soil amendment
- (+) Easy to link with education purposes
- (−) Requires a large, well located land area
- (−) Pre-composting phase recommended
- (−) Worms are sensitive to environmental conditions (too hot, too cold, too wet, too much sunlight; if too many) and these must be well controlled

> References and further reading

1. Lohri, C.R., et al., Treatment technologies for urban solid biowaste to create value products: a review with focus on low- and middle-income settings. Reviews in Environmental Science and Bio-Technology, 2017. 16(1): p. 81-130.
2. Khadka, R. and S. Chaudhary, Vermicomposting A promising technology to turn kitchen waste to organic compost. 2017.
3. Lenkiewicz, Z. and M. Webster, Making Waste Work: A toolkit - How to turn organic waste into compost using worms, wasteaid, Editor. 2017.

ISWA: A handbook for schools on organic waste management, 2015

MOOC Youtube videos:

— *MOOC Mod. 3.10 Vermicomposting of biowaste*

BIOGAS PRODUCTION

Input materials	Pre-condition/Pre-treatment	Operation & maintenance needs	Description	Key technical parameters
Suitable organic waste: – Fish or meat waste – Vegetables/fruit peels – Animal manure **Unsuitable waste:** – Garden trimmings – Big chunks of woody materials – Feedstock with high salt content	Waste segregation at source Optional: shredding	Regular operation and maintenance required.	Anaerobic degradation of waste producing biogas, which can be used as fuel, and digestate.	Process time: 10-40 days Mass reduction: None (or 20% total solids (SOWATT) Space: 100-530 m2/t*d SOWATT
Outputs / products	**Technical complexity**	**Maturity level**	**Educational aspect**	
Biogas, combustible gas (mainly CO_2, CH_4) Digestate	Higher-level skill required for appropriate design of infrastructure Higher-level skills required on construction (gas-tight) Medium-level skills required regarding O&M	Proven technology globally Experience with application may vary depending on country	**Topics:** Anaerobic processes, Organic degradation, Microbiology, Emissions calculations, Renewable energy, Nutrients recovery **Practical exercises:** pilot example with balloon	



Anaerobic digestion (AD) is a microbiological process through which organic materials are biochemically decomposed while generating biogas and nutrient-rich digestate. Biogas is a mix of methane (CH_4), carbon dioxide (CO_2) and other trace gases, which can be converted to heat, electricity or light. The AD process occurs in absence of oxygen in airproof reactor tanks called digesters.

The AD process is common to many natural environments, such as swamps or the stomachs of ruminants [1].

A wide range of different biomasses can be used as substrates for biogas production. AD feedstock includes sewage sludge, animal manure, food industry waste (incl. slaughterhouse waste), energy crops and harvesting residues (incl. algae), and the organic fraction of municipal solid waste [2]. Usually, feedstock of with high moisture content (> 60% water content) can be processed without pre-treatment.

The main products of AD are biogas and digestate. The biogas is a combustible gas mainly composed of methane (CH_4) and oxygen dioxide (CO_2). Apart from CH_4 (55–60%) and CO_2 (35–40%), biogas also contains several other gaseous "impurities", such as hydrogen sulphide, nitrogen, oxygen and hydrogen. The energy value of biogas derives from the contained methane and shows typical lower heating values (LHV) for biogas of 21–24 MJ/m^3 or around 6 kWh/m^3.

Directly burning biogas in stoves is the easiest way of taking advantage of biogas energy. The produced slurry (digestate) is rich in nitrogen.

The AD process is only partly able to inactivate weed seeds, bacteria, viruses, fungi and parasites and depending on if sewage sludge is used as feedstock, a treatment is necessary to be able to use it as fertilizer.

Applicability: Biogas digesters can be used at different scale and with different use of technology mechanization. They are particularly applicable in rural areas where animal manure can be added and there is a need for using digestate as fertilizer and gas for cooking. Biogas reactors are less appropriate for colder climates (< 15°C) as the rate of organic matter conversion into biogas becomes very low. Even though biogas reactors are watertight, it is not recommended to construct them in areas with high groundwater tables or where there is frequent flooding [3].

Design considerations: Biogas reactors can be built as fixed dome, floating dome or tubular digesters (also called flexidigester). In the fixed dome, the volume of the reactor is constant. As gas is generated it exerts a pressure and displaces the slurry upward into an expansion chamber. When the gas is removed, slurry flows back into the reactor. The pressure can be used to transport the biogas through pipes. In a floating dome reactor, the dome rises and falls with production and withdrawal of gas.

The hydraulic retention time (HRT) in the reactor should be at least 15 days in hot climates and 25 days in temperate climates. This means the size of the reactor should be able to contain 15-20 days of waste volume (incl. water if required). For highly pathogenic inputs, a HRT of 60 days should be considered. Sizes can vary from 1,000 L for a single family up to 100,000 L for institutional or public toilet applications. Because digestate production is continuous, there must be provisions made for its storage, treatment, use and/or transport away from the site [3].

Materials needed: A biogas digester can be made out of bricks, cement, steel, sand, wire for structural strength (e.g. chicken wire), waterproof cement additive (for sealing), water pipes and fittings, a valve and a prefabricated gas outlet pipe. Prefabricated solutions include geo-bags, reinforced fiber plastic modules, and router molded units and are available from specialist suppliers [3].

Operation & maintenance: To start the reactor, it should be inoculated with anaerobic bacteria (e.g. by adding cow dung). Once running, waste needs to be added regularly (ideally daily) else the bacteria will starve. Digestate needs to be removed from the overflow frequently and will depend on the volume of the tank relative to the input of solids, the amount of indigestible solids, and the ambient temperature, as well as usage and system characteristics. Gas production should be monitored and the gas used regularly. Water traps should be checked regularly and valves and gas piping should be cleaned so that corrosion and leaks are prevented. Depending on the design and the inputs, the indigestible materials accumulating at the bottom of the reactor should be emptied and the reactor cleaned and checked every 5 to 10 years.

Health and safety: The digestate is partially sanitised but still carries a risk of infection, therefore during digestate removal, workers should be equipped with proper personal protective equipment (PPE). Depending on its enduse, emptied liquid and digestate require further treatment prior to use in agriculture. Cleaning of the reactor can be a health-hazard and appropriate safety precautions (wearing proper PPE, ensuring good ventilation) should be taken. There are also dangers associated with the flammable gases but risks are the same as natural gas. There is no additional risk due to the origin of the gas [3].

Costs: This is a low to medium cost option, both in terms of capital and operational costs. However, additional costs related to the daily operations needed by the digester need to be taken into consideration. Community installations tend to be more economically viable, as long as they are socially accepted. Costs for capacity development and training for operators and users must be budgeted for until the knowledge is well-established.

Social, legal, and environmental considerations: Social acceptance might be a challenge for communities that are not familiar with using biogas or digestate. Social cohesion can be created through shared management and shared benefits (gas and fertiliser) from Biogas Reactors, however, there is also a risk that benefits are unevenly distributed among users which can lead to conflict [3].

If the digester is not gas-tight, there is a risk of methane leakages which is a greenhouse gas contributing to climate change. Also, digestate has an organic load (COD) 5 times higher than regulations for discharge into surface water. Digestate may contain pathogens and should not be used directly on crops without prior treatment nor directly discharge into the environment without appropriate treatment.

Strengths and weaknesses:

- ⊕ Generation of useable products like gas and fertilizer
- ⊕ Small land area required (if structure sis built underground)
- ⊖ Requires expert design and skilled construction
- ⊖ Incomplete pathogen removal, the digestate might require further treatment
- ⊖ Variable gas production depending on the input material and limited gas production below 15°C
- ⊖ Medium level investment cost

> References and further reading

1. Zabaleta, I., et al., Selecting Organic Waste Treatment Technologies. SOWATT, Eawag, Editor. 2020.
2. Lohri, C.R., et al., Treatment technologies for urban solid biowaste to create value products: a review with focus on low- and middle-income settings. 2017.
3. Gensch, R., et al., Compendium of Sanitation Technologies in Emergencies. 2018.

Vögeli et al. Anaerobic Digestion of Biowaste in Developing Countries. 2014

MOOC Youtube videos:

- *MOOC Mod.3.7 The Basics of Anaerobic Digestion of Biowaste*
- *MOOC Mod. 3.8 Anaerobic Digestion Technologies and Operation*
- *MOOC Mod. 3.9 Using the Products of Anaerobic Digestion*

MATERIAL RECOVERY FACILITY (MRF)

Input materials	Pre-condition/Pre-treatment	Operation & maintenance	Objectives / Key features	Key technical parameters
Suitable recyclables waste: – Paper, cardboard – Metal – Glass – Clothes – Dense plastic (HDPE, PET) **Unsuitable waste:** – Organic waste – Hazardous waste	Waste segregation at source Optional: cleaning & drying	Regular low operation and maintenance required. Can be done internally or externally (outsourced).	Facility, which receives, sepa-rates and stores recyclables to facilitate their further use/recy-cling.	Space required depends on the recyclables generation rate & storage time

Outputs / paroducts	Technical complexity	Maturity level	Educational aspect
Sorted recyclables ready for selling	Limited infrastructure required (covered area with storage space) Low-level skill required for construction & appropriate O&M	Widespread practice	**Topics:** Consumption; Finances **Practical exercises:** Storage size calculation; Revenue calculation

A Material Recovery Facility (MRF) is a facility that receives, separates and stores solid waste to facilitate the further use and recycling of the materials.

At the MRF, the waste fractions are separated into specific categories such as Paper, Cardboard, Glass, PET bottles, Light plastic, etc. and then stored in different containers/compartments. Since an large part of the waste materials are recyclables, an MRF allows to maximize the recovery of these material that can be further sold, while reducing the quantity of materials requiring further transportation and final disposal.

Applicability: MRF can be used at school and community level and serves as storage unit before selling recyclables and partially also as sorting station. It can be managed by individuals and staff at the school or outsourced to external individuals or companies.

Technical design considerations: A covered area protecting from rain and winds is required. It is recommended to construct a concrete floor for easy cleaning of the area. The space needed will depend on the volume of recyclables generated and the storage time required. Metal cages or simple jute bags can be used to store different recyclables separately. Access to water and power are needed when cleaning of recyclables (and/or shredding) is envisaged to increase the market value.

The following formula can be used to determine the MRF compartment volume:

MRF compartment volume m3=

$$\frac{Daily\ compacted\ waste\ generated\ \left(\frac{L}{day}\right) * n_{storage\ days}}{1000\ \left(\frac{L}{m3}\right)}$$

Criteria for MRF location are:

— Easy road access

— Closest as possible to main waste generators

Materials needed: Cages or containers to store the different recyclable materials. Personal protective equipment (PPE) with gloves is necessary for workers. Broom are used to clean the floor. A table can be used to further sort the waste.

Technical operation & maintenance: Recyclables should be sorted on a regular basis. Depending on the local recycling market, cleaning and drying might be necessary. Shredding could also performed to increase the recyclable market value. Keeping records of recyclable amounts sold is advisable.

Health and safety: While sorting waste at a MRF is not an inherently dangerous activity, precautions are necessary to protect against injury, especially in presence of sharps.

Costs: Costs of building an MRF vary depending on the chosen design and further processing steps (i.e. sorting only, cleaning and drying, shredding, etc.).

Social, legal and environmental considerations: Collection and sale of recyclables are often informal sector livelihoods that could be negatively influenced by the implementation of an MRF. Where possible, opportunities to integrate these people into the management of the MRF should be assessed.

Strengths and weaknesses:

- (+) Enhance resource recovery
- (+) Easy-to-do
- (+) Revenue generation
- (−) Time consuming if managed by the school
- (−) Potentially negative impact on informal sectors livelihoods

> References and further reading

Wasteaid, Making Waste Work: A toolkit – How to prepare plastics to sell to market. 2017

ECOBRICKS

Input materials	Pre-condition/Pre-treatment	Operation & maintenance	Objectives / Key features	Key technical parameters
Suitable plastic waste: – PET (container) – Plastic film: – LDPE (e.g. plastic bags) – PP (food packaging) – PS (food containers & packaging)	Waste segregation at source Clean and dry plastic film and PET bottle	No operation and maintenance required	Very simple way to fill PET bottles with plastic films and then use as construction material. Effective way to reduce waste littering and reduce concrete or cement volume in construction.	Optimal ecobrick density: > 0.37 g/ml; Normal density: 0.33 g/ml (e.g. 600ml PET bottle: 200g ; 1500 ml PET bottle, 500 g)
Outputs / products	**Technical complexity**	**Maturity level**	**Educational aspect**	
Filler for construction (e.g. benches, small walls, chairs, tables, etc.).	No infrastructure required No skills required to do ecobricks Medium-level skills required for constructing with ecobricks	Proven globally for small-scale application (e.g. schools, small community, etc.)	**Topics:** Plastic litter reduction, consumption **Practical exercises:** Produce ecobricks with students (school + home)	

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Making ecobricks is a downcycling method consisting in packing PET bottles with clean and dry non-recyclable plastics. They are a great way to mitigate the amount of plastic sent to landfill and the environment and can be used as building blocks for non-structural constructions (e.g. benches, small walls).

Soft and hard non-recyclable plastics such as bags, packaging, food containers, among others, are tightly packed in PET bottle to reach a density of 0.33 g/ml for further use in construction. The ecobricks can be stored indoors, away from heat, sun, and humidity until they are used.

Applicability: Ecobricks are aimed toward small-scale application (e.g. at communities or neighborhoods level), when appropriate solid waste management service is lacking.

Design considerations: The ecobrick should meet minimum weight requirements of 0.33 x bottle volume (i.e 600ml bottle should weigh more than 200 grams, and 1500ml bottle more than 500 grams). Experienced ecobrickers consider a density of > 0.37 g/ml as optimal [1]. Bottle selection should align with local availability. For building modules (small constructions that can be moved once, such as benches or stools), bottles should be of similar size and shape. For outdoor building projects, size and shape matter less than volume (e.g. small bottles make sturdier walls, large bottles make good benches).

Materials needed: To produce ecobricks, a stick is needed which is a smaller diameter then the bottle opening. An indoor storage space with low humidity and sun exposure is recommended. To construct small infrastructure with ecobricks, water and locally available earth/soil, clay and sand are needed. Once soil and clay are mixed together, they should achieve a non-crumbly texture referred to as "cob". Rice straw, coconut fiber or other organic source can be used as binder. Cement can also be used as construction material and binder.

Technical operation & maintenance: It is important to clean and dry the plastic used as bottle filling, as dirty plastic and moisture inside an ecobrick lead to microbiological growth and methane formation. Pushing of the plastic filling into the bottle must be done carefully in order to not break bottle walls. For efficient packing, the bottle is filled halfway and the filling pressed using the stick. The same is repeated for the second half of the bottle. A 1-2 cm between the plastic filling and the cap should be left to avoid overpressure. The bottle then needs to be closed with the cap.

It is recommended to protect ecobricks with a cloth or tarp during storage as PET attracts dust and chemicals. Horizontal stacking slightly above floor level with ends pointed outwards enables efficient brick categorization and prevents rats from chewing the ecobricks.

It is recommended to not leave the ecobrick caps exposed on walls facing the outdoors as the HDPE plastic of the cap degrades quickly with even small amounts of sun exposure. When filling around the ecobricks with cob, it can be helpful to lay small stones between the bottles to take up space and minimize the use of cob.

Health and Safety: The ecobricks should always meet the minimum density/weight requirements; if not, they are a potential fire hazard.

Costs: As ecobricks can be made out of plastic waste and construction with locally available material, the cost associated with it is very low.

Social, legal, and environmental considerations: Ecobricks should be closed correctly as their plastic filling can leach chemicals when exposed to sunlight, which can cause immediate damage to the soil and ultimately leach into water bodies [2].

Strengths and weaknesses:

- ⊕ Inexpensive
- ⊕ Effective way of mitigating release of macro and microplastics into the environment
- ⊕ Low technical know-how needed
- ⊕ Use locally available resources
- ⊕ Easy to get students and households involved in making ecobricks
- ⊕ Easy to link with education purposes
- ⊖ Downcycling option (no further recycling possible)

> References and further reading

1. Alliance, G.E., 10 step guide to making eco-bricks. 2020.
2. Duarte, L. and C. Barajas, Is the use of filled PET bottles as a building blocks a safe practice. Journal of Solid Waste Technology and Management, 2016. 42: p. 930-934.

Wasteaid, Making Waste Work: A toolkit – How to turn mixed plastic waste and bottles into ecobricks. 2017

www.ecobrickexchange.org

www.ecobricks.org

PAVING TILES

Input materials	Pre-condition/Pre-treatment	Operation & maintenance	Objectives / Key features	Key technical parameters
– Sand **Suitable plastic waste:** – LDPE (e.g. plastic bags, etc.)	Waste segregation at source Clean and dry LDPE	No regular operation and maintenance required.	Simple process of mixing LDPE plastic with sand to produce paying tiles.	Softening temperature: 70°C [1] Min. Melting temperature: 121°C [1]
Outputs / products	**Technical complexity**	**Maturity level**	**Educational aspect**	
Paving tiles	Low-level skill required for appropriate construction of infrastructure Low-level skill required for making tiles	Few documented cases worldwide	**Topics:** Plastic litter reduction, Consumption **Practical exercises:** Calculation of plastic quantities per produced items	


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The process of making paving tiles is a downcycling method consisting of grinding plastic, melting it, mixing it with sand and eventually pouring it in tile molds before cooling.

LDPE plastic films, such as plastic bags and water bags are melted in a container (e.g barrel) using a fuel source (e.g. woodor gas) . Once the plastic has melted, sand is added and the mixture is then transferred to a greased mold. Once the mixture has hardened, the tile is removed from the mold and the tiles are left to cool down further.

Applicability: Paving tiles are aimed towards small-scale application (e.g. at communities or neighborhoods level).

Design considerations: The melting container can be made out of an oil drum barrel cut in half, (~80cm wide and 50cm high) and three legs made of rebar attached to it [2]. If possible use a shield to keep the fire concentrated under the barrel.

The mold can be constructed the same way as mold for concrete floor tiles. The walls of the mold should not be more than 4cm deep to avoid the material to stick to the sides [2].

Materials needed: To produce paving tiles a melting barrel, stirring equipment (e.g. spade with metal shaft), a metal table, tile mold and trowel are needed. In addition to that, fuel (firewood, other solid fuel or gas), as well as grease or oil (e.g. used engine oil)and clean, dry, and sieved sharp sand (e.g. construction sand) are required.

Technical operation & maintenance: It is important to select the right type of plastic to ensure an even melting temperature (120-150°C).

Plastic is slowly added to the warm container. As it melts it should be stirred continuously until no lumps remain. The melting process can take up to 20min. Care should be taken to avoid the melted plastic to get too hot and start burning.

Once plastic is melted, sand is added continuously in small amounts while still heating and stirring. Usually the sand to plastic ratio is 3:1, but may differ depending on the sand and type of plastic used. It is recommend trying out different mixture ratios before starting producing paving tiles in mass.

The mixture of plastic and sand is then removed using a shovel or spade and poured into a clean and oiled mold with a trowel. The mixture is pressed into the mold to avoid air gaps and left to set for a few minutes, while repeatedly shaking the mold to loosen the edges. Once the mixture has hardened enough that the tile does not collapse, the mold is removed. The tile is then left to further cool.

Health and safety: The process of making paving tiles should take place in a well-ventilated area. Workers should be equipped with proper personal protective equipment (PPE) with fireproof gloves (fabric and not rubber), heatproof boots, and appropriate mask.

People should not stand directly over the melting plastic while stirring and try to avoid breathing any fumes released from the melt.

Ensure that there is only LDPE and especially that no PVC or other plics are melted, as as fumes from other plastic can dangerous for health. You can consider having a temperature measuring device on the barrel to have a better control over the melting temperature.

Consider that the equipment will get hot to avoid accidental burns.

Costs: As paving tiles are made out of plastic waste and construction sand, the associated cost is very low. Installing a temperature control device would considerably make the process safer but would also increase the associated cost.

Social, legal and environmental considerations: Plastic is flammable in nature, which is why sand is used as fire retardant. After the tiles are worn out, it is not possible any longer to separate plastic from sand for recycling. The plastic tiles may crack over time when loaded with weight, which can cause a release of micro plastic.

Strengths and weaknesses:

- (+) Cheaper than conventional tiles
- (+) Tiles are water resistant
- (+) Tiles are good insulators for keeping warm and cold weather
- (+) Uses locally available resources
- (−) Downcycling option (no further recycling possible)
- (−) Risk of harmful gas release if temperature is too high and plastic is burnt

> References and further reading

1. PreciousPlastic, Commodity plastic practical info poster. 2018
2. Wasteaid, Making Waste Work: A toolkit – How to transform plastic waste into paving tiles. 2017

P:3

SHREDDING

Input materials	Pre-condition/Pre-treatment	Operation & maintenance needs	Objectives / Key features	Key technical parameters
Suitable plastic waste: – Solid plastic (HDPE, PS, PP) **Unsuitable plastic waste:** – Soft plastic	Clean and dry plastic	Regular maintenance required	Process of breaking down plastic into smaller pieces for further processing or selling	Voltage: 380V AMP: 5.8A Nominal power: 1.5kW min Output speed: +/- 70 r/min [1]

Outputs / products	Technical complexity	Maturity level	Educational aspect
Shredded plastic	Higher-level skill required for appropriate design & construction of infrastructure Lower-level skill required for O&M	Proven technologies	**Topics:** Plastic litter reduction; Consumption **Practical exercises:** -


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Plastic shredding is the process of breaking down large plastic into small flakes by motorized mechanical means. The obtained shredded plastic can either be used for further processing onsite or be sold with a higher market value.

Cleaned and sorted plastic according to plastic type, and potentially color, are shredded separately to create homogenous plastic flakes of defined size. The size of the shredded plastic depends on the requirement for further plastic processing. While large flakes of 0 to 30mm are good to use in sheetpress, 0 to 7mm flakes is need for extruders.

Applicability: Shredding plastic is a process that can be used up to industrial scale. Yet, the design and infrastructure presented here is aimed towards small-scale application (e.g. at communities or neighborhoods level).

Design considerations: Shredders can either be built from scratch or purchased from the Precious Plastic bazar. Higher-level skill is required for appropriate design & construction. Link to blueprints for shredder construction are available in the references [1].

Materials needed: The shredder is composed of a hopper, a shredding box and mesh. Electrical components needed are a motor (approx.. 2.2kW geared down to 70 rpm), LED indicator and common household power cable.

Technical operation & maintenance: While shredding, blades should be regularly checked and plastic pushed down towards the blades. When finished working with the shredder, it is recommended to label and store the shredded plastic for further use [1].

When changing the type of plastic used, the mesh should be first removed and the little shredded flakes in the machine brushed away. Optionally pressured air or vacuum cleaner can be used to blow them away.

Health and safety: Shredder blades are sharp so hands must never be used to push the plastic towards the blades. Wearing any loose clothing, jewelry or having long untied hair should be avoided as they can get caught in moving parts. Power should always be switched off for maintenance.

Costs: Material cost is around 500 USD. Shredder prices on Precious Plastic bazar is around ~3000 USD. The price can decrease if built locally.

Social, legal and environmental considerations: Microplastic might be released to the environment due to the shredding process.

Strengths and weaknesses:

- (+) Important first step of most plastic recycling processes
- (+) Effective way to granulate plastic and reduce volume for storage
- (+) Relatively cheap
- (−) Higher-level skills are needed to construct the equipment from scratch

> References and further reading

1. Precious Plastic, Build a Shredder Machine, 2022.

Precious Plastic – Shredder starter kit

EXTRUSION

Input materials	Pre-condition/Pre-treatment	Operation & maintenance needs	Objectives / Key features	Key technical parameters
Suitable plastic waste: – HDPE or – PP	Waste segregation at source Clean, dry and shredded homogenous plastics (HDPE or PP)	Regular flushing of extruder with virgin material is recommended	Process of extruding plastic waste into a continuous filament to create new product	Voltage: 380V AMP: 5.8A Nominal power: 1.5kW min Output speed: +/- 40-140 r/min [1]
Outputs / products	**Technical complexity**	**Maturity level**	**Educational aspect**	
Plastic filament, plastic beams, ornaments/ decorative objects, etc.	Higher-level skill required for appropriate design & construction of infrastructure Medium-level skill required for setting up and operations	Proven technology with large internet-based community of practice to provide support	**Topics:** Plastic litter reduction; Consumption **Practical exercises:** Calculation of plastic quantities per produced items	

Plastic extrusion is an upcycling technology that converts discarded plastic waste into a continuous plastic filament, which can be further molded into any desired end-product shape.

Clean and shredded homogenous plastics such as HDPE or PP are put through an extruder, where plastic is transported by a screw powered by a motor, to the heating section of the machine. The heat created by the machine along with the pressure created by the screw allows the plastic to melt, and it passes through a nozzle. A continuous plastic filament exits the nozzle. A mold can be placed at the end of the nozzle to receive the melted plastic filament and shape it into the mold shape.

Applicability: Plastic extrusion is a process that can be used from small to large industrial scale. The design and infrastructure presented here shows a small-scale application (e.g. at communities or neighborhoods level).

Design considerations: Extruders can either be built from scratch or purchased from the "Precious Plastic" bazar. Higher-level skill is required for appropriate self-design & construction of the extruder. Link to blueprints for extruder construction are available in the references [2].

Materials needed: The extruder is composed of a metal hopper, a screw, a barrel, a nozzle and a electric powered motor. An electronic box and heating elements are necessary, such as: PID controller for temperature control, SSR switch, thermocouple, mechanical power switch with indicator and band heater.

If the equipment is built locally, a workspace with a lathe, drill press, welding machine, belt sander and an angle grinder are needed.

As a mold to produce beams, simple metal tubes can be used.

Technical operation & maintenance: Temperature testing is required when starting using the extruder. Indicative temperature values for different plastics are: PP 180°C in barrel, 200°C in nozzle; HDPE 190°C in barrel, 210°C in nozzle). Homogenous shredded plastic flakes should be continuously fed into the hopper during extrusion. If a mold is used after the nozzle, make sure to cool down the mold in water before opening it. Regular flushing of extruder after use with virgin material is recommended.

Health and safety: It is advised to use the extruder in a well-ventilated area. Consider that the barrel is hot and direct contact may lead to accidental burns. Workers should be equipped with proper personal protective equipment (PPE) with heat proof gloves, work clothes covering arms and legs, safety glasses or face shield to protect from spontaneous ejection of hot substances from the nozzle area.

Costs: Material cost for a Precious Plastic design is around 1’300 USD. Full extruder prices on Precious Plastic bazar range from ~2’000 – 6’000 USD.

Social, legal and environmental considerations: Toxic fumes can be released during plastic melting, however this can be mitigated with the use of appropriate temperature control equipment. Batches of mixed plastic should not be extruded, as melting plastic at incorrect temperature increases the risk of harmful emissions.

Strengths and weaknesses:

- (+) Continuous output of plastic
- (+) Effective plastic recycling technology
- (+) Simple to use, once the right settings are defined
- (+) Possibility of large variety of output product
- (−) Higher-level skills are needed to construct from scratch
- (−) Medium-level skill needed to test and set the right temperature

> References and further reading

1. Precious Plastic, Build an Extrusion Machine, 2022.

2. Precious Plastic, Set up an Extrusion Work space, 2019

Precious Plastic – Extrusion starter kit

PLASTIC FILM CROCHET

Input materials **Suitable waste:** – Clean light plastic (LDPE, PP)	Pre-condition/Pre-treatment Washing and drying plastic	Operation & maintenance Cutting of plastic strips	Objectives / Key features Crochet plastic films into bags and mats	Key technical parameters Crochet needle type K hook
Outputs / products Robust plastic bags, baskets, mats	**Technical complexity** No infrastructure required Low-level skill required	**Maturity level** Widespread use	**Educational aspect** **Topics:** Reuse; Consumption **Practical exercises:** Crochet film plastic	


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Strips of film plastic such as water sachet and single-use plastic bags can be easily crocheted and converted into long-lasting reusable plastic bags, baskets and mats.

Washed and dried plastic are cut into thin strips and crocheted into various product [1]. This is a very easy and cheap process to make use of low-value plastic waste.

Applicability: Handicrafts are aimed towards small-scale application by individuals or group of individuals.

Design considerations: -

Materials needed: Large sharp scissors and crochet needle size K (6.5mm) or larger are required.

Technical operation & maintenance: To make a plastic ribbon, plastic bags or films are rolled neatly. While the lip is kept intact., thumb-width strips are cut with a scissor along the way. Once done, plastic is unfolded and lied on a table. Diagonal cuts are made on the intact lip. The long ribbon can then be crocheted into bags, purses, baskets and mats.

Health and safety: Only clean plastic should be used and hand washing ensured after handling of dirty plastic.

Costs: -

Social, legal and environmental considerations: -

Strengths and weaknesses:

- ➕ A very easy and cheap option to make use of single-use soft plastic
- ➕ Easy to link with educational purposes
- ➖ Very limited amount of plastic waste can be handled with such practice
- ➖ Low-market value of end-product

> References and further reading

1. WasteAid, Making Waste Work: A toolkit - How to crochet film plastic into bags and mats 2017, L., et al., Blue Schools - Linking WASH in schools with environmental education and practice, Catalogue of Technologies. 2018.

WASTE PIT

Input materials	Pre-condition/Pre-treatment	Operation & maintenance	Objectives / Key features	Key technical parameters
Suitable waste: – Inert waste **Unsuitable waste:** – Organic waste – Recyclables – Hazardous waste	Waste separation	Low operation & maintenance required	Safely dispose of solid waste	Space required depends on the waste generation rate & pit lifetime (usually 5 years)
Outputs / products	**Technical complexity**	**Maturity level**	**Educational aspect**	
Safe waste disposal	Limited infrastructure required (pit) Low-level skill required for construction Low-level skills required for appropriate O&M	Widespread practice	**Topics:** waste degradation rate; environmental pollution **Practical exercises:** Calculating waste pit size	

When plastic or other non-organic "inert" waste cannot be recycled, burying waste can be the easiest and safest option. However burying or dumping organic and hazardous/ contaminated waste poses a threat to the environment and should be avoided.

Practically, waste is dumped into a hole and then covered with a layer of soil. When the hole is full of waste a final soil cover is added to build a slightly elevated hill. Once full, a new hole is dug and the cycle starts over.

Applicability: Waste pits can range between houshold small pits to medium sized community or school waste pits depending on the amount of waste to be safely disposed of. At larger scale, it is often referred to as landfill.

Technical design considerations: A hole is dug and surrounded by a small berm and ditch to avoid rainwater flowing into the hole. The required size is determined by how much waste will require disposal over at least the next 5 years [1]. The bottom of the hole should be well above (>2m) the highest groundwater level. If possible, a clay layer at the bottom and covering the walls can avoid further water leaching into the surrounding [2].

The following formula can be used to determine the pit volume:

$$\textit{Pit volume } m^3 = \frac{\textit{Daily waste generated } (\frac{L}{day}) * 365 * 5 \textit{ years (or more)}}{2 * 1000 \ (Lm^3)}$$

Criterias for identifying the location of the pit are [2]:

– Close to an empty area to allow for site expansion
– Highest groundwater lever should be >2m lower than the bottom of the pit
– At least 200m away from the nearest residential area
– Far from main school activities

Materials needed: The pit can be dug manually with shovel or mechanically with excavator depending on the size required and the available resources. A shovel is used to regularly cover the pit with cover material (soil or low-quality compost).

Technical operation & maintenance: A layer of soil is regularly added onto the waste in the pit to avoid wind transport of waste and to hinder access to waste by birds and vermin. Burning waste in the waste pit is not allowed as this releases harmful gases and pollutants into the environment and endangers health.

Health and safety: While dumping waste in pit is not an inherently dangerous activity, precautions are necessary to protect against injury, especially in presence of sharps.

Costs: Waste pit is a low-cost disposal method.

Social, legal and environmental considerations: Social acceptance for waste pits is usually quite low. The major environmental burden results from waste burning in the pit (release of harmful gases and pollutants), which is not allowed, or elseby leachate contaminating groundwater if the distance between waste pit and groundwater is too small.

Strengths and weaknesses:

- (+) Easy and safe disposal method
- (+) Avoids waste burning and wind blowing waste around
- (−) Damages landscape
- (−) Possible soil contamination
- (−) Not sustainable solution (no resource recovery)

> References and further reading

1. Lenkiewicz, Z. and M. Webster, Making Waste Work: A toolkit - How to design and operate a basic waste disposal site, wasteaid, Editor. 2017.

2. Leclert, L., et al., Blue Schools - Linking WASH in schools with environmental education and practice, Catalogue of Technologies. 2018.

MOOC Youtube videos:

MOOC Mod. 1.9 Upgrading a Dump Sit