United Nations Institute for Training and Research

Project: "Promotion of BAT/BEP to reduce uPOPs releases from waste open burning in the participating African countries of SADC sub-region"

Module 8

Waste to energy concepts for organic wastes

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Table of contents

I. Introduction

This presentation addresses policy-makers, administrators and practitioners working in the field of solid waste management in low and middle income Countries.

The information presented supports the identification the causes of the open air burning of waste, its hazards and the Best Practices that can be adopted to eliminate it.

What is biowaste?

For a practical classification (used e.g. in the EU), bio-waste includes

- Garden and park waste
- Food and kitchen waste from households, restaurants, caterers, retail premises and comparable waste from food processing plants.

Bio-waste does not include forestry or agricultural residue and, thus, should not be confused with the wider term *biodegradable waste*, which also covers other biodegradable materials such as wood, paper, cardboard, sewage sludge, natural textiles.

Biowaste from municipal waste usually includes:

- ✓ food and kitchen waste from households, restaurants, caterers and local retails
- ✓ branches, grass and other plants portions from private gardens and public parks

I. Introduction

For the efficient management of bio-waste the definition of 'similar waste' is relevant to integrate waste from different sources and reach economy of scale in the operation of recovery and treatment plants

CLASSIFIED BY **SOURCE**

MUNICIPAL

- **HOUSEHOLD**
- **COMMERCE AND BUSINESS:** can be DECLARED 'SIMILAR' and managed together with household

INDUSTRY

AGRICULTURE

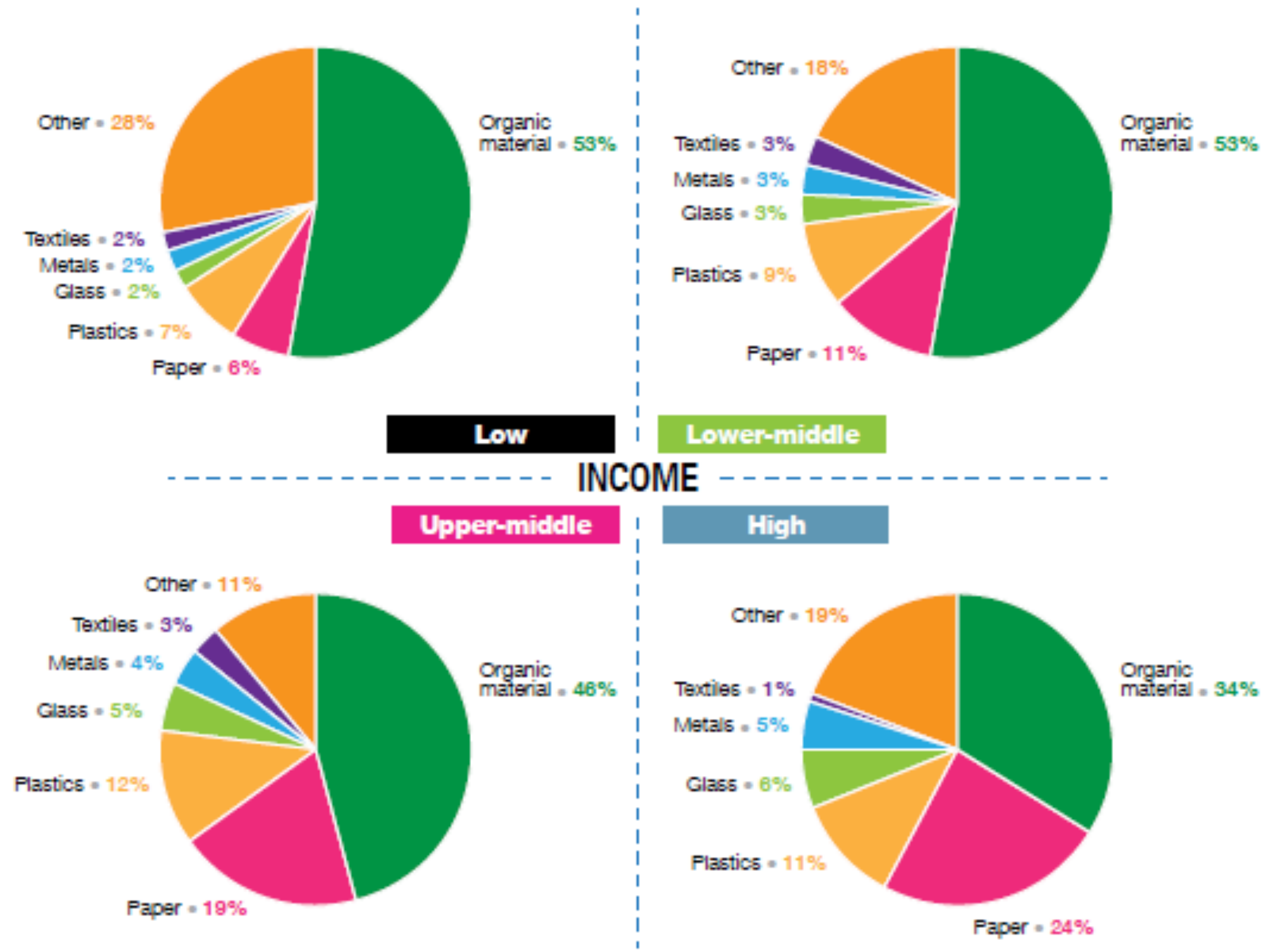
HEALTH

…

SIMILAR WASTE	Waste which in nature and composition is similar to household waste, even if from other origins, and it can thus be collected, disposed of and treated together with household waste.

The overall waste composition varies with the national income

Figure 3. 3 Variation in MSW composition grouped by country income levels



Best practice

Municipal waste characterisation (sorting and registering) in Ouagadouogu (Burkina Faso) in 2019

I. Introduction

A high percentage of the organic fractions lowers the calorific value of waste due to water contents:

- ↓ not suitable for incineration and recovery of energy by thermal treatment
- ↑ suitable - after segregated collection - for composting and anaerobic digestion.

Currently the main environmental threat from biowaste (and other biodegradable waste) is the generation of methane as a result of decomposing processes in landfills.

The most significant benefits of effective bio-waste management - besides avoided emissions of greenhouse gases – is the production of good quality compost that contributes to enhanced soil quality and bio-gas or bio-methane which contribute to energy recovery from waste.

An integrated solid waste management system
and the role of energy recovery
from the organic fractions of waste

The overall goal of the application of SWM Best Practices is the step-by-step the development of an Integrated SWM System

The goal in 20-30 years is to build at the national scale an effective integrated SWM system

- **Technical:** an integrated SWM system recovers both materials and energy from waste; it contextually deals with household and other waste streams, such as similar waste from commercial units, restaurants, agriculture, industries.
- **Economic:** optimize the performance of the recovery from waste while being financially sustainable.
- ***Social***:
  - it enhances the protection of public health and the environment (no/less open air burning of waste)
  - it provides collection service to all citizens irrespective of their ability to pay service fees
  - it guarantees safe working conditions to both the formal and informal sectors
  - it involves stakeholders in the decision-making process.

With contributions from the "Global Waste Management Outlook" – UNEP – ISWA. 2015

The waste hierarchy

It is a priority order in waste prevention and management:

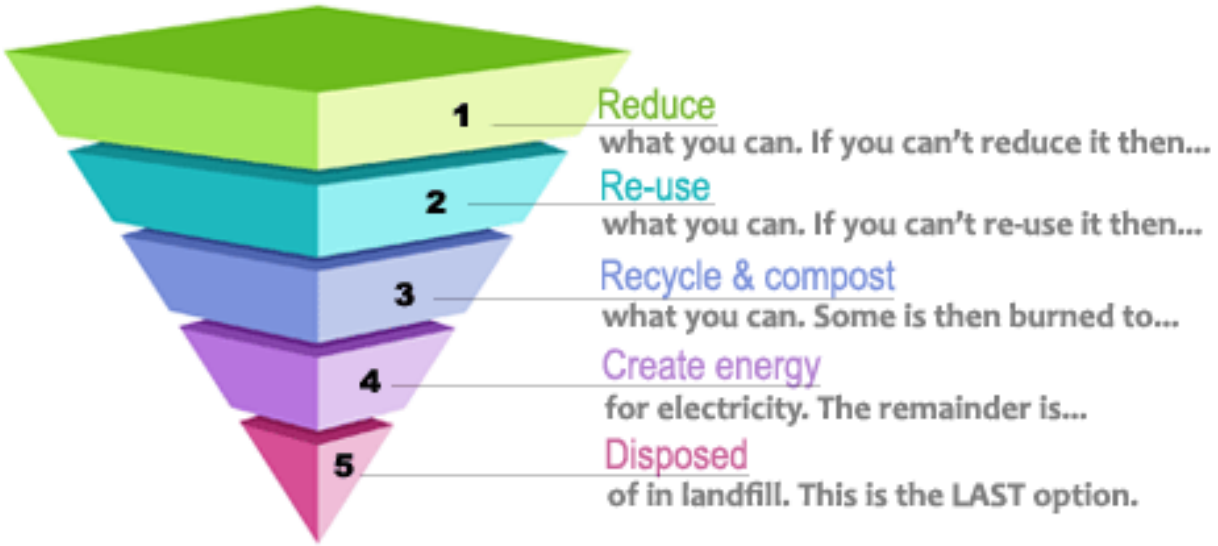
a) Prevention (in conceptual design of products and services, etc.)

b) Preparing for re-use (longer lasting products, etc.)

c) Recycling (design for dismantling, collect, recover, sell)

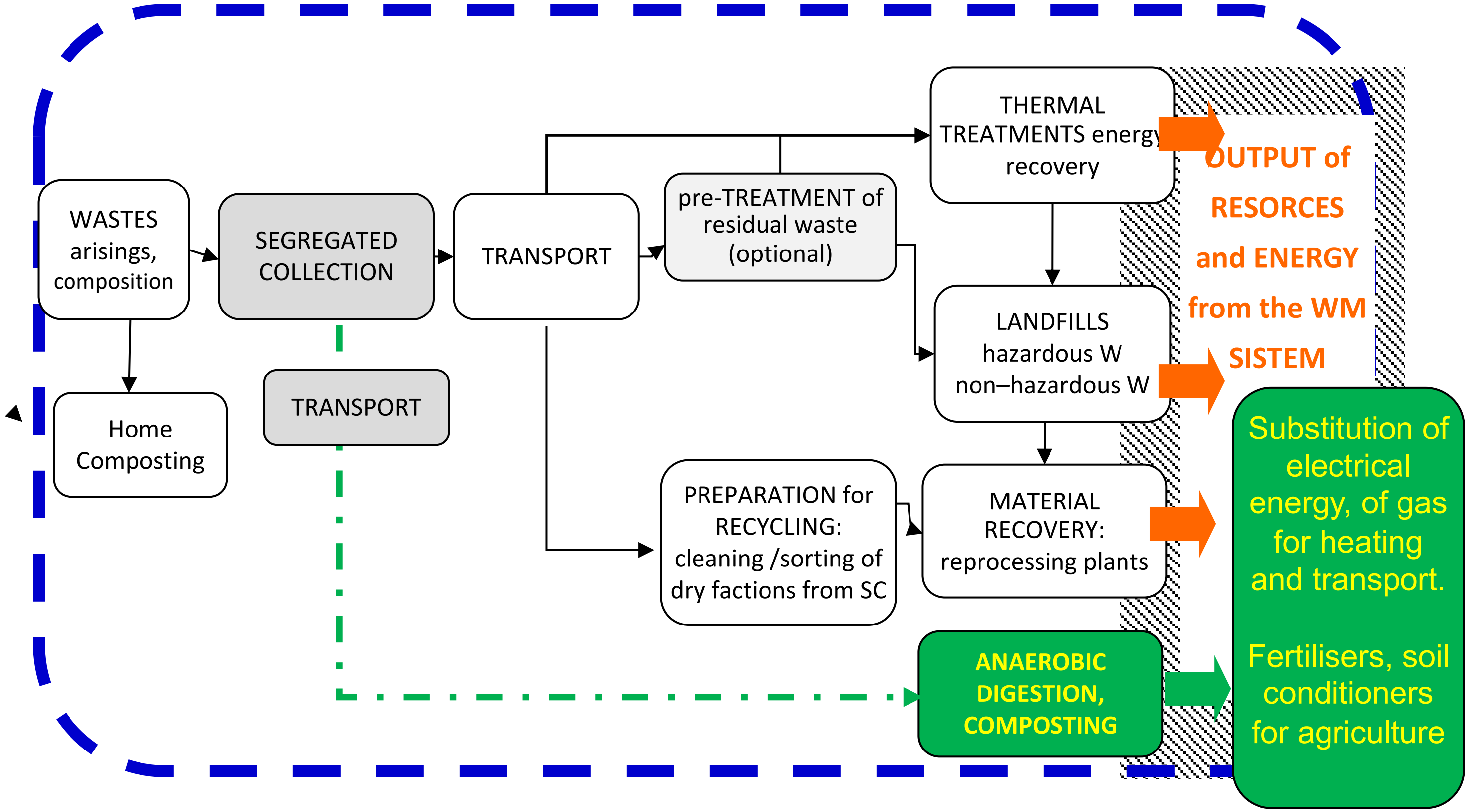
d) other recovery, e.g., energy recovery

e) disposal



The role of the recovery of compost and energy from the organic fractions

Beware: the phases and plants of an integrated SWM system are more complex



S. Tunesi - Modified from Gentil E. C. et al. "Models for waste LCA: Review of technical assumptions". Waste Management. 30, 2010, pp. 2636-2648.

II. SWM concepts

To activate the chain for the recovery of compost and energy from the organic fractions, policy-makers and service providers need to:

- Understand how an integrated SWM system works
- Understand the function, in the overall SWM system, of the chain for the recovery from the organic fraction
- Know the organizational choices (such as segregated collection and logistic) and plants that can step-by-step be adopted to build an effective biowaste recovery system

Best practice: understand what different plants and equipment are useful for

Waste management

The collection, transport, recovery (including sorting), and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker.

Waste treatment

Recovery or disposal operations, including preparation prior to recovery or disposal.

Best practice: understand what different plants and equipment are useful for

Recovery

Any operation of which the principal result is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function (such as recycling of metals or energy recovery from organic waste).

Recycling

Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery.

Beware: to adopt the thermal treatment of residual waste, very specific conditions must be in place at national and local levels

Energy from waste (also called "waste to energy")

Energy from waste is the process of recovering energy in the form of electricity or heat from the thermal breakdown of waste through any thermal conversion technology or combination of conversion technologies.

Thermal treatment

Thermal waste treatment technologies refer to mass-burn incineration, co-incineration, pyrolysis, gasification and plasma gasification.

Beware: to adopt the thermal treatment of residual waste, very specific conditions must be in place at national and local levels

Before introducing energy-recovery by thermal treatment of residual waste (so-called incineration) in a national / local situation specific economic and technical conditions must have been reached:

- the preceding levels of the waste hierarchy must operate regularly and effectively
- segregated collection is used to separate dry recyclables, hazardous wastes not suited for incineration, and the food fraction (which has a low calorific value) from the residual waste
- High capital funding must be available: if donors or PPP projects are approved, there is a risk of creating a long-term financial debt
- High operational skills must be available in the national and local working force
- The thermal treatment plant must be built, operated and maintained adopting BAT/BEP
- Adequate monitoring and enforcement is ensured by a public agency
- Transparency is adopted in informing citizens about the plant’s emissions.

Best practice: understand the use of different plants and equipment

To reduce the biowaste disposed to landfill, organise the segregated collection of biowaste to facilitate composting and anaerobic digestion.

Composting

Composting is the natural biological breakdown of organic material, such as food, green waste, wood or agricultural residues, wastewater sludge.

During aerobic composting (in the presence of oxygen) microorganisms consume the organic matter and release heat and carbon dioxide (CO_2), compost is generated that can replace manufactured **fertilisers** and/or peat, reduce the need for pesticides, improve **soil structure**, and reduce the need for irrigation.

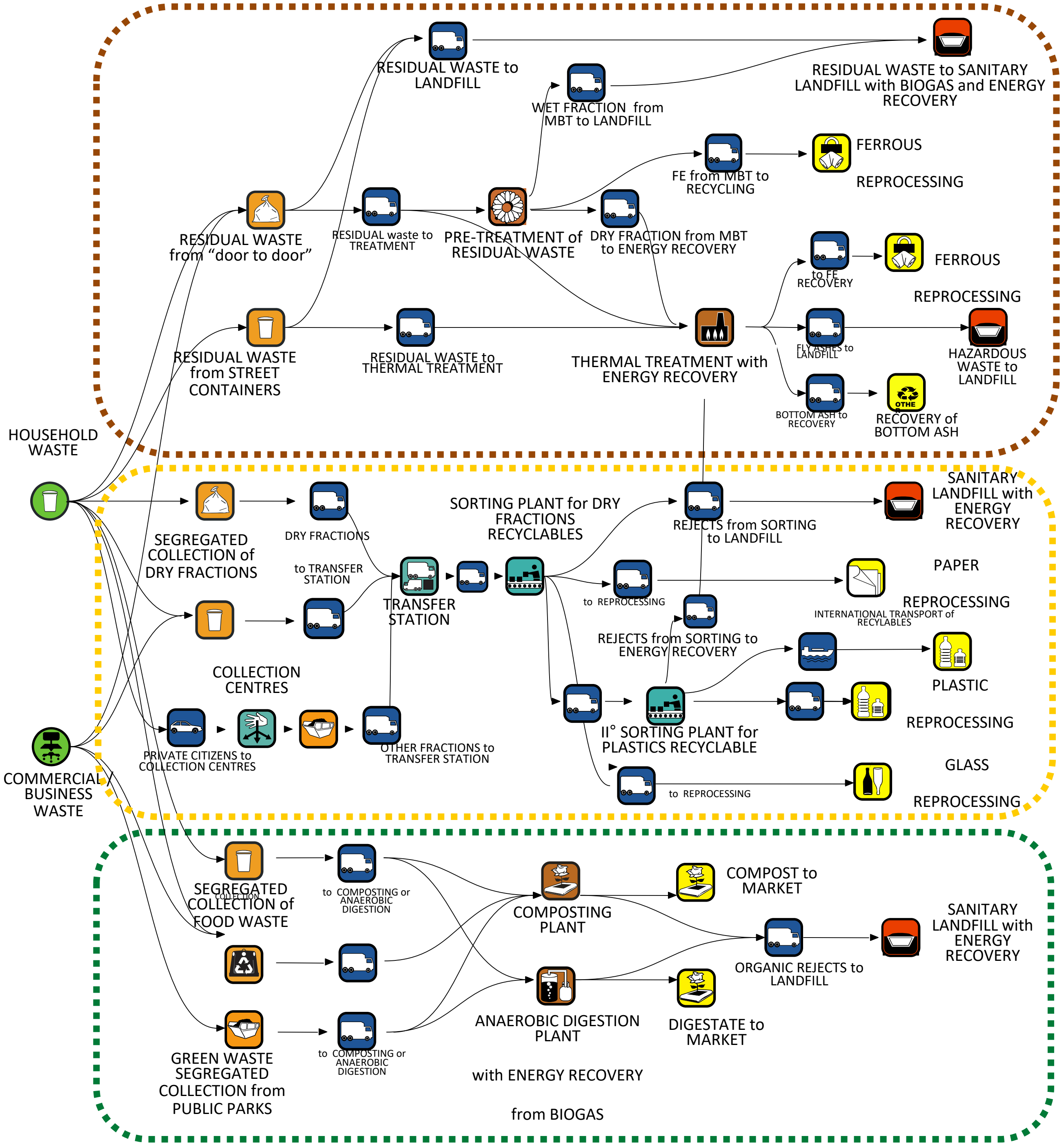
Anaerobic digestion

Anaerobic digestion engineers the capacity of anaerobic bacteria to degrade organic matter in the absence of oxygen. The main products are methane and carbon dioxide, which form **biogas**, and decomposed organic material.

An anaerobic digestion plant recovers both compost (called digestate) and **energy**: biogas can be used to generate electricity in dedicate engines; it can be distributed in the gas grid or, upgraded to biomethane, used to substitute transport fuels.

The chain for the recovery of compost and energy from biowaste

WASTE FLOWS of a schematic INTEGRATED SWM system



UNDERSTAND AND DESCRIBE THE SWM SYSTEM BY **THREE WASTE FLOWS**

from which materials and energy can be recovered:

- ❖ Residual waste
- ❖ Segregated collection of Dry recyclables
- ❖ Segregated collection of food and green waste

II. SWM concepts

In Lusaka, Zambia: the formal, municipality, COLLECTION SERVICE

Imola – Italy → Fixed street containers for waste separation

II. SWM concepts

"We need to rethink waste!" says Melanie Ludwig from The Organics Recycling Association of South Africa (ORASA).

In the Western Cape more than 40% of all waste delivered to landfills is organic waste. By recycling our organic waste into compost, we have the power to reverse climate change and replenish the health of our soils!

Households can easily practice home composting to produce compost that can be used in their own gardens, while on a larger scale and to ensure sustainability, composting at community gardens can grow wholesome food for less fortunate communities."

"We need a new approach to all waste streams in South Africa, not just organics," says Ludwig. "Source separation of waste is required to ensure that each waste stream can be effectively and efficiently recycled, composted or reused!"

Composting of organic waste

Good quality compost is produced only if the organic waste comes from segregated collection

↓ Even if several countries allow for agricultural use of compost of poor quality from composting or pre-treatment of residual waste

Composting of organic waste

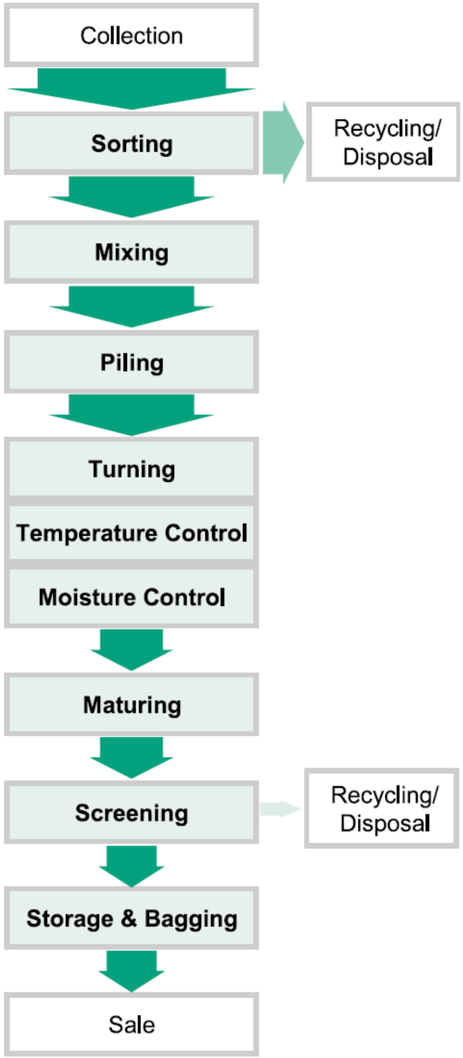
Composting is the biological decomposition of animal and vegetable materials, it is a natural process where bacteria and other organisms eat food they like in a favourable environment.

The products of aerobic composting are water vapour, carbon dioxide, and decomposed organic material, usually called compost.

It is a suitable way to manage waste in countries with a high percentage of biodegradable fractions.

Applications have failed because the task of maintaining the correct environment for bacteria requires significantly knowledge and operating skills.

Composting bacteria operate on the surfaces of compostable materials; thus composting works well with small particles of waste and poorly with large pieces of organic material: for this reason, size reduction or shredding is frequently required prior to composting.



III. Composting

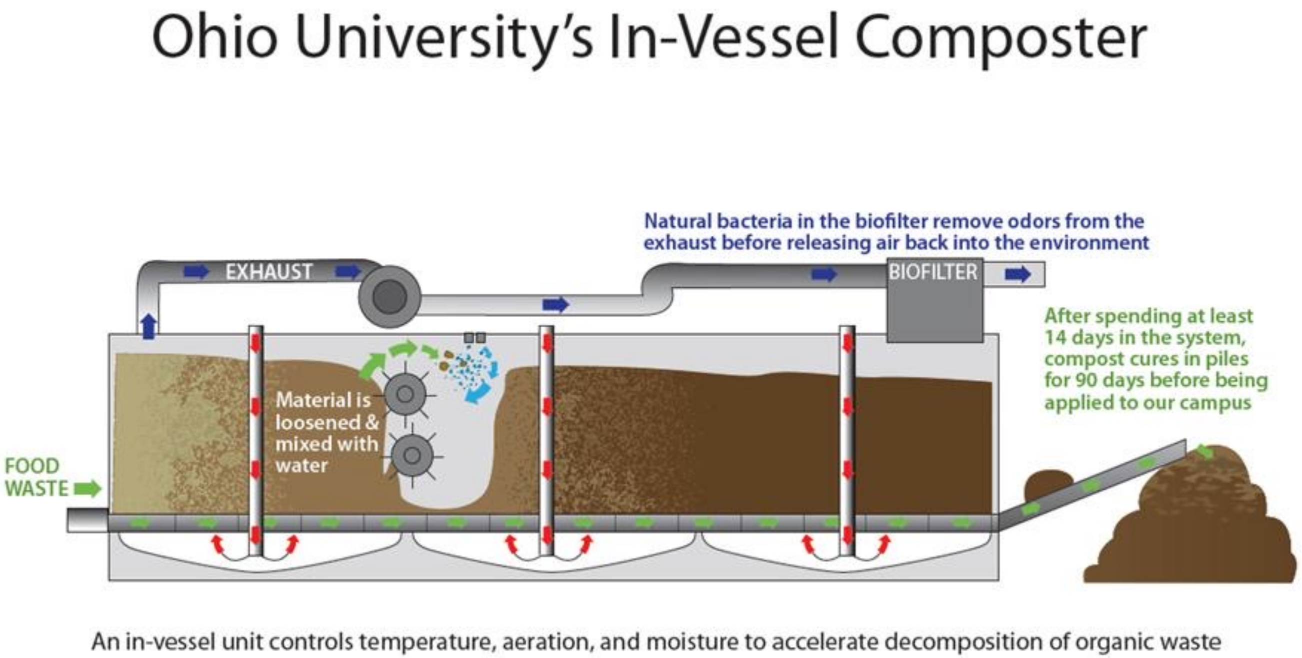
Composting can be performed at an ample range of scale: from home-composting to industrial plants producing a few MWh

III. Composting

Sample temperature taking at pilot composting facility in Kangemi - Kenya.

https://no.myclimate.org/no/klimaprosjekter/projekt/kenya-waste-management-7190/

III. Composting



III. Composting

Recycling and composting centre in Guatemala

Anaerobic digestion of organic waste gives compost of good quality and energy recovery from biogas

Anaerobic digestion

Energy recovery technologies must be appropriate to the socio-technical context and the characteristics of the waste to be treated, otherwise it may fail.

- This was the case for several thermal treatment plants in low- and middle-income countries, where waste has a high percentage of organic fractions (70-50%) resulting in high humidity and a low calorific value.
- These same waste characteristics make anaerobic digestion a suitable technology.

The source-segregated organic fraction of municipal and similar waste can be digested in combination with substrates from agriculture, agro-industries, sewage sludges and livestock waste, and strategic mixing of fractions to promote microbial growth can increase the efficiency.

IV. Anaerobic digestion

Anaerobic digestion (AD) is a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. AD allows for the recovery of both materials and energy:

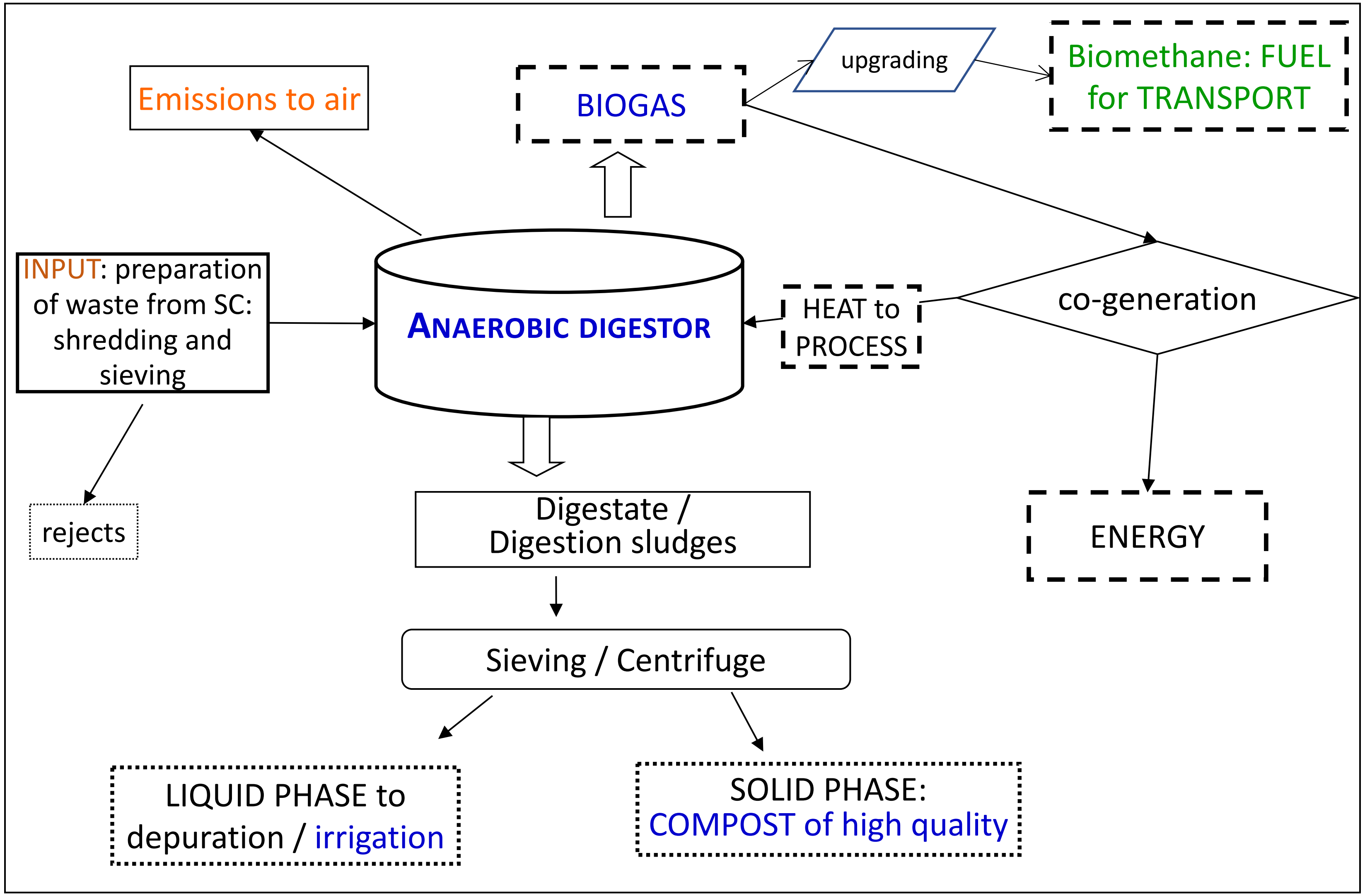
- both **heat and electricity** are generated by burning the biogas in co-generation engines: biogas is a mixture of 60% methane, 40% carbon dioxide and traces of other contaminant gases. The exact composition of biogas depends on the type of feedstock being digested;
- biogas can be upgraded to pure bio-methane to be used as fuel to transport or injected to an existing gas grid;
- after the organic fraction is digested, **compost** of good quality is produced form the maturation of the 'digestate';
- **irrigation waters** can be produced by wet and semi-dry treatment.

The energy produced from the anaerobic digestion of organic waste can be classified as coming from 100% renewable sources and it can be included in carbon reduction programs.

IV. Anaerobic digestion

Anaerobic digestion:

MAIN PROCESSES



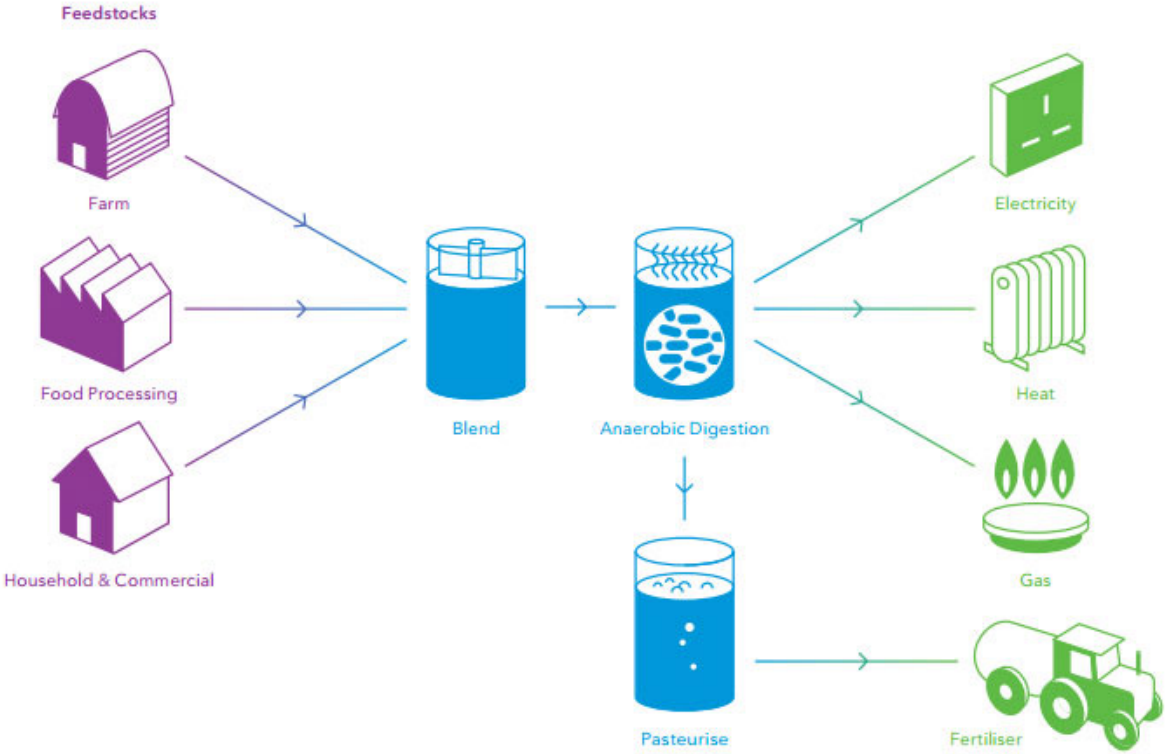
Types of reactors

	Dry matter	Pros	Cons
DRY	**25 – 40 %**	• It does not require any particular pre-treatment • High loads can be applied • Low operational and heating costs	• If batch is contaminated there is no possibility for dilution
SEMI-DRY	**15 – 20 %**	• Simple pumping and mixing equipments • Pre-treatments are simple for organic waste from SC • Low pumping costs	• High production of process waters • Contamination might be difficult to handle
WET	**10 - 15%**	• Consolidated technology • It allows dilution of concentration peaks • Widely present on the market	• Pre-treatment are complex • High pre-treatment costs • High production of process waters

IV. Anaerobic digestion

Anaerobic digestion:

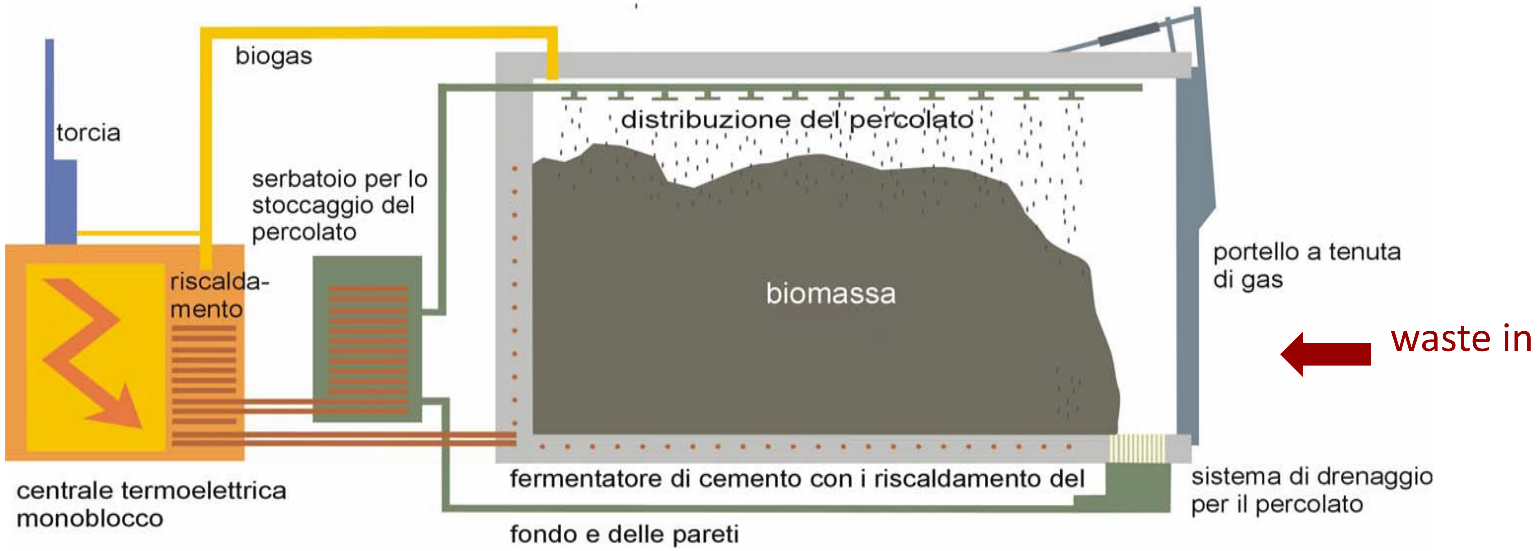
WET 10- 15% DRY MATTER



IV. Anaerobic digestion

Anaerobic digestion:
DRY 25 -40 % DRY MATTER

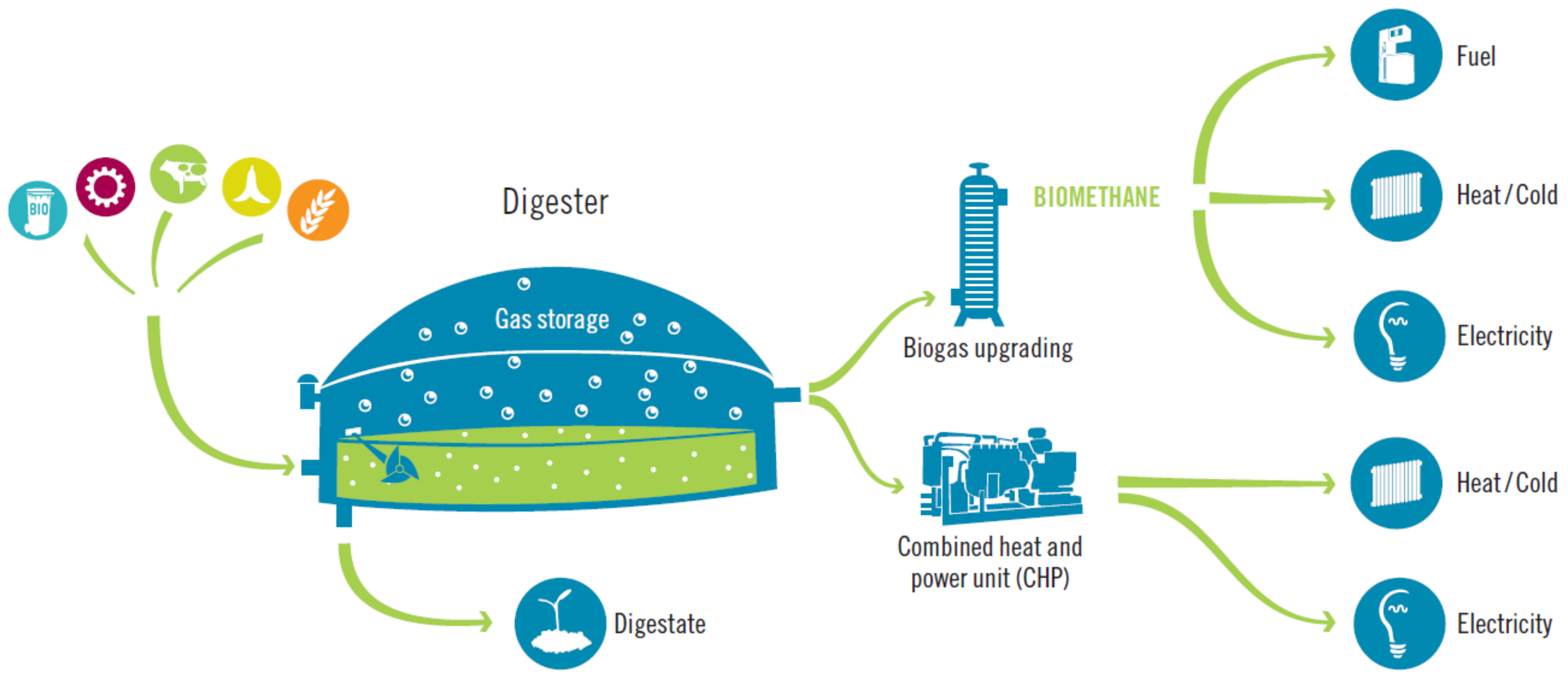
From : BEKON technology



IV. Anaerobic digestion

Biogas is up-graded to bio-methane to produce fuel (renewable source) for transport

Process description of production and use of biogas and biomethane



IV. Anaerobic digestion

All types of scale for anaerobic digestion

IV. Anaerobic digestion

The choice of the basic AD design is influenced by the technical suitability, cost-effectiveness, and the availability of local skills and materials.

In developing countries, the design selection is largely determined by the prevailing and proven design in the region, which in turn depends on the climatic, economic and substrate specific conditions

3 main types of digesters that have been implemented in developing countries:

- fixed-dome digester
- floating-drum digester
- tubular digester

which are wet digestion systems operated in continuous mode under mesophilic conditions.

These are

- inexpensive,
- built with locally available material,
- easy to handle,
- do not have many moving parts and are thus less prone to failure.

Vögeli Y., Lohri C. R., Gallardo A., Diener S., Zurbrügg C. (2014). "Anaerobic Digestion of Biowaste in Developing Countries: Practical Information and Case Studies." Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland

IV. Anaerobic digestion

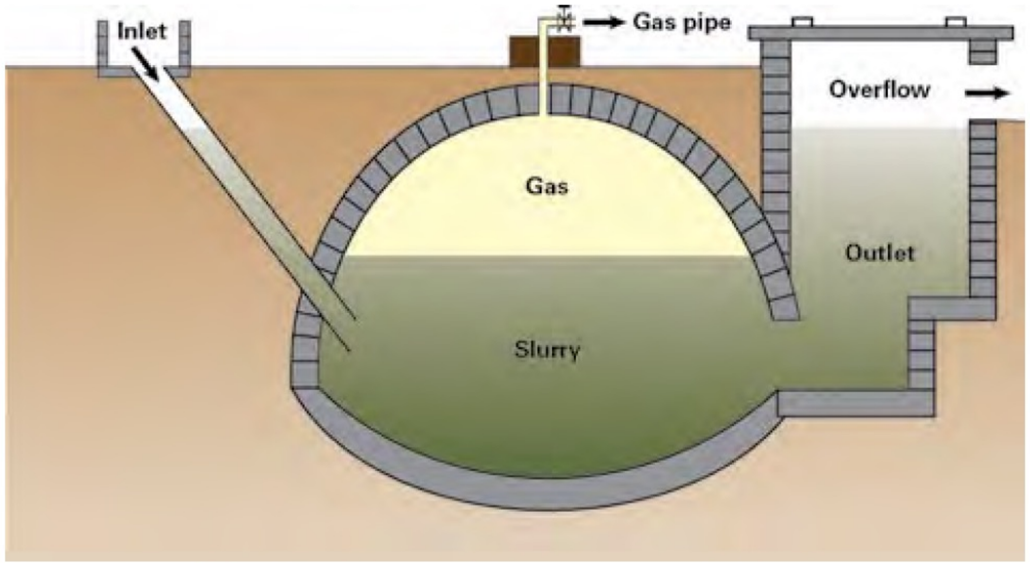


Figure 6: Scheme of fixed-dome digester

Fixed-dome digester

A fixed-dome plant is comprised of a closed dome shape digester with an immovable, rigid gas-holder, a feedstock inlet, and a displacement pit (compensation tank).

The gas produced in the digester is stored in the upper part of the reactor. With a closed outlet gas valve, increasing gas production elevates the gas pressure inside the digester thereby pushing the digestate into the compensation tank. When the gas valve is open for gas utilisation, gas pressure drops and a proportional amount of slurry flows back from the compensation tank into the digester. Given this design, gas pressure varies continuously depending on gas production and use.

Typically such a plant is constructed underground, protecting the digester from low temperatures at night and during cold seasons. Surrounding soil, up to the top of the gas-filled space, counteracts the internal pressure in the digester.

Fixed-dome digester

Picture 9: Fixed-dome digester under construction in Lesotho (photo: Sandec).

IV. Anaerobic digestion

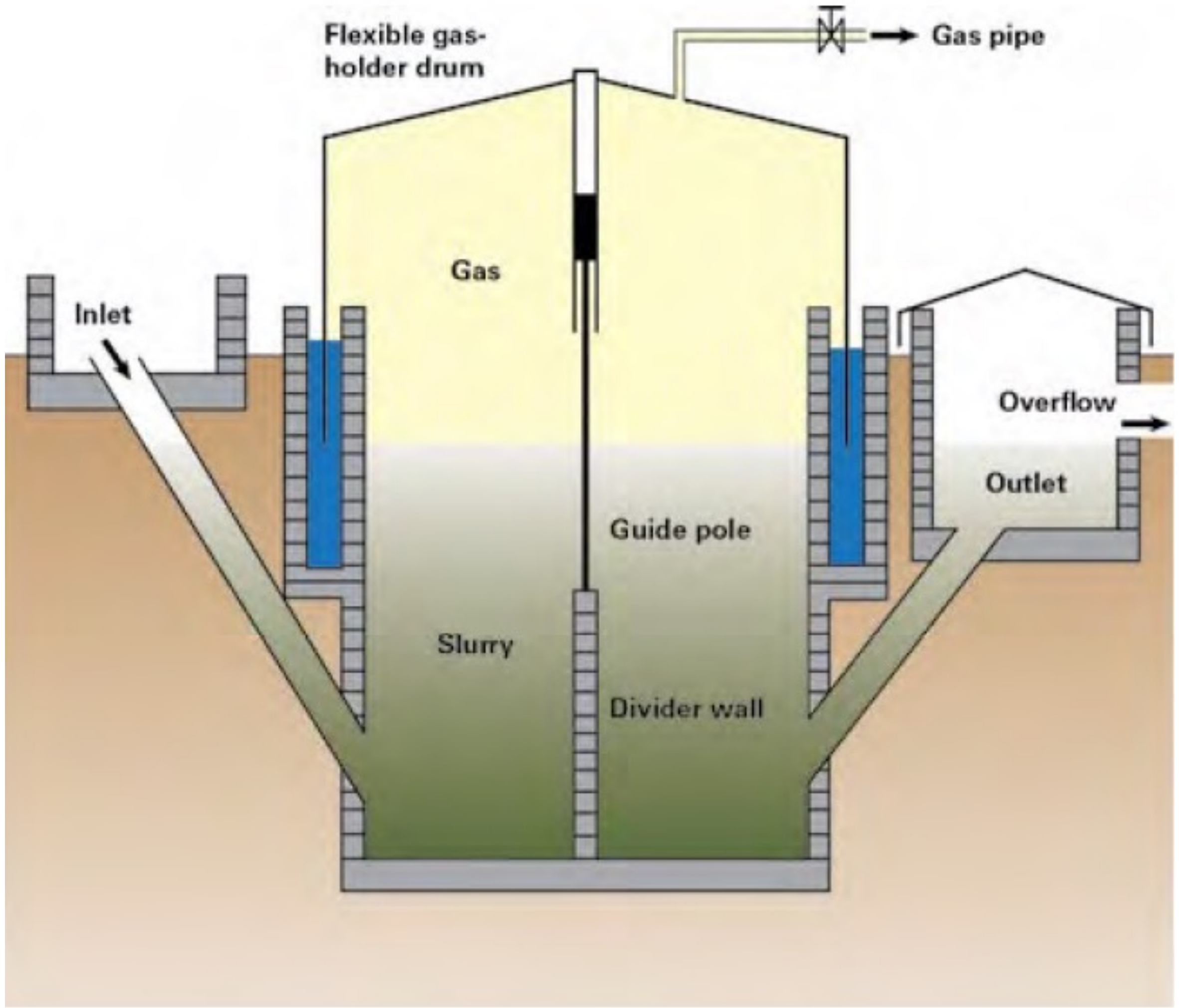


Figure 7: Scheme of floating-drum digester (Estoppey, 2010).

Floating drum digester

A floating-drum biogas plant consists of a cylindrical digester and a movable, floating gasholder (drum).

The digester is generally constructed underground whereas the floating gasholder is above ground. Smaller household-scale systems may also be fully above ground.

The digester section of the reactor is usually constructed with bricks, concrete or quarry-stone masonry and then plastered. The gas-holder is typically made of metal and is coated with oil paints, synthetic paints or bitumen paints to protect it against corrosion. Regular de-rusting is however essential to ensure sustained use, and the cover coating should be applied annually. A well-maintained metal gas-holder can be expected to last between 3 – 5 years in humid areas, or 8 –12 years in a dry climate. A suitable alternative to standard grades of steel are fibreglass reinforced plastic or galvanized sheet metal.

IV. Anaerobic digestion

Picture 10: Floating-drum digester for market waste in India (photo: Sandec).

Picture 11: Above ground floating-drum digester for households in India, made of fibreglass reinforced plastic (photo: Sandec).

Floating drum digester

Advantages	Disadvantages
• Simple and easy operation • The volume of stored gas is directly visible • Constant gas pressure • Relatively easy construction • Construction errors do not lead to major problems in operation and gas yield	• High material costs for steel drum • Susceptibility of steel parts to corrosion (because of this, floating-drum plants have a shorter life span than fixed-dome plants) • Regular maintenance costs for the painting of the drum (if made of steel) • If fibrous substrates are used, the gasholder shows a tendency to get "stuck" in the scum layer (if gasholder floats on slurry)

able 8: Advantages and disadvantages of floating-drum plants (Kossmann et al., undated).

IV. Anaerobic digestion

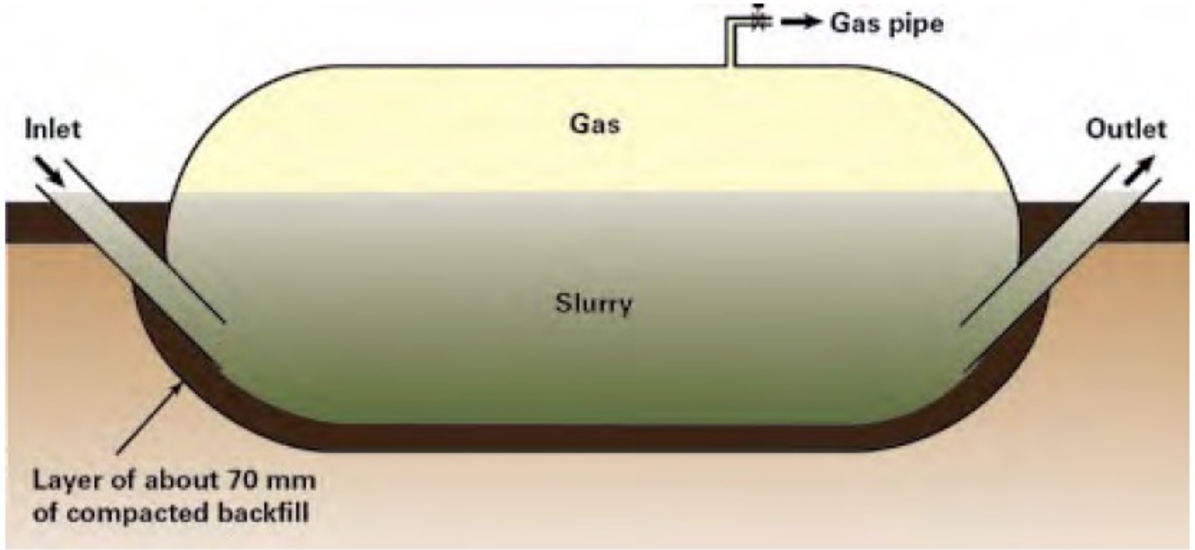


Figure 8: Scheme of balloon digester.

Tubular digester

A tubular biogas plant consists of a longitudinal shaped heat-sealed, weather resistant plastic or rubber bag (balloon) that serves as digester and gas holder in one. The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the skin of the balloon. As a result of the longitudinal shape, no short-circuiting occurs, but since tubular digesters typically have no stirring device, active mixing is limited and digestate flows through the reactor in a plug-flow manner. Gas pressure can be increased by placing weights on the balloon while taking care not to damage it.

Tubular digester

Picture 12: Tubular digester in Yanaoca, Cuzco (photo: Herrero, 2007).

Picture 13: Tubular digester in Costa Rica (photo: Sandec).

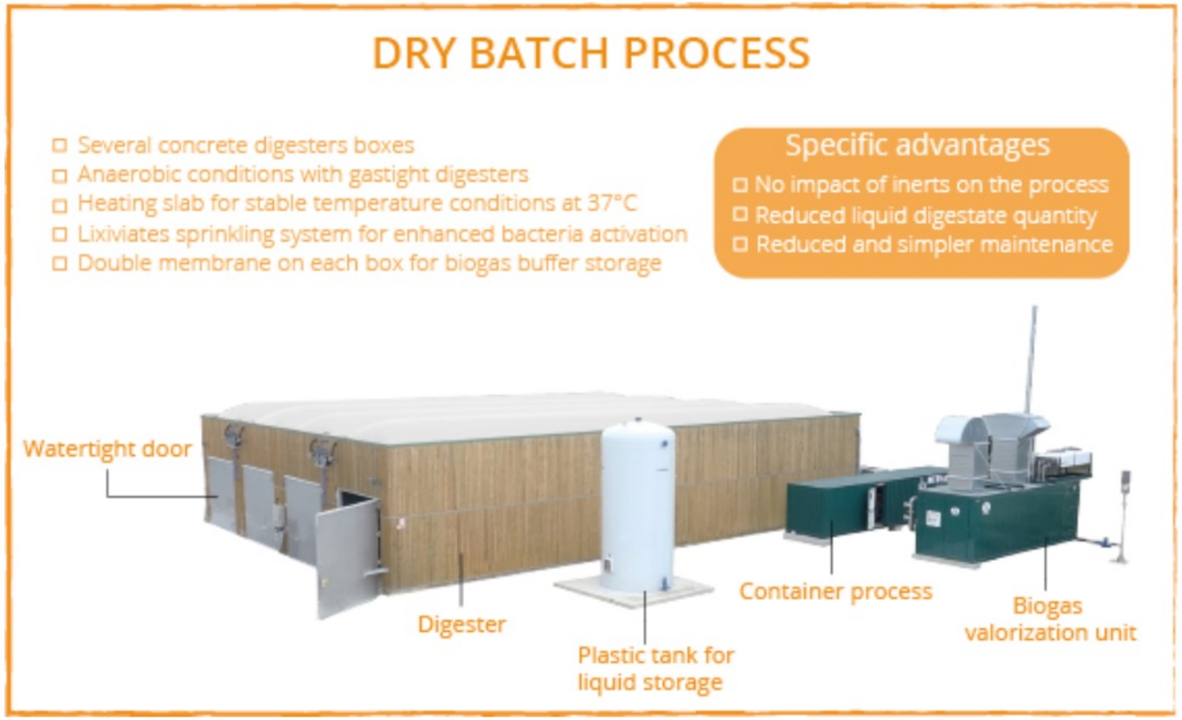
Advantages

- Low construction cost
- Ease of transportation
- Easy to construct
- High digester temperatures in warm climates
- Uncomplicated emptying and maintenance
- Shallow installation depth suitable for use in areas with a high groundwater table or hard bedrock

Disadvantages

- Relative short lifespan
- Susceptibility to mechanical damage
- Material usually not available locally
- Low gas pressure requires extra weights
- Scum cannot be removed from digester
- Local craftsmen are rarely in a position to repair a damaged balloon

IV. Anaerobic digestion



A further digester type, the garage-type digester, which is operated as a dry digestion system in batch-mode, is considered as another potential biogas technology suitable for developing countries.

Although this technology is being tested in Ghana by converting a used shipping container, it is not yet ready for the commercial market as no viable low –cost design exists that has been successfully tested at full-scale.

The treatment of selected biowaste should not be confused with the recovery of energy from residual waste performed after pre-treatment

Mechanical Biological pre-Treatment (pre-MBT) of residual waste

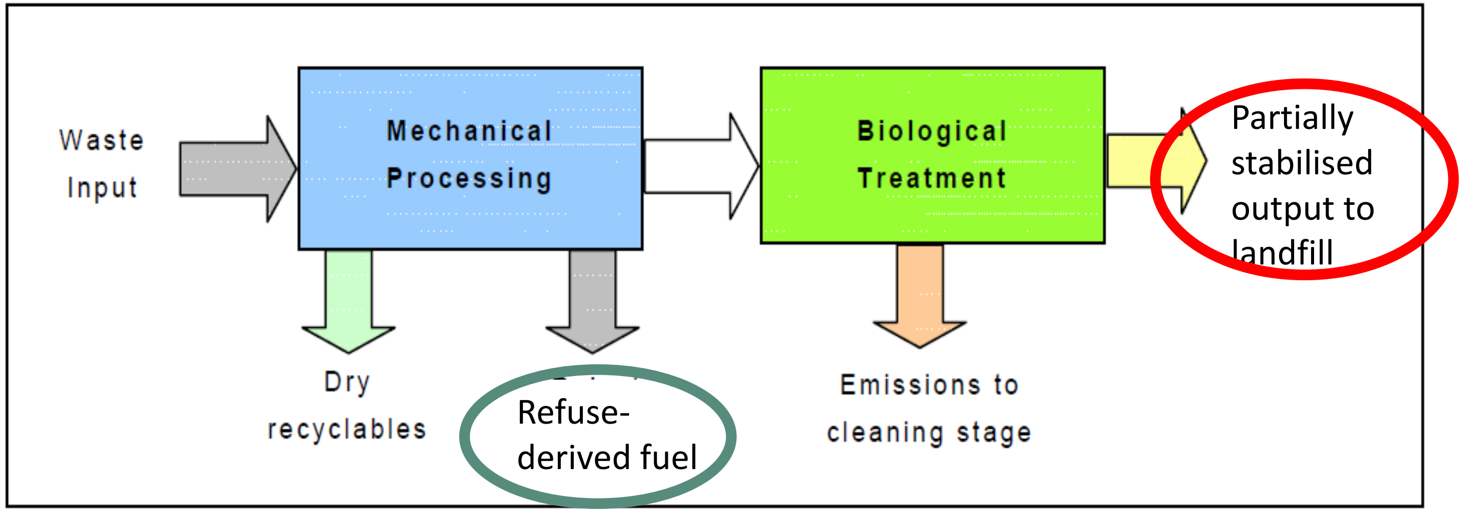
Pre-MBT is used for the pre-treatment of residual MSW to:

1. **High income countries:** homogenise and increase the calorific value of the outcoming waste (refuse-derived fuel; RDF) for thermal treatment or co-incineration → it still requires a high volume for landfilling

2. **Low income countries** prepare waste for landfilling by biostabilising the organic fractions.

It can allow the recovery of ferrous (and non-ferrous) fractions.

Figure A2 MBT: Mechanical Biological Treatment



V. Pre-MBT

Pre-treatment of residual waste (MBT or MT) is not a clearly defined technology; it assembles several operations which can be arranged in different order →

SHREDDING

SIEVING

BIOSTABILISATION

Figure A3 BMT: Biological Mechanical Treatment

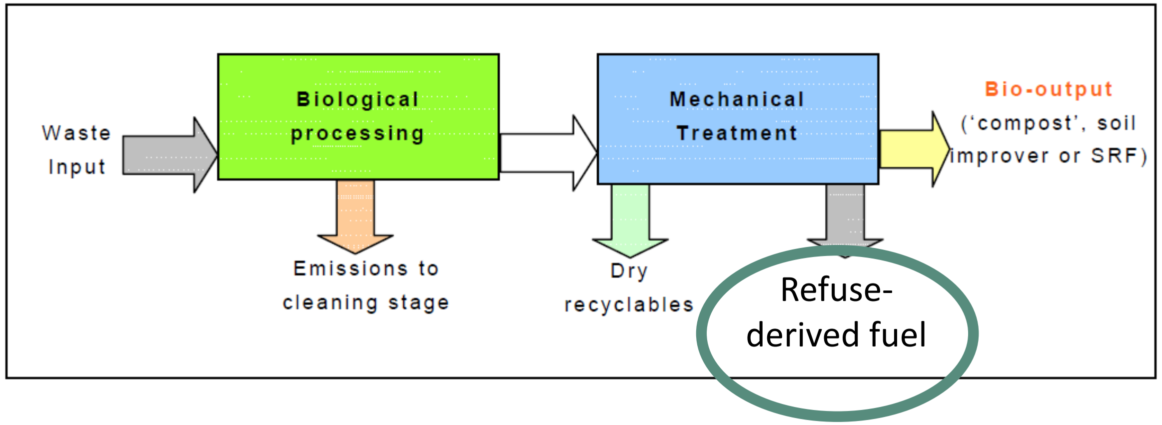
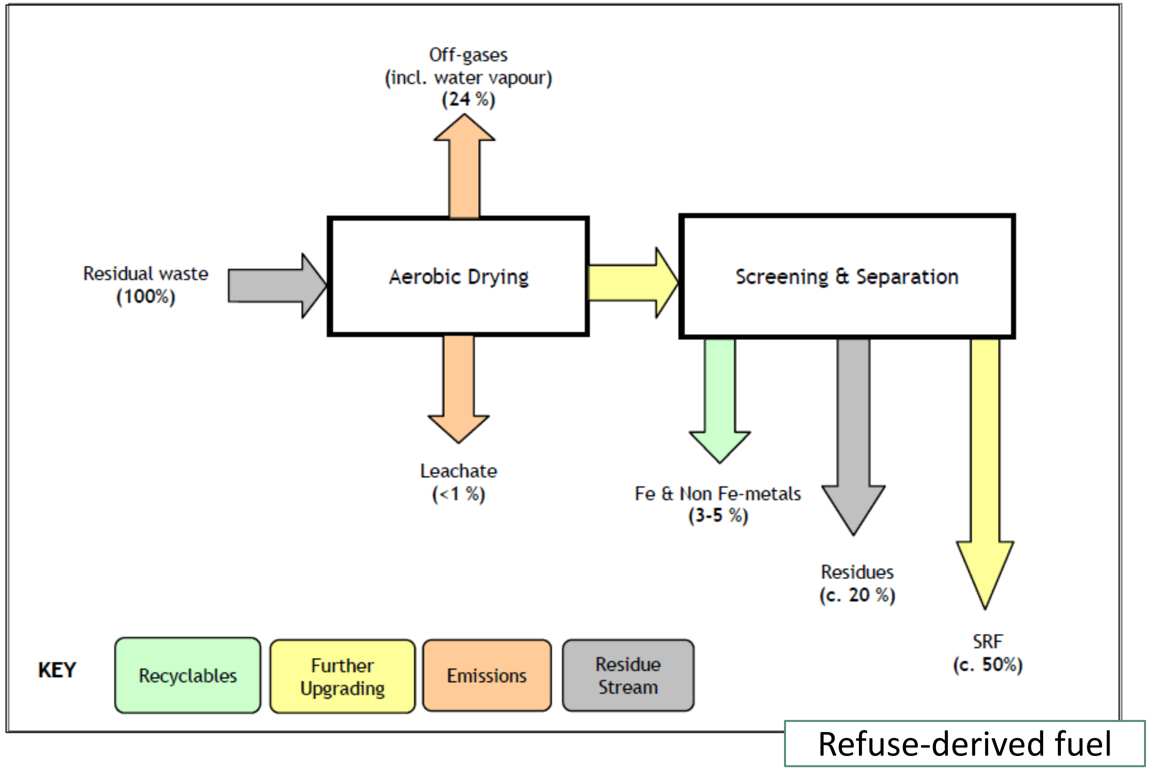


Figure D77: Typical inputs and outputs for Ecodeco's bio-drying process



In MBT residual waste are treated: thus the bio-stabilate (the mostly biological fraction)is not of a sufficient quality to be used as compost.

SUMMARY OF COSTS

Table 5.2 Typical Waste Management Costs by Disposal Type

US$/tonne

	Low-income countries	Lower-middle-income countries	Upper-middle-income countries	High-income countries
Collection and transfer	20–50	30–75	50–100	90–200
Controlled landfill to sanitary landfill	10–20	15–40	20–65	40–100
Open dumping	2–8	3–10	—	—
Recycling	0–25	5–30	5–50	30–80
Composting	5–30	10–40	20–75	35–90

Source: World Bank Solid Waste Community of Practice and Climate and Clean Air Coalition.
Note: — = not available.

Table 5.3 Capital and Operational Expenditures of Incineration and Anaerobic Digestion Systems

US$/tonne

	Incineration		Anaerobic Digestion	
	Capital Expenditures[a] (US$/annual tonne)	Operational expenditures (US$/tonne)[b,c]	Capital Expenditures (US$/annual tonne)	Operational expenditures (US$/tonne)
Europe	$600–1000	$25–30	$345–600	$31–57
United States	$600–830	$44–55	$220–660	$22–55
China	$190–400	$12–22	$325	$25

Source: Kaza and Bhada-Tata 2018.

World Bank. 2018. "What a waste-2.0".

How do composting and anaerobic digestion compare?

COMPOSTING	ANAEROBIC DIGESTION
	It recovers an ENERGY source – biogas - which is considered renewable
	Biogas can be upgraded to biomethane to provide fuel for transport
It gives a compost of high quality (if from properly segregated biowaste)	The digestate gives a compost of high quality (if from well segregated biowaste)
The operation of the plant always results in carbon emissions (from energy use,...).	It results in a net energy saving: thus it contributes to reducing the carbon emissions of a SWM system.
The cost is relatively low	It requires a significant investment
It requires skilled personnel	It requires highly skilled personnel

Thank you for your attention!

United Nations Institute for Training and Research