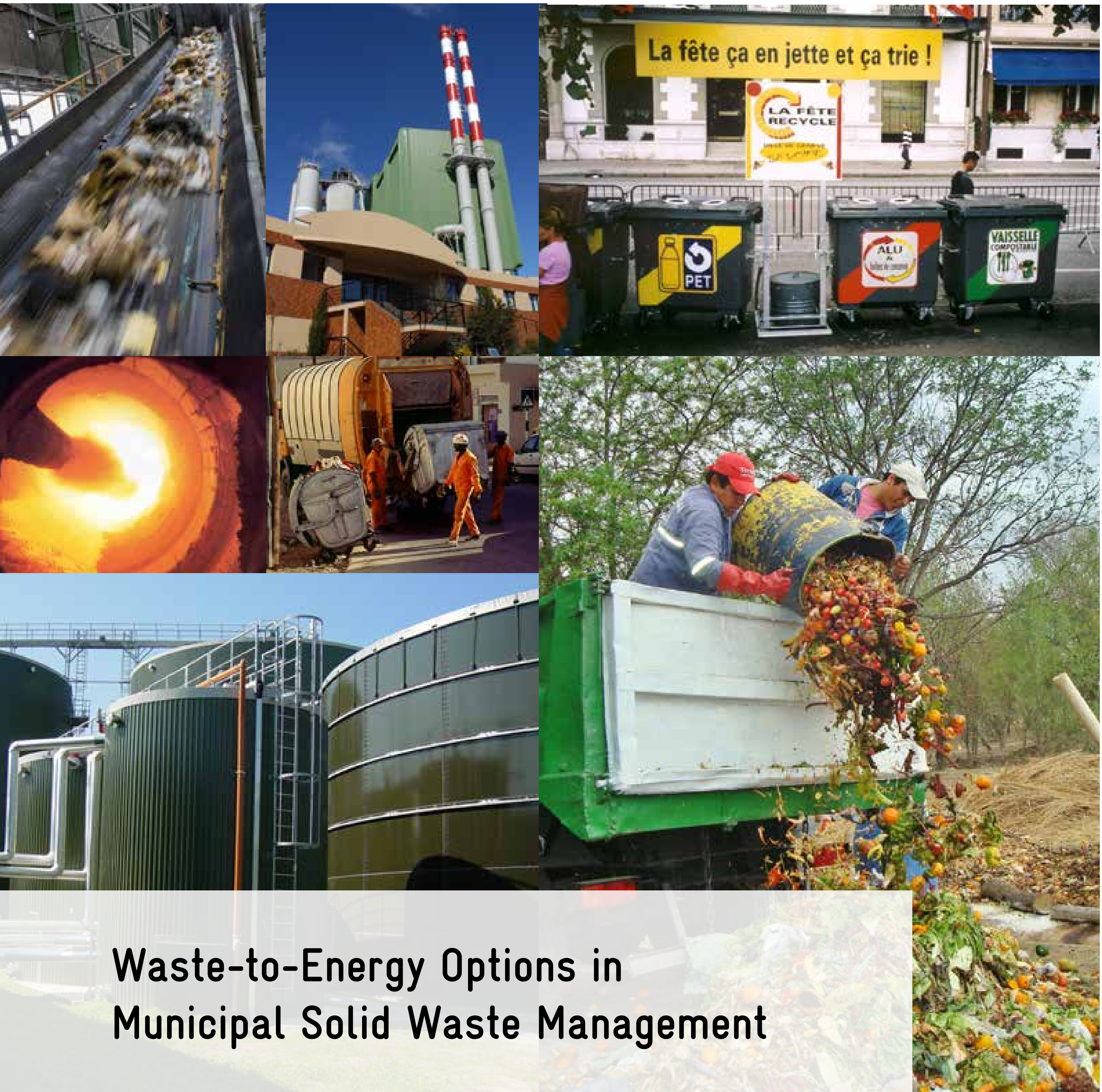

Waste-to-Energy Options in Municipal Solid Waste Management

A Guide for Decision Makers in Developing and Emerging Countries

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Registered offices
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Friedrich-Ebert-Allee 36 + 40
53113 Bonn, Germany
T +49 228 4460-0
F +49 228 4460-1766

E info@giz.de
I www.giz.de

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Authors:
Dieter Mutz, Dirk Hengevoss, Christoph Hugi, Thomas Gross from the University of Applied Sciences and Arts Northwestern Switzerland (FHNW).

Edited by:
Daniel Hinchliffe, Johannes Frommann and Ellen Gunsilius from GIZ.

Design/layout:
Jeanette Geppert pixelundpunkt kommunikation, Frankfurt

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Eschborn, May 2017

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List of Abbreviations

AD	Anaerobic digestion
AT	Alternative Technologies (Pyrolysis/Gasification)
AFR	Alternative Fuel and Raw materials
CDM	Clean Development Mechanism
CH4	Methane
CHP	Combined Heat and Power
CO	Carbon Monoxide
CO2	Carbon Dioxide
CWG	Collaborative Working Group
HCl	Hydrogen Chloride
HF	Hydrogen Fluoride
LCV	Lower Calorific Value
LFG	Landfill Gas
MBT	Mechanical Biological Treatment
MSW	Municipal Solid Waste
MSWI	Municipal Solid Waste Incineration
MSWM	Municipal Solid Waste Management
NAMA	Nationally Appropriate Mitigation Actions
NGO	Non-Government Organizations
NOx	Nitrogen Oxides
OLR	Organic loading rate
O&M	Operations and Maintenance
PET	Polyethylene terephthalate
PVC	Polyvinyl Chloride
RDF	Refuse derived fuel
SDG	Sustainable Development Goal
SO2	Sulphur Dioxide
SLF	Sanitary Landfilling
SRF	Solid Recovery Fuel
SWM	Solid Waste Management
WBCSD	World Business Council for Sustainable Development
WtE	Waste-to-Energy

EXECUTIVE SUMMARY

The tremendous rise in municipal solid waste (MSW) in the fast-growing cities of developing and emerging countries have led to increasing public concerns with regards to the resultant health and environmental impacts. Today, the waste of about 3 billion people is still disposed of in an uncontrolled manner [1]. As citizens and decision makers become more sensitive to environmental pollution and its impact on their quality of life, municipal solid waste management (MSWM) is gaining importance on the local political agenda. In the quest to modernise their waste management systems, local decision makers frequently face the question of whether they should invest in Waste-to-Energy (WtE) technologies. WtE technologies are increasingly presented as an attractive option to solve not only the pressing waste disposal problems but several other challenges simultaneously: shortages in power generation, limited space for landfills, and greenhouse gas emissions from inappropriate waste disposal. However, the introduction of WtE technologies is often jeopardized by common obstacles such as missing tariff systems to fund investments and operation costs, weak enforcement of environmental laws and limited qualified staff to run the installed systems in an efficient and effective manner. If such aspects are not taken into account, WtE projects risk failing at the cost of the municipality and local environment.

Why this Guide?

The Waste-to-Energy discussion can be difficult to follow due to the high complexity of the different technologies, and indeed WtE is sometimes advertised as a silver bullet to solve all of a municipality's waste and energy problems. However, framework conditions in most developing and emerging countries are essentially different to those that have seen the rise of WtE projects in industrialised countries, where utility size waste to energy plants are increasingly common. Even though from a technological point of view almost anything is possible, it does not follow that every technology can be made to fit local conditions. The bigger picture must be taken into account to decide upon the applicability and the suitability in a given context. Advice must go beyond mere technical aspects.

Waste-to-Energy Options in Muncipal Solid Waste Management - A Guide for Decision Makers in Developing and Emerging Countries outlines the different WtE technologies currently applied at the municipal level and their potential role in an integrated waste management system. This Guide seeks to assist decision makers and their advisors in assessing the opportunities, limits and risks of the various WtE technologies for effective planning and efficient investments in waste management. It aims to 1) make the present discussion on WtE more transparent, 2) provide a technical, financial, institutional, social, environmental and legal overview of the most often applied WtE technologies, and 3) highlight the implications and boundaries for their application while considering internationally recognized environmental standards. In particular, it explains the need to look closely at whether local waste management conditions are appropriate before considering a WtE option. It does not replace the need for a professional feasibility assessment in the planning of a WtE project.

This guide was developed by the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ) in cooperation with the University of Applied Sciences and Arts Northwestern Switzerland (FHNW).

What is Waste-to-Energy?

WtE refers to a family of technologies that treat waste to recover energy in the form of heat, electricity or alternative fuels such as biogas. The scope of the term 'Waste-to-Energy' is very wide, encompassing a range of technologies of different scales and complexity. These can include the production of cooking gas in household digesters from organic waste, collection of methane gas from landfills, thermal treatment of waste in utility size incineration plants, co-processing of Refuse Derived Fuel (RDF) in cement plants or gasification. This guide takes a very broad understanding of WtE, referring to large scale plants at the municipal level (i.e. utility size) using the technologies of incineration, co-processing, anaerobic digestion, landfill gas collection and pyrolysis/gasification. These five technologies apply to different waste streams and have different functions and characteristics. Their applicability must therefore be assessed independently based on the local context and waste stream in question. Chapter 3 gives a more detailed overview of these five technologies.

Key findings and recommendations

When considering the introduction of WtE technologies, decision makers should consider the following aspects:

» **The development of MSWM systems should follow the waste hierarchy:** Waste reduction through prevention should take priority, followed by preparation for re-use and the material recycling of waste. WtE projects can be categorized as a complementary technology for the recovery of energy from remaining non-recyclable MSW fractions, and should therefore not compete with waste reduction, reuse and material recycling measures. When done under controlled conditions WtE is preferable to disposal but takes a position of low priority in the waste hierarchy.

Evaluate your waste stream and identify additional potential for reuse and recycling of specific waste fractions.

» **WtE must fulfil high emission standards:** A comprehensive legal framework for all types of WtE exists in a few cases only. Where laws are not available or existing ones cannot be enforced, the high emission standards required will not be achieved. Low emission standards shall not be tolerated as they have irreversible health impacts.

Look out for international experiences and apply internationally recognized standards in tendering processes, ensuring that monitoring and enforcement mechanisms are in place to assure compliance.

» **WtE requires knowledge on waste quantities and characteristics:** Waste quantities will double in the next 20 years in many cities but consistent waste management plans, which consider demographic and social changes, are often missing.

Prepare a waste management plan for the city that looks into mid- to long term development of waste quantities and describes the most relevant waste streams, their characteristics and treatment options. Possible inter-municipal cooperation should also be considered to reach a feasible economy of scale.

» **WtE builds on an efficient MSWM system:** Only municipalities which are able to run an efficient waste collection and transport system with secure final disposal might have the capability to manage WtE systems successfully.

Prove and document that the present waste management system is technically and financially mature.

» **WtE requires significant financial resources:** Secure finance for operation and maintenance is a key for sustainable operation of WtE plants.

If your municipality is unable to finance its present waste collection and treatment system continuously, you should reconsider building a WtE plant.

» **Income from energy sales does not cover WtE costs:** Capital and operation costs of WtE plants are high and cannot be expected to be fully financed by the selling of energy at market prices alone.

Make a realistic forecast of the generated income through energy sale and look out for additional and robust financing schemes.

» **WtE requires qualified staff:** WtE plants are not an easy to handle black box for generating electricity, gas, heat or steam but are sophisticated technologies which require skilled staff and regular maintenance.

Make sure that qualified staff can be hired and retained and that existing employees receive regular training. For certain technical and managerial tasks, outsourcing should be considered.

» **WtE is just a potential part of a functioning MSWM system:** WtE plants are never isolated technical elements and will not solve existing waste problems alone.

Make sure that a possible WtE plant forms an integrated part of your waste management system already in the planning process. Back-up and contingency capacities have to be considered.

» **Legal security for WtE investors must be ensured:** The private sector plays a vital role in the construction and operation of WtE plants. However, private investors will only invest if they are confident of profiting from the service they offer. In many countries the private sector is still reluctant to invest due to the associated financial risks.

Provide an atmosphere which guarantees legal security, is based on transparency and trust and guided by the vision to jointly offer a sustainable waste management service to the citizens.

» **WtE technologies must fit for developing countries:** Experiences with WtE plants are limited in developing countries and the few successful cases most often refer to landfill gas collection and co-processing.

Be critical if a salesman offers you an advanced WtE technology for which no proven operation record in a similar context can be made available.

Approach and Structure of this Guide

This guide is based on expertise from bi- and multilateral development agencies, practical experiences from plant operators and private companies active in the MSWM sector, and information in the literature. **It is intended for a wide group of readers:** politicians, decision makers and advisors at national, regional and local level as well as environmental experts or members of Non-Government Organizations (NGOs) engaged in promoting sustainable urban development in developing and emerging countries. This document should also be of interest to engineering companies, plant operators, and the general public.

The introductory Chapter 1 begins with an overview of municipal solid waste management in general and Waste-to-Energy in particular. Chapter 2 covers the pre-conditions to be met to consider WtE as an option for treatment of MSW. In chapter 3 an overview of five WtE technologies is given: (a) incineration, (b) co-processing, (c) anaerobic digestion, (d) landfill gas and (e) alternative technologies (pyrolysis/ gasification). Finally in chapter 4, a decision matrix for the different technologies indicates the pre-requisites for each technology before further steps can be taken.

Acknowledgement

This document represents an aggregation of information collected from a number of sources, in particular the expertise of practitioners (development authorities, consultancies, equipment suppliers, operators of WtE plants etc.) from industrialized, developing and emerging countries. All contributions are gratefully acknowledged. Special thanks also go to those experts who contributed valuable comments in the peer review.

1. INTRODUCTION

In many countries, municipal solid waste management (MSWM) has often been regarded as a public service with low priority: a nuisance and a burden. However, insufficient solid waste management (SWM) appears more and more on the political agenda due to increasing health and environmental problems and the discontent of a growing number of citizens with the decreasing quality of life due to rubbish in public spaces. The relevance of MSWM as a public service has often been neglected and its complexity is underestimated. The United Nations Sustainable Development Goals[1] (SDG) as well as UN Habitat's New Urban Agenda[2] call for improvements in waste management practices as a basic service to citizens.

Waste managers and decision makers in developing and emerging countries have to respond to these new challenges, and in recent times waste-to-energy (WtE) has been increasingly viewed as a solution to the problems derived from rising waste quantities in expanding cities as well as rapidly growing energy demands. However, WtE can never solve the problem alone but rather needs to be embedded in an integrated solid waste management system that is tailored to the specific local conditions with regards to waste composition, collection and recycling, informal sector, environmental challenges, financing, resource prices, and other aspects.

This chapter highlights why there is an urgency to improve waste management in cities, how MSWM is embedded into the concept of a circular economy, and what frequent misperceptions and challenges are when talking about WtE.

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1 The UN General Assembly adopted 17 SDGs on 25 September 2015, see https://sustainabledevelopment.un.org/

2 The New Urban Agenda was adopted at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III) held from 17 to 20 October 2016 in Quito, Ecuador see https://habitat3.org/the-new-urban-agenda

Growing waste quantities are a challenge but also have potential for resource recovery.

A cement plant under construction.

1.1 Urbanization and new Challenges in Waste Management

MESSAGE: The 21st century will be the century of the cities.

The 21st century will be the century of the cities. The urban population of the world has grown rapidly since 1950, from 746 million to 3.9 billion in 2014 [2]. According to UN data it is expected to increase up to 9.7 billion by 2050, with nearly 90 per cent of the increase to take place in the urban areas of Africa and Asia.

Already today, the global amounts of municipal solid waste are estimated at 2 billion tonnes per year. Unlike world population and urbanization trends, there are no UN forecasts of future waste generation per capita [1]. However, there is a common understanding that waste quantities will substantially increase. The drivers are increased consumption of goods in growing urban populations, changes in lifestyle, and increasing wealth of the rising middle class. Figure 1 illustrates the steep increase in waste quantities in urban areas until the year 2050.

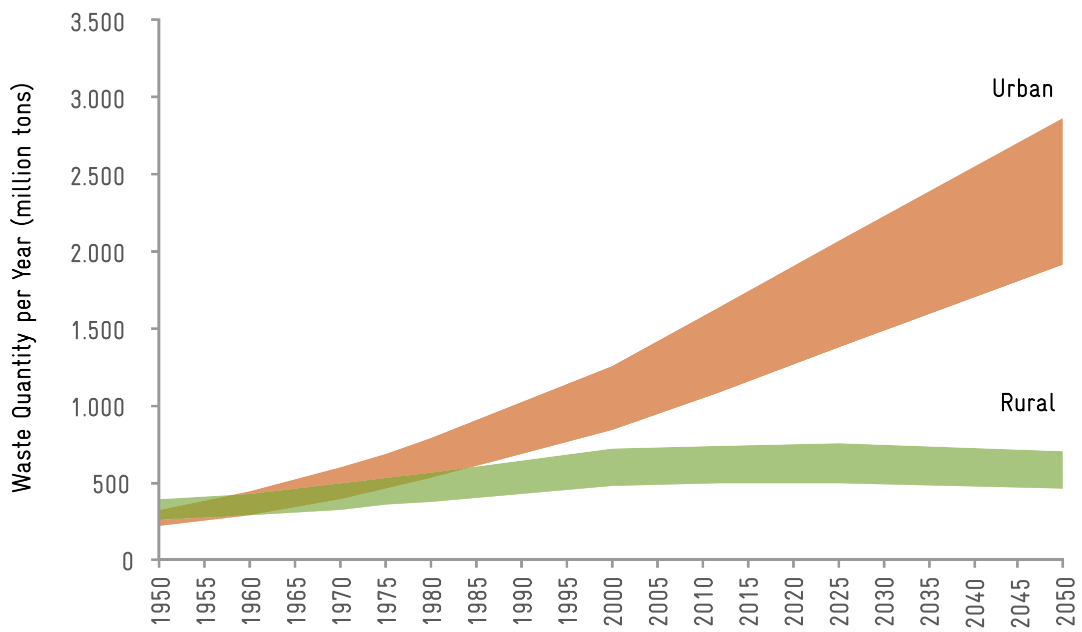


Figure 1: Projection of the development of urban and rural waste quantities of the world, 1950–2050. Based on UN-data [3] [4] [5] [6] and a daily waste production per person between 0.8 and 1.2kg in urban areas and between 0.4 and 0.6kg in rural areas.

According to the International Energy Agency, waste generation rates will more than double over the next twenty years in lower-income countries [7]. Irrespective of the accuracy of these forecasts, these enormous waste volumes will pose a tremendous challenge to most to many local urban authorities which are already struggling to manage the waste quantities of today.

MESSAGE: Landfilling is an intermediary or transitional, but still necessary, solution for waste disposal. It is however not the ultimate goal of sustainable waste management. MSWM systems should continue to prioritise material recycling.

To date, about 70% of MSW still ends up on landfills or uncontrolled dumpsites, which often contaminate surface water, ground water or soil and emit greenhouse gases [8]. Waste disposal close to coastlines and along rivers pose a risk for land-based marine littering. Landfilling is no longer considered state-of-the-art. Although good examples for the management of sanitary landfills (SLFs) with substantially reduced negative environmental impacts exist, the search for new SLF sites is often accompanied by public protests and space for new sites is rarely available near metropolitan areas or urban centres due to land scarcity, conflicting land use, and rapidly increasing land prices. Proper treatment and disposal of waste remains highly challenging and often overwhelming for many municipalities. Incentives to reduce waste generation and to increase recycling are urgently needed. Segregation at source, collection, transportation, treatment and proper disposal of MSW has become the legal objective in many developing and emerging countries. However, despite good progress in the past decades on recycling of "classical" materials such as paper, metal, glass or plastic, the current recycling levels are still insufficient.

MESSAGE: For specific non-recyclable waste streams, WtE could be a viable alternative to manage the increasing waste quantities in the coming years if environmental standards are met and social aspects are carefully considered.

1.2 Waste-to-Energy: a Temptation for Municipalities

MESSAGE: Dealing with the issue of waste-to-energy means reaching a new level of complexity in an already challenging waste management situation.

Growing concerns regarding shrinking natural resources, contribution of improper waste management to global warming and shortage of power generation have triggered discussions regarding waste as a resource in general and WtE concepts in particular. Decision makers at national and local level in developing and emerging countries may be tempted by technology providers who promise that WtE plants will solve their waste disposal problems, create a lucrative business opportunity and contribute positively to energy supply. As such, waste seems to be an ideal feedstock for energy recovery. So far however, only a limited number of projects built in developing and emerging countries have operated successfully in the long term.

Some positive experiences so far lie in state-of-the-art co-processing in cement kilns and landfill gas collection applied to sanitary landfills. However to date, there are hardly any anaerobic digesters fed with segregated organic MSW in successful operation on a large scale in developing countries, nor are there more than a handful of waste incinerators in continued operation in developing countries in Africa or Asia. Alternative technologies such as pyrolysis and gasification never moved beyond pilot scale (even in industrialised countries) for mixed MSW fractions.

The framework conditions in most developing and emerging countries are essentially different to those that have seen the rise and successful application of WtE projects in Europe, North America, Japan and China, where utility size WtE plants are increasingly common. A simple technology transfer is often not successful as it does not meet the conditions of developing and emerging countries, especially in terms of financial requirements, input material composition and local capacities. Nevertheless, WtE technologies can improve waste management in fast-growing cities of developing and emerging countries but its application is complex and must consider, amongst others, the following specific circumstances:

- Lower calorific value in MSW than in industrialized countries due to the high moisture (high organic content) and mineral content in waste (e.g. ash, construction and demolition waste);
- Substantial seasonal change in waste composition (i.e. changing consumption pattern during festival seasons, seasonal crops);
- Limited practice of waste segregation at source, a precondition for anaerobic digestion;
- Weak business and operation models;
- Lack of knowledge on how to operate and maintain WtE plants;
- High investment and operating costs which cannot be recovered by existing waste fees and generated additional income from energy sales alone;
- Neglecting of livelihood issues for marginalized persons and informal sector workers dependent on the availability of recyclables in the waste;
- Lack of monitoring and weak enforcement of environmental standards, leading to public health issues.

1.3 Waste-to-Energy and the Circular Economy

The core vision of moving towards a circular economy aims to replace the currently largely linear economy of 'take, make and dispose' with one in which resources circulate at high value, avoiding or reducing the need for primary resources and minimizing residual waste, pollutants and emissions. The main drivers of the circular economy are the increasing price volatility and supply restrictions of primary resources, environmental policies such as producer responsibility regulations and, arguably, a changing consumer culture. Figure 2 shows the principle of the circular economy as developed by the Ellen MacArthur Foundation [9]. The linear economy runs through the centre, whilst inner circles represent the actions which can be taken to make material flows more circular regarding biological and technical materials.

MESSAGE: The objective of a modern waste management system is not to dispose of waste products but to supply the economy with secondary raw materials and energy from waste.

Separation of recyclables is important to enable the circular economy.

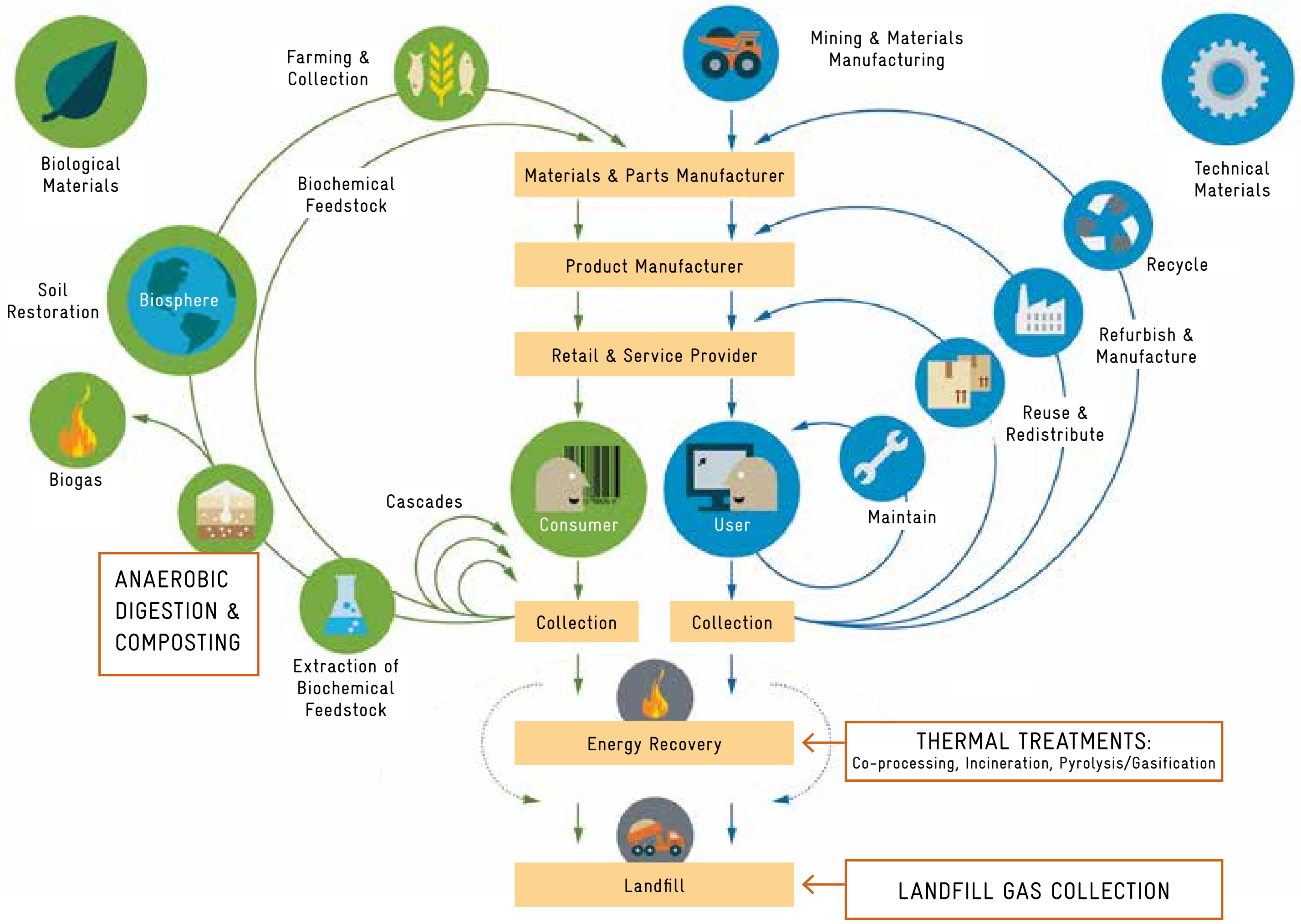


Figure 2: The principle of the Circular Economy. The role of WtE Technologies covered in this guide are indicated in boxes.
Source: Ellen MacArthur Foundation [9].

Already today many countries intend to develop their national integrated waste management strategy based on the 3Rs concept (as an integrated element of a circular economy) in the order of "reduce, reuse and recycle":

1 Reducing:

First priority in waste management must be an overall reduction of solid waste quantities, e.g. food waste, packaging, unnecessary waste of raw materials and energy during production processes. Reducing waste also reduces the cost of waste collection and treatment.

2. Re-using:

Second priority should be given to the reuse of materials, i.e. a discarded product is cleaned and repaired to be used again.

3. Recycling:

The third priority in the 3Rs concept is to recycle materials, i.e. to collect waste and to transform it into a secondary raw material. Recycling of e.g. plastic or paper can normally save more energy in the production of products than the energy that can be produced in waste-to-energy plants from these materials.

The different WtE technologies have different roles within the circular economy; these are indicated in Figure 2. Even with intensive recycling, there is always remaining waste which has no material or market value and is in some cases classified as hazardous. This residual waste with a certain calorific value can be utilised to recover energy and substitute the use of fossil fuels. A thermal treatment such as incineration or co-processing that is compliant with environmental emissions standards can also play a role in destroying toxic organic substances and removing them from the circular material flow. Some valuable materials like metals may also be further recovered from the remaining slags and ashes of incineration; however, the rest must be treated separately and disposed of at a secure landfill site. If biological materials are successfully separated from technical materials, anaerobic digestion can play an important role in recovering biogas and compost in the biological cycle. Landfill gas collection enables mitigation of methane released from biological materials sent to landfill.

MESSAGE: WtE projects should not compete with waste reduction and cost efficient reuse and material recycling measures. WtE is a complementary technology for the treatment of remaining non-recyclable MSW fractions.

1.4 Myths around Waste-to-Energy

Energy recovery from MSW has a role in the circular economy when used for non-recyclable and hazardous waste fractions, respecting environmental standards and carefully considering social aspects. However, its integration in developing and emerging countries is still in the initial stages. Responsible options may be offered by some firms, however many discussions on this topic can be biased and non-transparent. It is important to be aware of several common myths that persist around Waste-to-Energy and may be pushed by inexperienced companies looking to take advantage of municipalities:

Myth 1: "WtE is an easy going solution to get rid of all the waste problems in a city"

The situation is much more complex and WtE needs professional planning, construction and operation. Unfortunately, there are several companies on the market which are inexperienced with the conditions in developing and emerging countries. Decision makers need to be aware that their objective is first and foremost to "sell" their product and not to solve the local problem.

Myth 2: "A WtE plant can finance its costs exclusively through the sale of recovered energy"

In Europe where calorific values of waste and energy prices are higher, the revenue from non-subsidized sale of energy (in form of heat and power) might cover operating costs but never the entire investment and capital costs.

Myth 3: "With a WtE plant in operation, a big fraction of the energy demand of a city can be covered"

In reality, energy from household waste will only be able to contribute a small fraction to the overall electricity demand of a city (~ 5%). Utilization of heat is the most efficient application in Europe, but hardly used in developing countries.

Myth 4: "You can make gold from garbage; even unsorted waste can be sold with profit to be used for further energy and material recovery"

In reality, WtE is not a business model that generates cost covering incomes. Revenues from energy sales help to cover part of the overall costs of thermal treatment but additional gate fees or other forms of revenues are required to cover full costs. In all countries, waste management as a whole has costs and cannot be considered as a profitable business that could depend exclusively on the sale of energy, Refuse Derived Fuel (RDF) and recycling materials at current prices for these products.

Myth 5: "Qualified and experienced international companies are queuing up to invest and operate large WtE plants in developing and emerging countries at their own risk"

This is only partly correct as experienced international companies are presently reluctant to invest in WtE in developing and emerging countries. The legal, financial and reputational risks are high and any project of the private sector has to be bankable.

These myths are often kept alive and can obstruct informed discussions. This guide seeks to provide a comprehensive orientation for decision makers in order to realistically address the myths above. An additional, useful overview tool to assist planners in assessing the quality of a technical and financial offer for a WtE plant has been developed by the Collaborative Working Group on Solid Waste Management in Low and Middle Income Countries, and is called the CWG Waste to Energy Rapid Assessment Tool, 2016 [10]. This tool is available online.

2. PRE-CONDITIONS FOR WASTE-TO-ENERGY

This chapter deals with the basic conditions to be met when considering WtE as a viable option for complementing an existing MSWM system. WtE cannot be looked at as an isolated choice of technologies but has to fit into an integrated SWM concept in which waste avoidance and material recycling is the preferred option. The different sub-chapters look into the given situation, outline minimal technical and operational requirements and provide an overview of environmental, legal and economic framework conditions.

2.1 Characteristics of Municipal Waste

An urban citizen in a developing or emerging country generates on average between 100 and 400 kg of MSW per year (see Figure 3). Reasons for this wide range and large uncertainty lie in different levels of economic development and consumption as well as the definition of the waste quantity generated. Some statistics use the total estimated waste generated per capita, including all recycled materials. Others look only at wastes managed by the concerned local authorities and thus exclude for example valuable materials separated and collected at source by the informal sector. Often the separate collection of recyclables such as glass bottles, newspapers, PET or tins is done before they reach the formal waste stream for which the municipality is responsible. As a consequence, municipalities have to deal with a "remaining" waste fraction characterized by high heterogeneity, high organic content and a low calorific value. Those uncertainties in terms of quantity and quality have to be carefully considered when planning WtE solutions as well as the social impact on the informal sector when a change in the given recycling and primary collection system is intended.

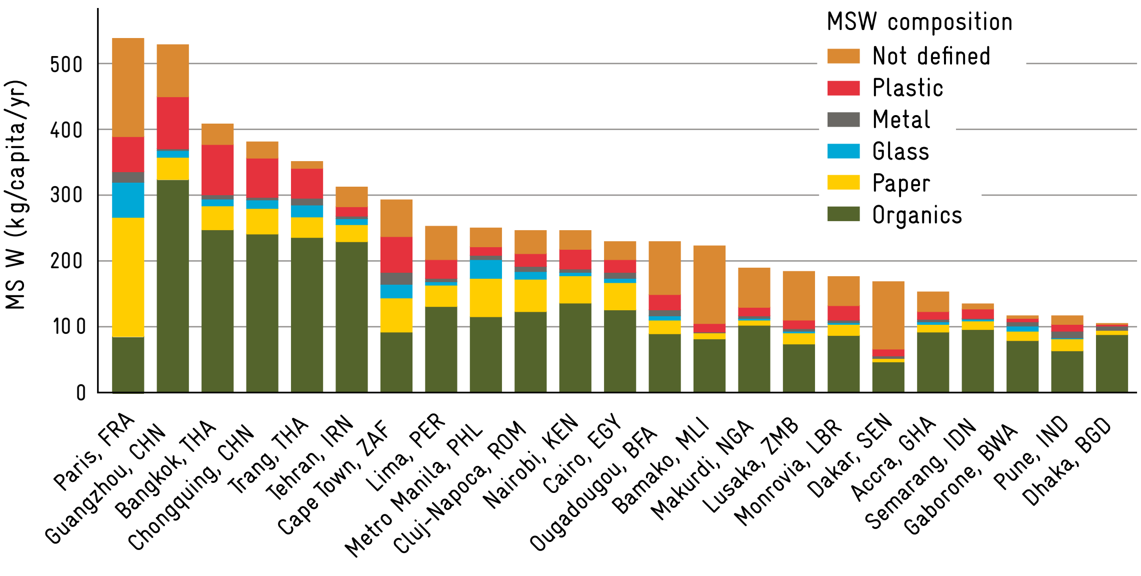


Figure 3: Composition of MSW per capita (kg/capita/yr) in various cities of the world [11].

In most developing countries organic waste with high moisture content is the most relevant fraction which ends up in the formal waste stream and needs treatment. In cities with high construction activity and no separate collection of construction and demolition waste, MSW has a high fraction of inert material as well.

Message: Mixed municipal solid waste in developing countries is by its nature different from that in industrial countries and has specific characteristics in every city. This diversity must be considered in any technology assessment.

Organic waste is often the largest waste fraction in developing countries.

2.2 Legal Framework and Environmental Impacts

Waste management in general and WtE especially needs to be covered by a legal and regulatory framework that is effectively implemented and enforced. A legal framework is necessary for several reasons: first of all, the law guarantees legal certainty. The relevant stakeholders – administrative authorities, waste producers, treatment and disposal companies, citizens etc. – have to know precisely what their roles and obligations are. Only detailed legally binding rules can provide an appropriate framework to reach these objectives. The legitimacy of administrative action also depends on legal rules. Furthermore, emission standards and other environmental prescriptions for WtE require legal anchorage and regular control by qualified and well-equipped public authorities.

Environmental framework legislation and a national waste act should determine the objectives and fundamental rules of WtE activities for MSW including emission control principles. In particular, it should contain:

» **Planning and tendering**: In general, the national standards are considered when planning new infrastructure. However, when looking at WtE options, it is recommended to apply internationally recognized emission and safety standards for any tendering process to minimize risks for decision makers.

» **Obligations of operators**: The legislation should require that WtE installations are subject to an environmental impact assessment and permitting under the national emission control and/or waste law.

» **Prerequisites for permitting**: In general terms, the act should provide the obligations of plant operators to ensure that no harmful effects on the environment or other hazards, significant disadvantages and significant nuisances to the general public and the neighbourhood may be caused by such installation or the surrounding premises.

» **Safety and environmental standards**: The emission thresholds and safety requirements have to be controlled on the basis of legally binding standards. Emission limit values imposed on WtE should comply with internationally recognized and applied standards. The application of low and inadequate environmental standards will lead to additional hazards for public health and environmental costs.

» **Monitoring of the compliance with safety and environmental standards**: Monitoring is the core responsibility of a competent and independent regulating authority. National laws should lay down air quality standards and ensure compliance near WtE installations.

MESSAGE: In many countries the legal framework for WtE including design, approval, operation and monitoring is weak or even non-existent. An applicable legal framework has to be ensured and its enforcement must be in the process of development before any WtE plant is considered to be built and operated.

In most developing and emerging countries, an environmental legislation exists. However specific regulations on WtE plants are in many cases non-existent or are very general and do not offer the necessary legal framework for design and approval, nor for operation and monitoring. This also holds true for the process of enforcement, where in most cases neither qualified staff nor financial resources are available to carry out this task. If a legal framework does not exist, experiences from industrialized countries could serve as a reference for developing it. For instance, the European Industrial Emissions Directive (2010/75/EU) [12]) could serve as an example for setting emission limit values for incineration.

2.3 Financial and Institutional Aspects of WtE Plants

MESSAGE: WtE projects are expensive and constitute a substantial financial risk for a municipality. An independent assessment of costs and a profound understanding on financial implications are crucial for decision making.

WtE projects require high investments not only for the treatment process itself but also for the mitigation of operational risks (accidents, fire, etc.). Operation and maintenance (O&M) costs for WtE plants are considerably higher than for sanitary landfills. Secure and permanent financing is key for any functioning MSWM system. The municipality has to make sure that financial requirements can be met. As this is often not possible through cost covering waste tariffs, additional funding possibilities should be considered. The following options are examples of sources to generate income:

- Direct waste fees from citizens;
- Cross financing of MSW services through other local fees or taxes;
- Gate-fees when waste is delivered at a plant site;
- Revenues from sale of recycled material and recovered energy (electricity, heat/steam);
- Local or national subsidies;
- Revenues from national or international carbon funds (e.g. Green Climate Fund);
- Tax refunds and application of special feed-in tariffs for electricity produced from non-conventional sources such as waste material.

Especially the last two options should be carefully addressed as they have the potential to provide a certain long term guarantee for the municipality or a private investor.

MESSAGE: A sound financial, social and technical concept which allows cost covering operation of a WtE as well as an adequate institutional arrangement are prerequisites and key for sustainable management of any integrated SWM system.

3. WASTE-TO-ENERGY TECHNOLOGY OPTIONS

This chapter gives an overview of five WtE technologies at the municipal scale (see Figure 4): incineration, co-processing, anaerobic digestion (AD), landfill gas (LFG) and pyrolysis/gasification (further also called alternative technologies). While the general principles of the last two chapters apply, these five technologies have different functions and applications in the municipal waste management system. The order of the technologies is based upon the perceived demand for advice on these technologies and does not imply any priority or applicability.

For each technology, some technical background information is given followed by a listing of the suitable waste types and a summary of related operational, environmental, legal and financial matters. The reader should gain a basic understanding of which technology fits which waste stream best and the ecological, legal and financial implications.

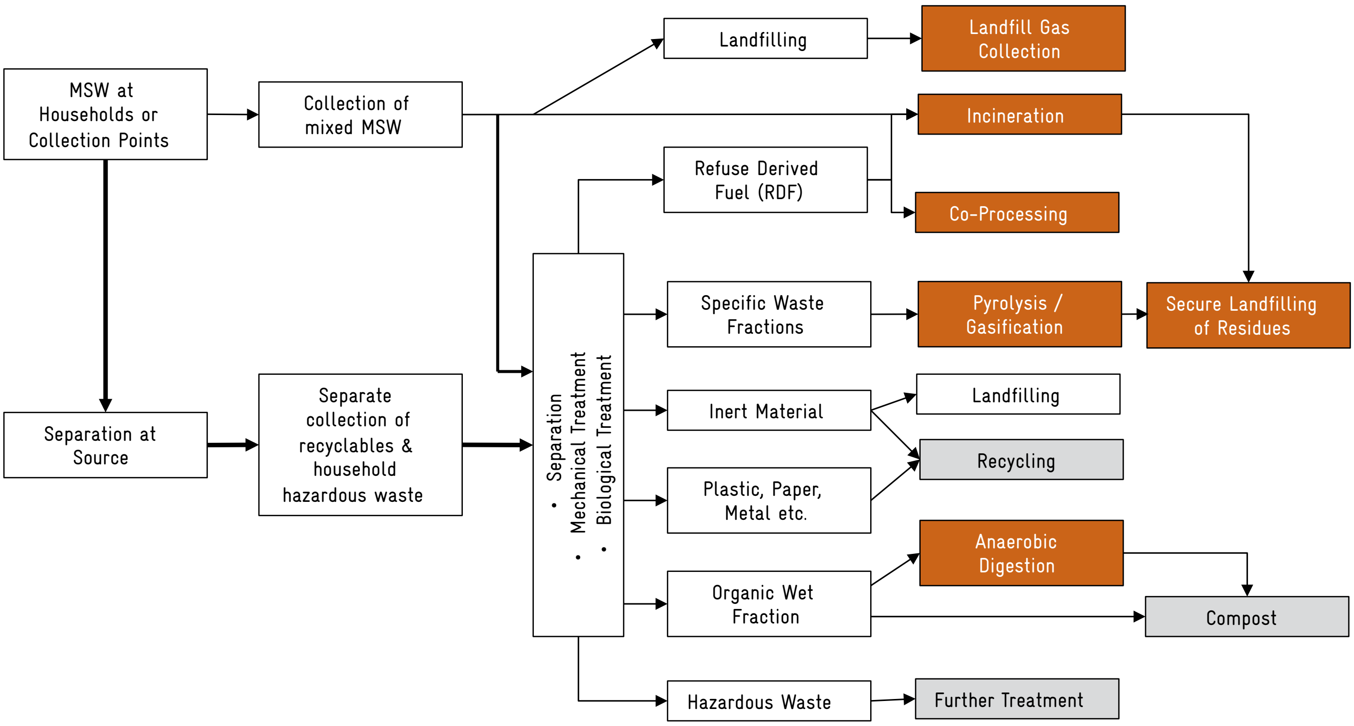


Figure 4: Overview of MSW material flow and its different utilization and treatment options. Collection of separated waste streams makes the utilisation of different treatments more viable.

Several publications are available from different stakeholders, describing in detail the essential differences and specifics of WtE technologies (see references and further reading sections). Some also include an analysis of necessary prerequisites such as market, policy, regulatory and financial sustainability issues. These documents are an invaluable source of information, especially for technical experts and implementation agents. However, many of these documents assume that pre-conditions can easily be met (e.g. enforced payment of waste charges, close to 100% separate collection of organic waste at the door step, or existence of the required legal framework), and implementation risks in local contexts often do not receive the required attention.

3.1 Municipal Solid Waste Incineration

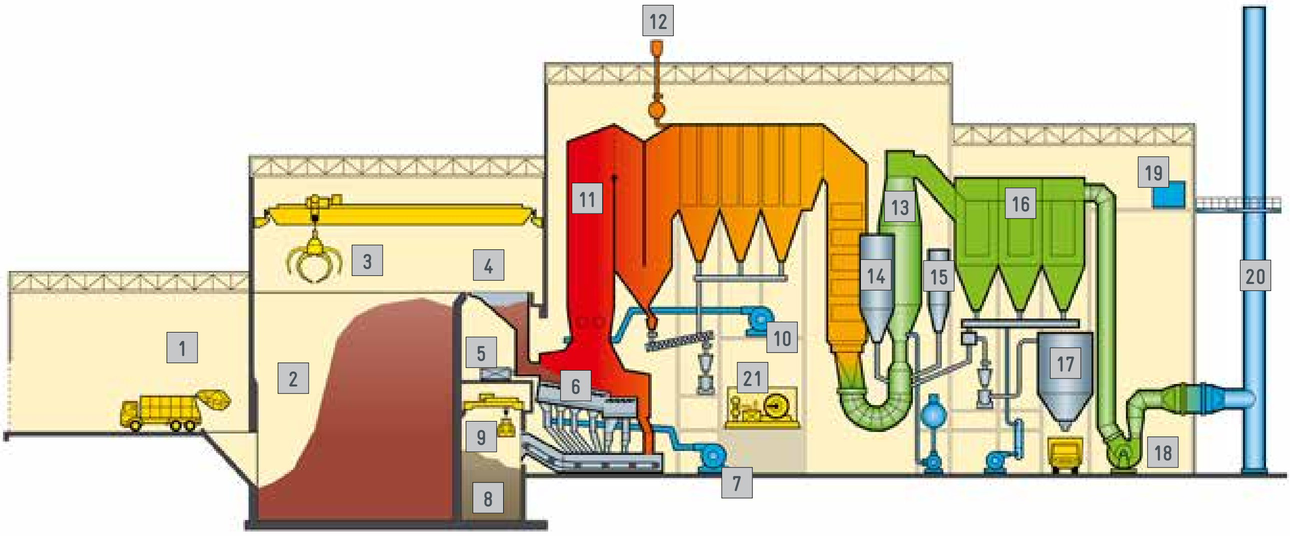
Municipal solid waste incineration (MSWI) is the burning of waste in a controlled process within a specific facility that has been built for this purpose. The primary goal of MSWI is to reduce MSW volume and mass and also make it chemically inert in a combustion process without the need of additional fuel (autothermic combustion). As a side effect it also enables recovery of energy, minerals and metals from the waste stream [13]. There are always about 25% residues from incineration in the form of slag (bottom ash) and fly ash. Bottom ash is made up of fine particulates that fall to the bottom of the incinerator during combustion, whilst fly ash refers to fine particulates in exhaust gases which must be removed in flue gas treatment. These residues need further attention and, in the case of the hazardous fly ash, a secure place for final disposal.

3.1.1 TECHNOLOGY DESCRIPTION

The combustible materials in waste burn when they reach the necessary ignition temperature and come into contact with oxygen, undergoing an oxidation reaction. The reaction temperature is between 850 and 1450°C, and the combustion process takes place in the gas and solid phase, simultaneously releasing heat energy. A minimum calorific value of the waste is required to enable a thermal chain reaction and self-supporting combustion (so-called autothermic combustion), i.e. there is no need for addition of other fuels.

During incineration, exhaust gases are created which, after cleaning, exit to the atmosphere via a pipe or channel called a flue. These flue-gases contain the majority of the available fuel energy as heat, as well as dust and gaseous air pollutants which must be removed via a flue-gas purification process. Excess heat from combustion can be used to make steam for electricity generation, district heating/cooling or steam supply for nearby process industry (components of a MSWI are illustrated in Figure 5). Plants that utilise cogeneration of thermal power (heating and cooling) together with electricity generation can reach optimum efficiencies of 80%, whereas electricity generation alone will only reach maximum efficiencies of about 20%.

A municipal solid waste incineration plant in Europe.



WASTE DELIVERY

1 Tipping hall
2 Waste bunker
3 Waste crane
4 Waste feeding chute

INCINERATION

5 Ram feeder
6 Incineration grate
7 Primary air fan
8 Bottom ash bunker
9 Bottom ash crane
10 Secondary air fan
11 Steam boiler
12 Boiler safety valve

FLUE GAS CLEANING

13 Flue gas reactor
14 Hydrated lime
15 Activated carbon
16 Bag filter
17 Residue silo (fly ash)
18 ID fan
19 Emissions Monitoring System (CEMS)
20 Stack

ENERGY RECOVERY

21 Steam turbine / generator

Figure 5: Components of a muncipal solid waste incineration plant with flue gas cleaning. Image source: Doosan Lentjes GmbH [14].

3.1.2 SUITABLE WASTE FRACTIONS

MSWI is designed to treat typically mixed and largely untreated domestic waste and certain industrial and commercial wastes. A key parameter is the energy content, the so-called lower calorific value (LCV) in MJ/kg. To ensure autothermic combustion of the waste LCV should not be below 7 MJ/kg on average over a year [15] (for comparison: The LCV of 1 kg fuel oil is about 40 MJ/kg). In developing countries the LCV of unsorted MSW is often below this threshold due to a dominant organic content with high moisture and a significant level of inert waste fractions such as ash or sand.

Prior separation of recyclables influences the characteristics of the remaining waste as presented in Table 1 below.

Fraction removed	Prime impacts of removal on remaining waste
Glass, metals, ash, minerals from construction and demolition waste	Increased calorific value Decreased quantity of slag and recoverable metals
Paper, cardboard and plastic	Calorific value decreases Chlorine loads (e.g. from PVC) in emissions decrease
Organic waste from kitchen and garden	Decreased moisture loads Increased calorific value
Bulky wastes	Reduced effort for shredding waste
Hazardous waste (e.g. batteries, electronics)	Reduced effort to remove toxic volatile heavy metals from air emissions (e.g. mercury) Reduced concentration of toxic pollutants in slag and fly ash (e.g. cadmium, lead, zinc)

Table 1: Influences of prior separation of recyclables on incineration.

3.1.3 OPERATIONAL ASPECTS

The operation of highly complex MSWI requires well developed technical and management skills. It is much more complex than the operation of a sanitary landfill. Requirements are: a continuous MSW supply chain, a homogenized waste mix fed continuously to the combustion chamber, process parameter and emission parameters adjusted and controlled, scheduled maintenance, the purchase of auxiliary materials and spare parts, guaranteed energy supply to direct customers, managed disposal or further use of process residues, etc. Operational health and safety must be well developed and frequent contact with environmental authorities, the municipality, local communities, civil society and other actors must be maintained. Siting of the MSWI where year-round use of thermal power (heating or cooling) or generated electricity can be ensured is an important factor, increasing the likelihood of reliable revenues. For this reason MSWI should be sited in industry parks, with short distances to waste sources.

Only managers, engineers and technicians with proven capabilities and experiences should be assigned to key functions. If the qualifications are not available locally, international experts need to be contracted long term and a capacity building program launched.

3.1.4 ENVIRONMENTAL ASPECTS

An objective of MSWI is to contribute to an overall reduction of the environmental impact that might otherwise arise from wild dumping, open burning or landfilling of the waste. The volume reduction of waste by incineration helps to save scarce and valuable space for landfill and protect the environment. A fraction of the energy recovered can also be considered to be carbon neutral, due to the biomass content in MSW. However, MSWI facilities also generate large amounts of flue gases which must be treated, even when incineration has taken place under optimum combustion conditions. To avoid irreversible health risks to local populations and the environment, compliance with international emissions standards is essential and continuous monitoring and reporting of emissions must be guaranteed. Pollutants in flue gases take the form of dust and gases such as hydrogen chloride (HCl), hydrogen fluoride (HF) and sulphur dioxide (SO2). A number of compounds containing mercury, dioxins or nitrogen dioxide (NO2) may only be removed using highly advanced chemical processes, which substantially increase project costs. The main environmental aspects to deal with are [13]:

- Control and monitoring of process emissions to air and water (including odour);
- Quality and use potential of slag production (e.g. heavy metal contamination levels);
- Secure disposal or recycling of hazardous fly ash residues;
- Process noise and vibration;
- Water and other raw material (reagent) consumption;
- Fugitive emissions – mainly from waste storage;
- Storage/handling/processing risks of hazardous wastes.

3.1.5 LEGAL ASPECTS

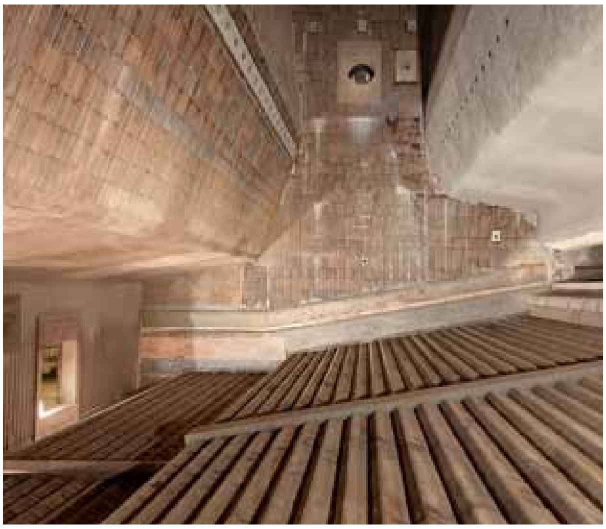
It must be assumed that environmental legislation in most developing and emerging countries does not explicitly deal with the application of MSW incineration technology. This makes the entire process of impact assessment and operation licensing more complicated and time consuming. If comprehensive and legally binding standards are not available, these should first be developed and should follow application of internationally recognized standards. An example for orientation can be the European waste incineration directive (Industrial Emissions Directive 2010/75/EU, [12]). It also needs good capacity for monitoring and enforcement within public institutions.

3.1.6 ECONOMIC ASPECTS

MSWI requires a major capital investment and must be supported by long term financial planning and sufficient resources to secure continuous operation and maintenance of the plant. In developing countries initial investment funds may be available; however, financial resources for the operation phase are often not adequately considered. To compare and assess the full financial viability of operating a MSWI, initial investment costs and expected operational costs have to be annualised. For a net cost calculation, any annual revenues from energy and material sales can be subtracted from the annualised capital investment and operational costs to derive an overall cost per tonne of waste based on the annually treated waste. Such an estimate is shown in Table 2 for a MSWI with a capacity to treat 150'000 metric tons of waste annually. The table shows that the market revenues from energy and material sales alone will not cover the full annual costs of the plant, and the expected net costs of 40 to 80 EUR per metric ton of waste must be covered by other financing means. Additional revenues from gate fees, public subsidies or other funds are required to ensure these full costs are met and that operations can be financed sustainably in the long term.

It should be understood that incineration solutions lead to increased costs for waste treatment compared to previously applied landfilling, which may make waste generators prefer to use the current disposal option. Whilst the cost estimates are relatively well established for industrialised countries, it is difficult to provide representative costing information for the developing country context. The investment and operation costs listed in table 2 provide rough figures derived from various sources worldwide and should therefore be understood as an orientation only.

Risks of low cost MSWI plants: High initial investment costs tend to be a major barrier to developing MSWI projects in developing countries. Attempts are being made to bring lower cost MSWI projects to the market with a basic technical standard for low income countries, however, as yet there is limited experience with these solutions and it remains to be seen if these plants can successfully meet the necessary technical and emissions standards in the long term. Low cost designs can differ significantly from plants in high income countries e.g. omitting technical backup systems such as pumps, piping, electronic control systems, a second furnace, or appropriate flue-gas filter systems. Other investment cost saving opportunities can be the use of lower steel qualities for highly stressed components in the plant such as the furnace or the plant housing. As a result, the risk of unplanned breakdowns and longer service down times increases due to missing backup systems, whilst critical components may suffer from heavy corrosion and lead to a shorter operable lifetime of the plant. This can significantly increase the costs for operation and maintenance, as well as reduce the utilisation rate and revenues from treated waste or energy sales. A continuous energy supply will consequently not be ensured (e.g. steam supply to industry) and in the worst case the plant may be inoperable after just a couple of years. It is therefore crucial that the cost and financing basis is critically assessed – as well as assuring that clear contractual agreements and guarantees are made which make it clear which stakeholder bears the risks in the project. Experience also shows the necessity of implementation in sufficiently advanced waste management systems. If the input waste composition differs to that for which the plant was designed (e.g. lower LCV), the plant components will degrade faster and may struggle to meet international emissions standards.

View of incineration grate from the outside (left) and inside (right).

Annual capital costs: The annual capital costs are calculated based on the initial investments, the required interest rate for such an investment (e.g. 6% per year) and the expected life span of the facility (e.g. 15-20 years). Large plants require higher absolute initial investments compared to smaller plants but have lower specific annual costs per ton of treated waste due to economies of scale. This cost development does not follow a linear relationship to the amount of waste treated. A second furnace line leads to only about 35% higher investments compared to a single furnace. If the MSWI provides power and heat, e.g. steam for industry, a second furnace increases the supply safety and reduces down time. The investments also depend on the applied incineration and flue-gas treatment technology, the number of technical backup systems, the housing of the facility and buildings etc. Process heating or district cooling require additional investments but also increase the overall energy efficiency of the MSWI plant. In many cases, land costs are not addressed as it is assumed that municipalities provide land for free. This could lead to legal issues and financial bottlenecks if not properly considered from the beginning.

Annual operational costs: The operational costs include mainly the personnel costs, auxiliary materials (e.g. chemicals for flue gas treatment), spare parts and maintenance, insurance and taxes, electricity, and the costs for the disposal of the residues such as slag or fly ash (in some cases slag can be used in road construction). Possible additional costs for extra waste handling (e.g. segregation of unwanted waste fraction such as inert material) should also be considered. The collection of the waste is not addressed here, but is crucial to be organised and financed properly to achieve high rates of utilisation.
The specific investment and operation costs per ton of waste decrease as the capacity of the plant and the utilisation rate increases. Therefore, the plant capacity should be preferably higher than 100'000 tons per year to achieve optimal economies of scale together with average collection distances.

Revenues: The derived revenues from energy sales depend on the prices for electricity and process heat, the efficiency of the plant and the LCV of the waste. Other incomes from recovered materials can in general be neglected. As these market revenues alone will not be sufficient, additional gate fees or subsidies are required to cover the full costs.

Cost estimate of MSWI in industrialised and emerging countries – figures are a rough orientation only						
Incineration Capacity: 150'000 t/a	Initial Investment	Capital costs per ton of waste input	O&M costs per ton	Total cost per ton	Revenues from energy sales per ton	Cost to be covered per ton waste input
Cost Basis in the EU (advanced technical set-up, 2 furnace lines)	135 – 185 million EUR	80 – 115 EUR/t	180 EUR/t	260 – 295 EUR/t	60 EUR/t (heat and electricity) 27 EUR/t (electricity)	200 – 235 EUR/t
Emerging country cost basis (basic technical set-up, 1 furnace line)	30 – 75 million EUR	22 – 55 EUR/t	20 – 35 EUR/t	42 – 90 EUR/t	2 – 10 EUR/t (electricity)	40 – 80 EUR/t

Table 2: Example of individual cost estimates of MSWI on industrialised and emerging country cost basis. Costs are derived from Swiss MSWI with a high technical standard and were adjusted to MSWI with a basic set-up for emerging countries. E.g. investment costs are assumed 20 – 40% of Swiss costs, maintenance and auxiliary materials 20 – 50%, staff and disposal costs for slag 10-20%, and insurance costs about 50%. Both standards must fulfill national and international emissions standards. The main differences are architectural design, number of furnace lines, level of automatization and the quality of materials applied in the plant. Assumptions for estimations: utilisation rate 100% over life span of 15-20 years, interest rate 6% per year.

3.1.7 CONCLUSIONS AND REQUIREMENTS

Incineration should generally only be considered as a feasible option if the following aspects can be guaranteed:

- An efficient waste management system has been in place for a number of years and present scarcity of land requires alternative solution to SLF for waste fractions for which recycling is not feasible;
- The basis for an adequate environmental monitoring system exists;
- Emission standards and other environmental prescriptions are met;
- Financial means to cover additional costs compared to landfilling should be ensured;
- The supply of combustible MSW should amount to at least 100,000 t/year;
- The LCV must be, on average, at least 7 MJ/kg and never fall below 6 MJ/kg;
- Slag can be used after processing in road construction. For a secure and environmentally sound disposal of the fly ash secure land filling has to be ensured;
- Skilled staff can be hired and retained;
- The community living next to the site of a planned MSWI is engaged with and their interests are considered from the very beginning. Transparent communication and adequate engagement are a pre-condition.

3.2 Co-processing

Co-processing is the use of waste derived materials to replace natural mineral resources (*material recycling*) and/or traditional fossil fuels such as coal, fuel oil and natural gas (*energy recovery*) in industrial processes. Co-processing is applied worldwide mainly in the cement industry and in thermal power plants; in a few cases it is also applied in the steel and lime industry. In thermal plants where only energy recovery takes place this is called co-incineration. In the European cement industry, the thermal substitution rate of traditional fuels by waste can reach up to 80% in certain facilities (averaged over the year), while the average substitution rate across the EU amounts to about 39% [16]. Co-processing in cement plants has also become a wide-spread part of waste management systems in a number of developing and emerging countries. Nevertheless, the share of MSW used in co-processing is still low compared to special waste streams such as used tires, hazardous industrial waste, contaminated soil, biomass residues or sludge from wastewater treatment plants.

Cement plant with co-processing functionality (left), rotary cement kiln (centre) and output clinker (right).

3.2.1 TECHNOLOGY DESCRIPTION

Co-processing requires relatively homogenous waste streams with a defined characteristic to ensure controlled combustion. Through different pre-treatment processes (pre-processing) waste can be transformed to so-called refuse derived fuel (RDF), the acronyms AFR (alternative fuel and raw materials) and SRF (solid recovery fuel) are also used. In Figure 6, the flow chart of a Mechanical Biological Treatment (MBT) plant is presented as an example of pre-processing municipal solid waste to RDF.

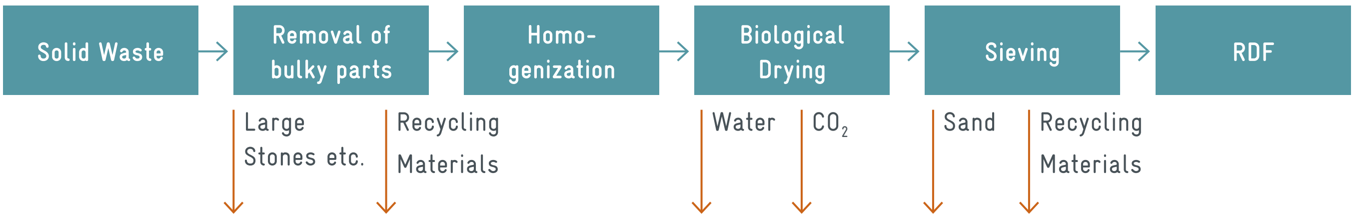


Figure 6: Generic process flow of MBT for the generation of RDF [17]

RDF is typically fed to the combustion process with a separate dosing system. Co-processing in cement kilns has the advantage that the clinker reactions at 1450°C allow a complete incorporation of ashes and in particular the chemical binding of metals into the clinker material. Toxic organic compounds are completely destroyed in the flame at higher temperatures of >2000°C. Direct substitution of primary fuel in the production process represents a significantly more efficient energy recovery than other WtE technologies, typically achieving 85-95% depending on waste characteristics.

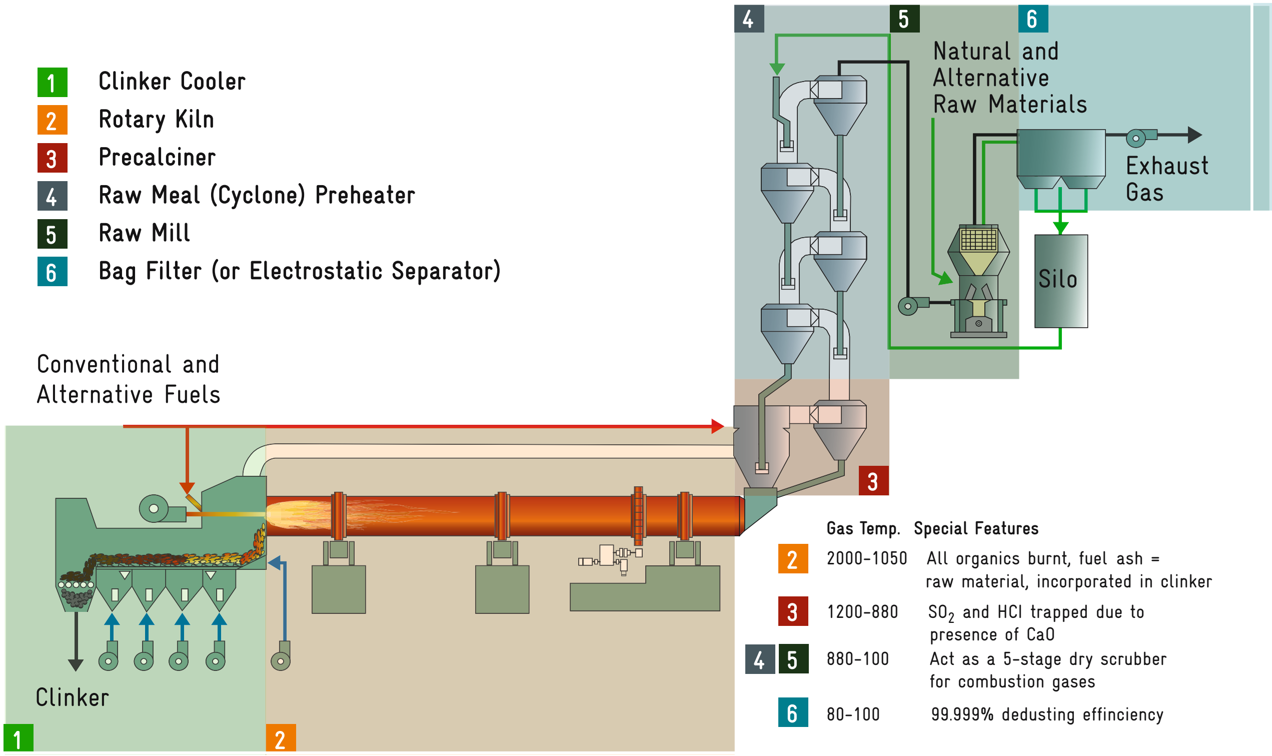


Figure 7: Components of a cement kiln form the type pre-calciner and its special characteristics [18].

3.2.2 SUITABLE WASTE

The suitability of waste for co-processing depends on its characteristics and the type of industry where it is applied. RDF usually refers to the segregated high calorific fraction of MSW, commercial or industrial process wastes.
A high content of chlorine or mercury in the waste can cause operational or environmental problems. Therefore PVC-plastic residues, for example, are not suitable for co-processing. Quality standards define the characteristics of RDF such as the content of trace metals, chlorine and sulphur. A calorific value of RDF of about 10 - 15 MJ/kg is desirable for economically sound operation [19].

3.2.3 OPERATIONAL ASPECTS

Safe and responsible use of waste requires careful selection of feeding points in the kiln system as well as comprehensive operational control according to the specific waste characteristics and volumes. Its application should not negatively affect smooth continuous kiln operation, product quality, or the site's environmental performance. Therefore, stable waste quality and feed rate must be assured. Delivery controls in routine operations must be carried out frequently for pre-processing of waste or RDF production. Operational personnel must be adequately trained according to the specific needs and to the nature of the wastes or RDF. Operational health and safety must be well developed and frequent interactions with environmental authorities, the municipality, neighbouring communities and other stakeholders be maintained. Cement plants often belong to international groups which can provide internal knowledge and experts for plant operation. For co-incineration in thermal power plants it is recommended to use RDF with well-defined characteristics and composition.



Processed RDF (left), conveyer belt in RDF production facility (centre), inside the cement kiln (right).

3.2.4 ENVIRONMENTAL ASPECTS

Through material and energy recovery, co-processing can contribute to the reduction of the overall environmental impacts of cement production, which is intensive in resource consumption and causes several emissions to the air that need to be monitored and reduced below legally prescribed limits through appropriate techniques. Potential emissions from cement kilns include dust, nitrogen oxides (NOx) and sulphur dioxide (SO_2) as well as dioxins and furans, carbon oxides (CO, CO_2), volatile organic compounds, hydrogen chloride (HCI), hydrogen fluoride (HF) and heavy metals. In order to ensure environmentally sound co-processing of RDF in cement kilns, cement plant operators need to adhere to certain principles such as those outlined by the Basel Convention (2012) [20], the WBCSD (2014) [21], or GTZ/Holcim (2006) [18]. When using RDF, the emissions need to be the same or lower than without RDF use. For this purpose, state-of-the-art technology and procedures such as the feeding of RDF directly into high-temperature zones of the kiln are mandatory. The design of modern cement plants often is already in compliance with international standards. Where this is ensured, the requirements to upgrade emission control for co-processing are low. Furthermore, the selection of suitable waste, its adequate transport and storage as well as its preparation to RDF is crucial to minimize environmental impacts. The final cement products have to be tested for potential leaching of heavy metals before they are used in buildings, roads or other constructions.

3.2.5 LEGAL ASPECTS

Many countries already have a legal framework for co-processing. The existence of appropriate regulation represents a pre-condition for successfully applying co-processing in cement kilns. Rules for co-processing should be part of the environmental and waste legislation. Emission standards, technical specifications for co-processing as well as a permission process need to be defined. Due to the high technical complexity of co-processing, effective enforcement and regular inspections by public authorities require adequately qualified and equipped staff members. Further orientation for legal requirements and the role of public authorities can be accessed via the above-mentioned guidelines of the Basel Convention (2012) [20], the WBCSD (2014) [21] or GTZ/Holcim (2006) [18].

3.2.6 ECONOMIC ASPECTS

The main objective of a cement plant operator investing in co-processing is to reduce fuel and raw material costs. It means that the investment decision depends on the volatile market prices for coal, pet coke, natural gas and raw materials or other economic incentives. The higher the costs for primary fuels or raw materials, the more attractive such an investment will be.

Pre-processing, RDF production and co-processing costs are affected by:

- Project planning and permit costs;
- Capacity of installations for waste handling, preparation and dosing of the waste to the cement kiln;
- Operational health and safety measures and emissions control;
- Capital costs, taxes, insurance;
- Plant utilization rate;
- Spare parts, maintenance and auxiliary materials;
- Lab analysis to determine waste and RDF composition;
- Administration, personnel, salaries.

Table 3 depicts ranges for the main cost items for co-processing.

Cost estimate of a cement co-processing plant in developing countries – figures are a rough orientation only						
Initial Investment	**Capital costs per ton & year of waste input**	**O&M costs per ton**	**Total cost per ton**	**Revenues* per ton**	**Cost** per ton waste input**	**Remark**
5 – 25 million EUR including pre-processing	10 – 25 EUR/t	10 – 20 EUR/t	20 – 45 EUR/t	1 – 5 EUR/t	19 – 40 EUR/t	LCV 10 MJ/kg, pre-sorted and capacity of 50,000 t/a, 20y operation, 6% p.a. IR

* Revenues are in form of substitution of fossil fuel. No subsidies.

** Costs to be covered by gate fee, subsidies etc.

Table 3: Example of comparative individual cost elements of Co-processing derived from GIZ-Holcim partnership experiences

The costs indicated are dependent on the local situation and it is difficult to draw broad conclusions from the available information on financial requirements, which differ quite substantially and partly depend on the specific business cases of different companies. Initial investments primarily include pre-processing to generate a homogenous mixed RDF, introduction of conveyer belts and new technical functions to enable input of RDF to the combustion process, as well as storage rooms and safety measures to e.g. reduce risk of fire. Newer cement plants can require fewer modifications if they have been built with the future co-processing of waste in mind. An example of a co-processing project in the cement industry under the Clean Development Mechanism (CDM)[3] calculates with investment costs of 3 million EUR if up to 60,000 metric tonnes per year of different waste types are used and about 25% of the primary energy input is substituted. 50,000 metric tonnes (83%) of the waste are MSW.
The project calculates with costs of 45 EUR per metric tonne of treated MSW [22]. One of the biggest cement producers worldwide considers that a minimum “gate fee” of 20 to 30 EUR per ton of MSW is needed to make investments in a pre-processing facility and final co-processing in cement plants feasible.

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3 CDM is still a legal and international recognized instrument but lost its relevance due to an oversaturation of CO_2 credits on the global market. However, new carbon credit schemes are emerging on bi- or multilateral level (e.g. Green Climate Fund) or on the national and international market (e.g. NAMA-Facility, Nationally Appropriate Mitigation Actions)

3.2.7 CONCLUSIONS

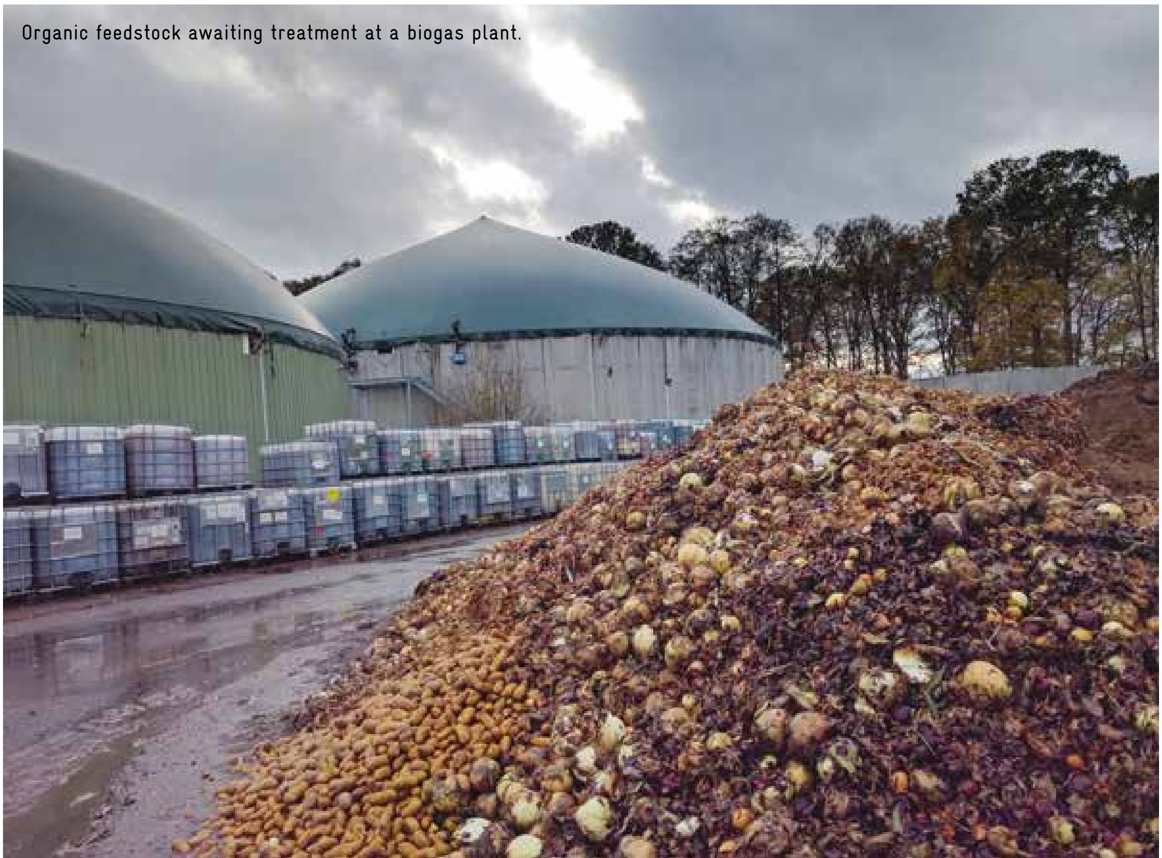
Many developing and emerging countries have collected – mostly positive – experiences with state-of-art co-processing during the past 10 years. It is a WtE technology that has already gained wide-spread acceptance amongst business communities and policy makers. Although its application is at present focused on specific high caloric industrial and hazardous waste, a few successful examples exist also for the non-recyclable fraction of municipal solid waste. A limiting factor consists in the transportation of waste from municipalities to the cement plant. Distances above 200 km make the entire operation financially and ecologically unattractive. Another limiting factor is the economic attractivity of alternative fuels due to the volatility of fossil fuel prices as well as the low revenues from waste disposal fees in most municipalities in developing and emerging countries.

3.3 Anaerobic Digestion for Biogas Production

Anaerobic digestion (AD) is the decomposition of organic matter through microorganisms in the absence of free oxygen. AD occurs naturally under oxygen deprived conditions such as some lake sediments and can be used under controlled conditions to produce biogas. For that purpose a gas-tight reactor, a so-called anaerobic digester, is used to provide favourable conditions for microorganisms to turn organic matter, the input feedstock, into biogas and a solid-liquid residue called digestate. The digestate can be used as organic fertiliser when the feedstock is source separated and non-contaminated organic waste. Biogas is a mixture of different gases which can be converted into thermal and/or electrical energy. The flammable gas methane (CH_4) is the main energy carrier in biogas and its content ranges between 50 – 75% depending on feedstock and operational conditions [23]. Due to its lower methane content the heating value of biogas is about two thirds that of natural gas (5.5 to 7.5 kWh/m^3).

AD using small-scale digesters has a long tradition in developing countries to use the energetic content of organic residues in rural contexts. Primary feedstock input is from agriculture, especially animal manure, which is relatively easy to operate and can be well applied at small scales. At the municipal scale, AD is receiving increasing attention as a possible option for energy recovery from waste in the urban context. However, the operation of biogas plants from heterogeneous MSW is a big challenge in terms of operational, safety and financial requirements. As a consequence there are very few successful examples of biogas from MSW in developing countries. A major challenge to successful AD operation is being able to guarantee a consistently well separated organic waste fraction. In many countries organic waste is often mixed with inorganic matter such as plastics, metals and other contaminants which often hampers the success of AD at larger scales. As opposed to other WtE plants it can be stated that small scale biogas plants are an option and can be well applied in developing countries.

Organic feedstock awaiting treatment at a biogas plant.

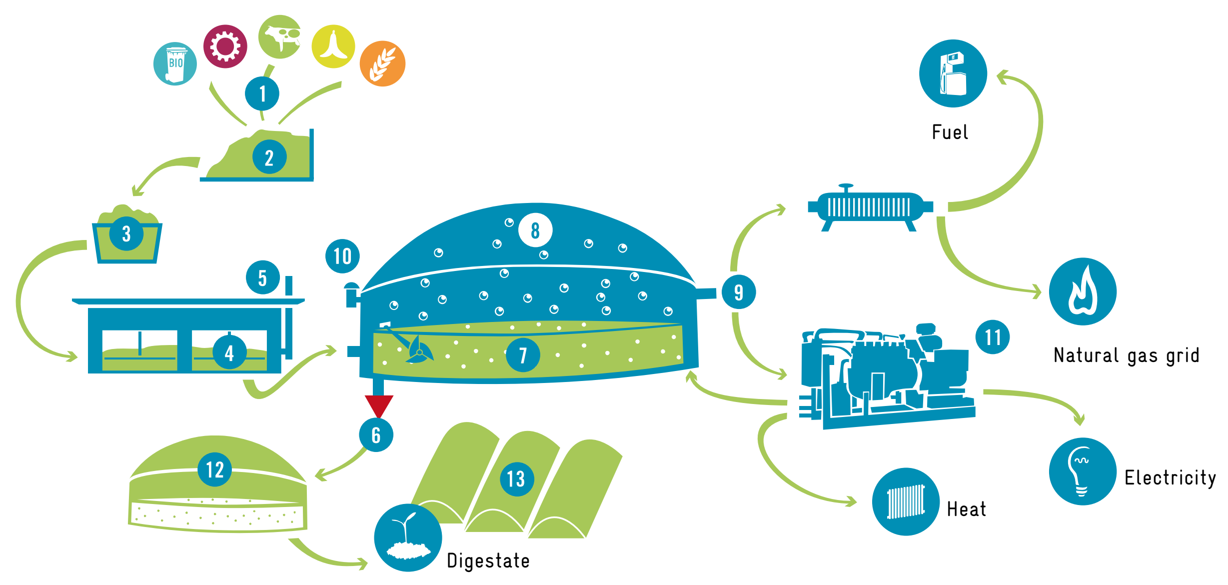


3.3.1 TECHNOLOGY DESCRIPTION

A large number of different anaerobic digester designs exist worldwide with varying levels of complexity. According to [23], [24] AD can be classified by:

- **Mode of feeding**: Batch or continuous feeding
- **Temperature range**: Psychrophilic (< 25°C), mesophilic (35-48°C) and thermophilic (> 50°C) conditions, where only the latter two are considered economically viable. Thermophilic conditions are recommended when risk of pathogens is prevalent. Alternatively a pasteurisation at 70°C for 1 hour or a thermophilic composting can be used to inactivate pathogens for mesophilic systems.
- **Reactor type**: Continuously stirred tank reactors are common for liquid feedstock such as catering waste or wastewater or industrial sludge from food processing while plug-flow and batch digesters are used for solid feedstock. Although solid feedstock can be dewatered to be used in continuously stirred tank reactors.
- **Number of stages**: One to multi-stage digestion is possible.

Biogas can be directly used to produce heat or converted to heat and electricity using a combined heat and power plant, the latter usually after desulphurization and drying. Another option is to upgrade biogas to bio methane with approximately 98% methane content, which can be used as a substitute for natural gas [23]. Figure 8 shows the process of biogas production through anaerobic digestion from organic waste and manures. The generated biogas can be utilized for example in a Combined Heat and Power (CHP) generator.



1 Different feedstocks
2 Reception and waste storage
3 Feedstock preparation, processing, sorting and cleaning
4 Enclosed building for putrescible waste preparation
5 Biofilter to reduce smells and organic compounds
6 Sanitation Unit
7 Digester
8 Gas Storage
9 Gas cleaning system
10 Safety Equipment (pressure relief devices, safety valves, gas flares etc.)
11 Combined heat and power unit
12 Digestate storage
13 Digestate Upgrading

Figure 8: Components and end-uses of an anaerobic digestion plant. Image source: Fachverband Biogas [25].

3.3.2 SUITABLE WASTE

AD is only suitable for processing organic matter, i.e. biomass. The content of fibrous material such as hemi-cellulose and lignin contained e.g. in straw and woody plants should usually be rather low, as these are degraded slowly through AD. Apart from using organic 'waste' biomass such as agricultural residues or organic fractions of MSW it is possible to use specially grown energy crops such as maize for biogas production. However, this can lead to potential conflict with food production, and is thereby not the subject of this guide, which instead considers AD only with organic waste matter from municipal waste. The inclusion of inorganic or hazardous matter is not desired in the process and can constrain microbial degradation, obstruct operation e.g. by clogging of pipes by plastic materials and/or limit the usability of the digestate as organic fertilizer.

Municipal organic waste such as source-separated household, market and garden waste can be considered a suitable source of AD feedstock. Furthermore, the co-digestion with agricultural residues, sludge from wastewater treatment plants or organic industrial or commercial waste can increase feedstock availability and thereby economic feasibility. The use of bio-waste from households is more sophisticated than the use of other feedstock like energy crops, industrial and commercial wastes, animal by-products or vegetable by-products [26].This is due to the fluctuation of the composition of the feedstock used over the year and because of the possibility of the high amounts of impurities. Methane and energy yields from AD vary strongly between different feedstock (indicative examples in Table 4).

Feedstock	Methane yield [Nm^3 CH_4 per t_{wet}]	Energy yield [MJ per t_{wet}]
Municipalities		
Wastewater	15	570
Kitchen and garden waste	40-100	1,510-3,780
Industries		
Fruit waste	60	2,270
Slaughterhouse waste	50	1,890
Agriculture		
Cattle manure	32	1,210
Grass	90	3,400

Table 4: Indicative examples of methane and energy yields of selected organic waste feedstock through AD (adapted from [23] [27]) with methane yields in norm m^3 (Nm^3, at 0 °C, 1.01325 bar and relative gas humidity of 0%) per ton wet weight (t_{wet}) of feedstock and 37.8 MJ per Nm^3 CH4 (higher heating value).

3.3.3 OPERATIONAL ASPECTS

Important operational aspects include the following:

- **Availability and composition of organic waste feedstock**: composition and amounts of organic waste can change significantly depending on the season, primarily driven by availability of agricultural products and their residues. This needs to be considered in planning anaerobic digesters and include dimensioning as well as the possibility of feedstock storage facilities when feedstock availability is higher than plant capacity.
- **Temperature**: The growth and reproduction of microorganisms is faster under higher temperatures, provided there are no other limiting conditions. In most cases, a mesophilic temperature range between ca. 35-48°C is considered most stable. Operation at higher temperatures in the thermophilic range >50°C can eliminate pathogens and help decrease reactor volumes, but generally requires heating and insulation. In colder climates psychrophilic AD has been successfully applied for small-scale digesters (e.g. [24]), however it may not be economically viable for larger scale digesters due to the need for heating and insulation.

» **Organic loading rate (OLR)**: OLR quantifies the amount of feedstock which a specific reactor can degrade per unit of time.

» **Carbon**: Nitrogen ratio (C:N): The relative abundance of carbon and nitrogen is an essential parameter of microbial growth and should be in the range of 16-25 for anaerobic digesters.

3.3.4 ENVIRONMENTAL ASPECTS

The conversion of organic waste to biogas can be associated with a number of environmental benefits. Biogas usually replaces another form of energy, in many cases either a fossil fuel or wood. If a fossil fuel is replaced, biogas from organic waste reduces the emission of additional greenhouse gases to the atmosphere, because carbon contained in biomass originates from atmospheric CO_2. If firewood is replaced, as is the case in many rural households, biogas substitute can reduce deforestation from firewood collection. AD digestate used as an organic fertilizer can replace energy intensive mineral fertilizers. Using the digestate as fertiliser is however also dependent on attaining a high quality, and ensuring this is not contaminated with e.g. metals or pathogens.

A possible environmental hazard is the leakage of biogas from improperly operated digesters. Since the global warming potential of methane is approximately 21 times higher than that of CO_2, such leaks must be avoided and correct operation assured. The leakage of digestate to water bodies must also be avoided, as this can disrupt local ecosystems.

3.3.5 LEGAL ASPECTS

AD is already widely applied in many developing countries at small scale and can generally be embedded into national legal and policy frameworks. However, for large-scale AD implementation in urban contexts additional legal regulations have to apply including safety regulations and concerns about odour nuisance. Unfortunately, those regulations are rarely in place and/or enforced in developing countries, which might negatively affect immediate implementation of this WtE technology. A legal framework to set minimum quality standards of digestate is also important to avoid potential risks in agricultural use. For guidelines on biogas safety aspects see the publication: Biogas Safety First! available at www.biogas-safety.com.

Organic waste must be well-separated at source.

Gas flares safely release excess pressure.

3.3.6 ECONOMIC ASPECTS

The revenues of AD depend very much on the quality of the feedstock. Contamination with inorganic substances increases separating costs and diminishes potential benefits derived from process residues which could be used as fertilizer in agriculture. Direct use of the biogas requires minimum additional investments. With further investments biogas can be upgraded to bio-methane, or converted to heat and power. In Table 5 an example of comparative individual cost elements of anaerobic digestion of pre-sorted MSW with a capacity between 50,000 and 150,000 metric tons of organic waste input per year is shown. The data were derived from [28], [29] and adjusted to conditions in developing countries (lower salary costs). The estimated net costs of 14 to 18 EUR per metric ton of organic waste input indicates that with energy sales alone the total cost cannot be covered.

Cost estimates of an anaerobic digestion plant in developing countries – figures are a rough orientation only						
Initial Investment	Capital costs per ton & year of waste input	O&M costs per ton	Total cost per ton	Revenues* per ton	Cost** per ton waste input	Remark
12 – 20 million EUR	12 – 19 EUR/t	10 – 15 EUR/t	22 – 34 EUR/t	8 – 16 EUR/t	14 – 18 EUR/t	capacity 50,000 - 150,000 t/a, 20y operation, 6% p.a. IR

* Revenues are in form of substitution of fossil fuel. No subsidies

** Final costs to be covered by gate fee, subsidies etc.

Table 5: Example of comparative individual cost elements of anaerobic digestion derived from [28], [29] and adjusted to conditions in developing countries.

Benefits from the anaerobic digestion of organic waste can derive from biogas as an energy source as well as digestate as fertilizer. Benefits from biogas production depend primarily on the price of energy it replaces. The possibility to use digestate as organic fertilizers and its monetary value depends on, among other things, the digestate quality, local or regional needs as well as acceptance by farmers [24]. Indirect benefits derive from the significant reduction of waste mass to be deposited at dumpsites or sanitary landfills, especially in developing countries.

3.3.7 CONCLUSION

The organic waste fraction of MSW in developing countries is usually much higher than in industrialised countries and agricultural waste is also often available for use as a co-substrate. Furthermore, many developing countries are located in warm climates. These conditions make AD particularly interesting.

Current waste management practices, particularly the missing separation at the source, hinder the uptake and stable operation of AD technology. Especially in the urban context the legal framework in terms of safety regulations needs special attention. Considered a low-tech solution, requirements in terms of operation and manpower are often underestimated, leading to failures in operation, lower biogas yields than expected and inferior digestate quality for agricultural application. Lastly, financial revenues from biogas (electricity, heat/cold or bio-methane) and digestate production from organic waste and its sale cannot be expected to exceed production costs when investment costs are fully accounted for, especially without the existence of a special feed-in tariff for electricity/bio-methane sold to the electricity or natural gas grid. Integrated into thorough MSW management planning, which should include waste segregation at household level, AD may complement other MSWM technologies and practices.

3.4 Capturing of Landfill Gas

Landfill Gas (LFG) Capture represents a different type of WtE technology compared to the others presented in this guide. It is to be seen as an essential component to partially mitigate negative climate impacts from the operation of sanitary landfills (SLF). Sanitary landfilling is an internationally adopted and accepted practice in developing countries and in many cases the only option to treat and store the collected waste in a controlled manner. Although SLF are an improvement on uncontrolled and open dumping, they also have negative long term environmental impacts such as the emission of methane landfill gas with high global warming potential to the atmosphere. Others include the loss of valuable resources in landfilled waste as well as the the presence of odorous and toxic compounds. The methane in LFG is formed by the anaerobic digestion of organic matter in the landfill body which can be seen as an over-dimensioned bioreactor. In order to reduce greenhouse gas emissions from landfill sites into the atmosphere the capturing of methane gas is essential. This is possible through LFG capture, however significant losses occur in the start-up phase of a landfill site, before the methane capturing system is installed and in operation. When in operation it is still not possible to capture all of the gas emitted by the landfill. Over 200 LFG collection projects were successfully realised under the Clean Development Mechanism of the Kyoto protocol for mitigation of climate gas emissions [30].

Landfill sites from above (left) and in construction (right).

3.4.1 TECHNOLOGY DESCRIPTION

LFG consists of 45 - 55% methane gas and is therefore suitable as a fuel for heat or power generation, combined heat and power generation or as fuel for transportation. The rest is mainly CO_2. The yield of LFG depends on a number of factors:

- Composition of the waste;
- How fresh waste is placed and compacted;
- Level of compacting and height of the individual layers;
- Water content in the landfill;
- Climate;
- Technical features for capturing the methane gas in the SLF.

An analysis of LFG generation in Thailand shows that at different landfills 1.9 to 5.5 times more LFG was generated in the wet season than in the dry season [31].

Various LFG capturing technologies are available and can be added to operating or closed SLF. All collect LFG from waste while at the same time avoiding the intrusion of water and air into the system. To collect the LFG, perforated pipes are inserted into the waste to collect the LFG. These pipes can be installed either vertically or horizontally. The gas enters the perforated pipes and is transferred to a gas purification system to remove hydrogen sulphide in particular. After cleaning, the gas can be used (see Figure 9).

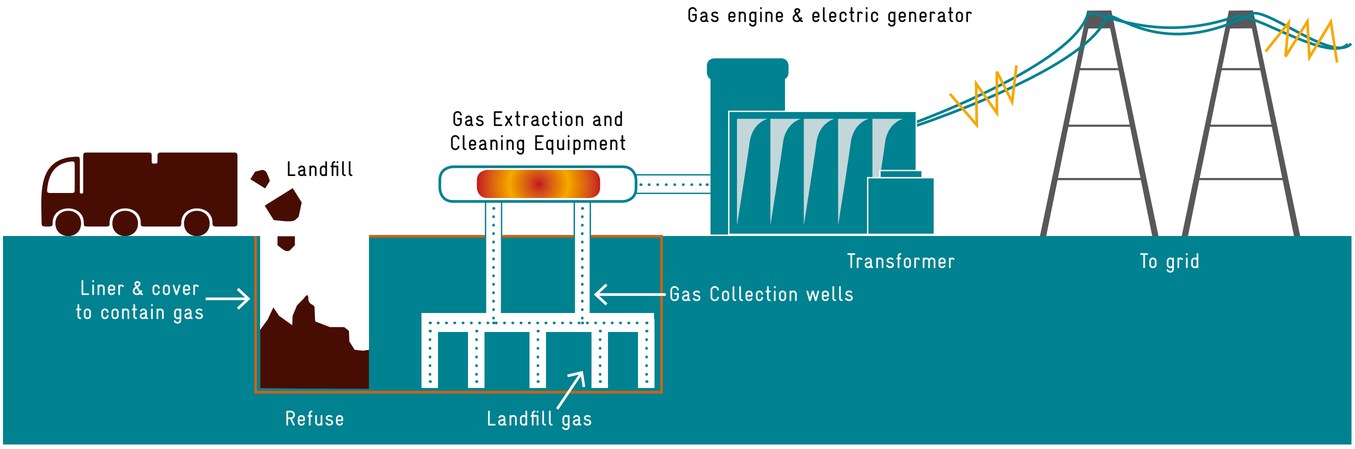


Figure 9: Components of landfill gas capturing system with electricity production [32].

3.4.2 SUITABLE WASTE

LFG capture projects require a high content of reactive organic waste in the body of the landfill. A high content of mineral waste or slow digesting organics (e.g. wood) reduce the yield.

3.4.3 OPERATIONAL ASPECTS

SLF operators must ensure that there is no significant risk of gas migrating out of the landfill through the subsurface or accumulating outside the landfill in a mixture that could be explosive or cause asphyxiation. They must ensure that the collection, treatment and use of LFG minimize the release of gases. Audits of the gas collection system should be undertaken annually to assess the efficiency of the system.

3.4.4 ENVIRONMENTAL ASPECTS

The collection and combustion of methane from LFG contributes to the mitigation of greenhouse gas and other toxic emissions. If LFG is used to substitute fossil fuels such as coal or oil in combustion processes or as a fuel to substitute diesel in transportation it also contributes to improved air quality. But international experience has shown additional disadvantages of LFG besides the known risks of sanitary landfills:

» Theoretical gas production and the real capturing of gas do not coincide. In many cases real gas yield is well below expectations, which means that part of methane escapes to the environment. United States Environmental protection Agency estimates a collection efficiencies range from 60 to 85% [33]. However, many SLF in developing countries reach a capturing rate of hardly 50% due to reduced technical standards and cost limitations. Comparing the amount of gas actually captured and collected in relation to the total gas emitted from a SLF over its entire lifespan, the efficiency rate drops further to less than 20-30%.

» LFG is generated over a period of 30-50 years, a time horizon which goes beyond the operation of a SLF. The question of who operates and maintains the gas system often remains unanswered.

» Leakages in the LFG system are a security risk as the escaping gas might be accumulated in neighbouring buildings and might lead to explosions.

3.4.5 LEGAL ASPECTS

In most cases no specific laws exist on landfill gas collection; appropriate legal conditions support its development through local waste legislation on how to plan and operate sanitary landfill sites.

3.4.6 ECONOMIC ASPECTS

In the scheme of the Clean Development Mechanism (CDM) many LFG capturing projects with power generation were realised in developing countries. Without additional revenue from certified emission reduction for CO_2 many LFG projects most probably would not have been implemented due to economic reasons. Table 6 gives an orientation on the costs for LFG capture based on CDM project information from Brazil [34] and China [35]. The costs depend heavily on the design and topography of the SLF. The costs for building and operating the SLF itself are not included.

Cost estimates of landfill gas collection applied to sanitary landfills in Brazil and China CDM projects						
Initial Investment	Capital costs per ton & year of waste input	O&M costs per ton	Total cost per ton	Revenues* per ton	Cost per ton waste input	Remark
6 million EUR (CDM-Brazil)	0.8 EUR/t	0.8 EUR/t	1.6 EUR/t	2.4 EUR/t	- 0.8 EUR/t	Capacity about 390,000 – 850,000 t/a, 21y operation, 8% and 12% p.a. IR
5.3 million EUR (CDM-China)	1.4 EUR/t	0.3 EUR/t	1.7 EUR/t	3.4 EUR/t	- 1.7 EUR/t	

* From the sale of gas/power and including revenues from CDM credits in the given projects

Table 6: Example of comparative individual cost elements of a LFG capture project with power generation derived from CDM projects in Brazil [34] and China [35]. In each case investment costs are for a complete plant generators. Costs for building and operating SLF are not included.

3.4.7 CONCLUSIONS

Collecting LFG is not the main reason for running a sanitary landfill but LFG should be considered as a by-product of SLF operation. It is well known that SLFs have many disadvantages such as groundwater and air contamination, generation of leachate to be treated and bad odours. Therefore landfill gas should not be considered as a primary WtE technology but as a compulsory task for those cities which have to run SLF as they have no other choice. LFG collection is seen as an opportunity for existing landfills rather than for new WtE projects. LFG capture can mitigate some of the climate impacts of SLF, however the low efficiency rate of gas capturing over the entire life span of shows the difficulty of mitigating climate impacts of SLF.

3.5 Alternative Technologies: Pyrolysis and Gasification

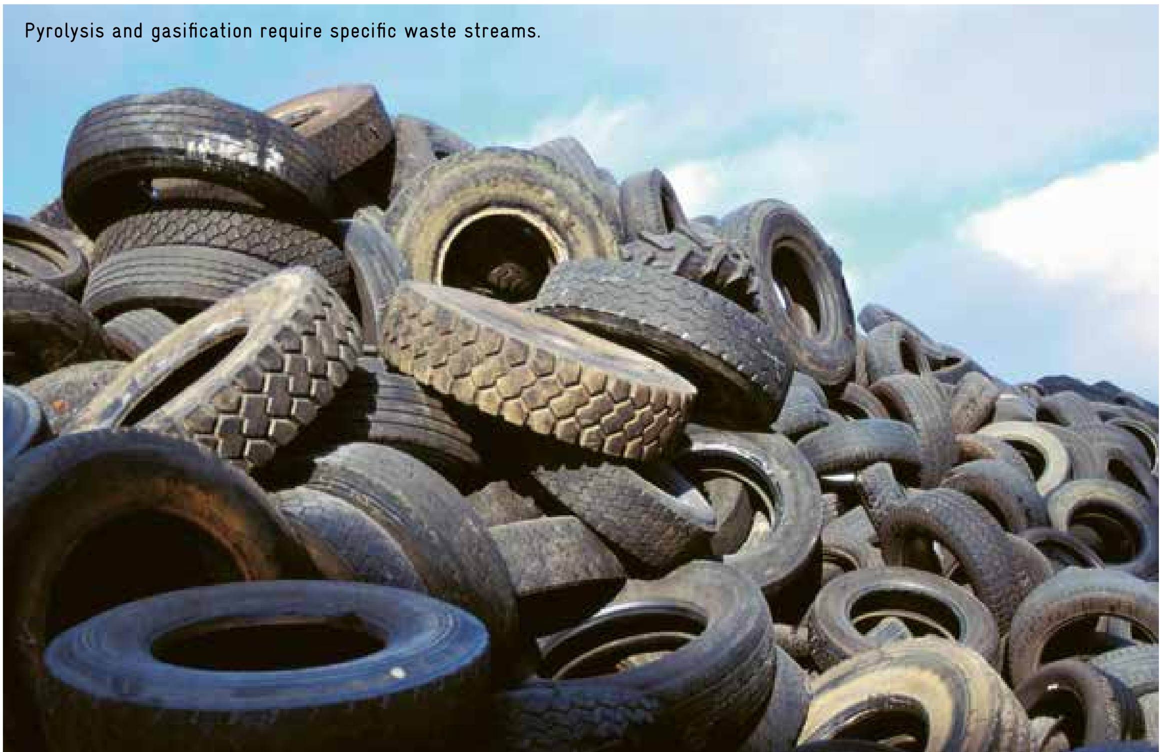
Over the last 40 years the development of so called „Alternative Technologies" (AT) for thermal treatment of waste has been in two main steps. The first step in the 1970s and 1980s was characterized by high motivation and potential of innovation to develop a comprehensive and efficient technology for waste treatment with maximum generation of process products and minimum negative environmental impacts. The second step in the mid-1990s was dominated by marketing strategies. Gasification and pyrolysis, later also plasma pyrolysis, were considered a technically and financially viable alternative to waste incineration and were labelled with the quality of being a non-pollution technology, compared to incineration. At present, no plant for the treatment of MSW is in operation on a larger scale in Europe, Africa or Latin America and the few plants in Asia (mainly Japan) and the USA are operating as an integrated element of a more complex MSWM system or for specific waste streams only. The advanced technology and operating requirements, highly specific waste input needs and high upfront capital costs make this technology difficult to apply at scale.

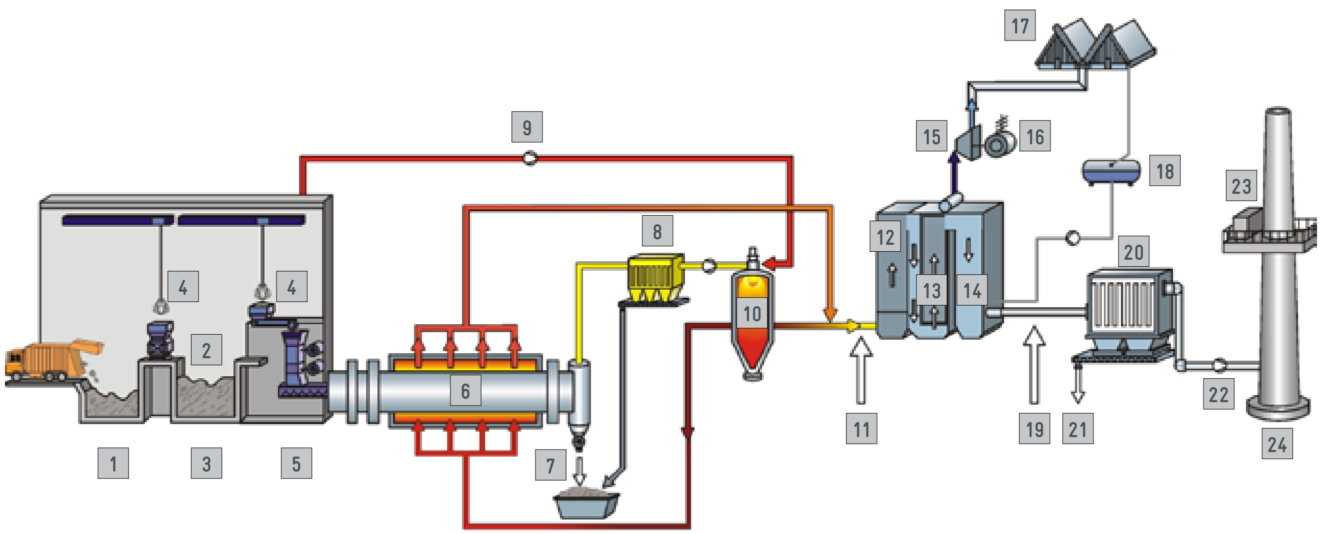
Like waste incineration, the objective of AT is to treat waste to reduce its volume and hazards, whilst capturing (and thus concentrating) or destroying potentially harmful substances. The process also provides a means to enable recovery of energy, mineral and/or chemical content from waste in the form of useful "recycling" products such as syngas, oil, char or coke (see Figure 10).

3.5.1 TECHNOLOGY DESCRIPTION

Pyrolysis/Gasification is the degassing of waste under oxygen controlled conditions, during which pyrolysis gas and a solid coke are formed. The heat values of pyrolysis gas typically lie between 5 and 15 MJ/m^3 based on municipal waste. In a broader sense, "pyrolysis" is a generic term including a number of different technology combinations that constitute, in general, the following technological steps:

- **Smouldering process**: Formation of gas from volatile waste particles at temperatures between 400 and 600°C
- **Pyrolysis**: Thermal decomposition of the organic molecules of the waste between 500 and 800°C resulting in formation of gas and a solid fraction
- **Gasification**: Conversion of the carbon share remaining in the pyrolysis coke at 800 to 1000°C with the help of a gasification substance (e.g. air or steam)
- **Incineration**: Depending on the technology combination, the gas and coke are combusted in an incineration chamber.


Pyrolysis and gasification require specific waste streams.



1 Coarse Refuse Bunker
2 Rotary Shears
3 Fine Refuse Bunker
4 Overhead Crane
5 Feeding System
6 Pyrolysis Kiln
7 Discharging System
8 Hot Gas Filter
9 Combustion air fan
10 Combustion Chamber
11 Selective non-catalytic reduction
12 Evaporator
13 Superheater
14 Economiser
15 Turbine
16 Generator
17 Condensor
18 Feed Water Tank
19 Additive Metering Hopper
20 Fibrous Filter
21 Filter Dust Discharging
22 Induced Draught Ventilator
23 Emissions Monitoring System
24 Stack

Figure 10: Components of a pyrolysis plant for specific solid waste treatment [36]

Other processes have been developed that are based on the de-coupling of the phases which also take place in an incinerator: drying, volatilization, pyrolysis, carbonization and oxidation of the waste. Some of these developments met technical and economic problems when they were scaled-up to commercial sizes, and are therefore no longer pursued. Some are used on a commercial basis (e.g. in Japan) and others are being tested in demonstration plants throughout Europe, but still have only a small share of the overall treatment capacity when compared to incineration and are applied for selected waste only.

3.5.2 SUITABLE WASTE

There are no successful experiences with the treatment of bigger volumes of mixed MSW due to its heterogeneous composition. For this reason pyrolysis might be an option for the final treatment of specific waste streams such as contaminated soil, clinical waste or mono hazardous industrial / commercial waste. It is not recommended for either mixed municipal waste, or for an environment in which robust and proven technologies are needed.

3.5.3 OPERATIONAL ASPECTS

Pyrolysis or gasification cannot be considered easy to handle stand-alone technologies but must be a component within an overall waste management system. Operation requires good understanding of the composition of the incoming waste and process knowledge. Experience has shown that trouble free operation of a pyrolysis plant requires highly skilled technicians.

3.5.4 ENVIRONMENTAL ASPECTS

The potential advantages of pyrolysis processes may include:

- Recovering the material value of the organic fraction e.g. as methanol;
- Increased electrical generation using gas engines or gas turbines;
- Reduced flue-gas volumes after combustion;
- Production of char or coke which can be used as fuel in power or cement plants.

3.5.5 LEGAL ASPECTS

It must be assumed that environmental legislation in most developing countries does not deal with the application of pyrolysis and gasification as combustion (or WtE) technology. This makes the entire process of impact assessment and operation licensing quite complicated and time consuming, if not impossible.

3.5.6 ECONOMIC ASPECTS

Due to high operation and maintenance costs the economics of AT can only be considered as acceptable if the process products (gas, coke) have a good market value. This depends very much on market conditions and the need for an end consumer (e.g. cement plant) close to the AT plant. Experiences from the last 40 years show that in addition to the technical challenges, pyrolysis and gasification companies often have to deal with economic challenges which led in many cases to shut downs in operation, since no adequate revenues could be obtained for the additional costs of product preparation. Compared to all other WtE technologies presented in this Guide, pyrolysis and gasification are the most expensive. Table 7 below gives an orientation on the costs for an alternative technology plant with an annual input of 150,000 – 200,000 tons.

Cost estimates of a pyrolysis/gasification plant in developing countries – figures are a rough orientation only						
Initial Investment	Capital costs per ton & year of waste input	O&M costs per ton	Total cost per ton	Revenues* per ton	Cost** per ton waste input	Remark
80 – 120 million EUR	35 – 45 EUR/t	30 – 40 EUR/t	65 – 85 EUR/t	2 – 5 EUR/t	63 – 80 EUR/t	Capacity 250,000 t/a, 20y operation, 6% p.a. IR

* From the sale of end-products

** Costs to be covered by gate fee, subsidies etc.

Table 7: Example of comparative individual cost elements of pyrolysis plant in Germany [37].

3.5.7 CONCLUSION

Future-oriented waste management concepts should fulfil economic and ecological needs. Within this context, pyrolysis or gasification of high calorific waste fractions can offer, in combination with power plants and industrial furnaces, an alternative technical solution, provided that it is mainly used for selected high calorific waste and waste fuels. The technical approach represents a possible choice within an already fully organized waste management system.

However, in most if not all developing countries the conditions do not exist in a municipal set-up which justifies the application of pyrolysis or gasification. In addition the relatively high operation and investment costs do not justify experimenting with a niche technology for very selective fractions which are seldom found in municipal waste.

4 DECISION MAKING SUPPORT MATRIX

4.1 Objective

Any WtE project is a complex undertaking and should be accompanied by a professional and thorough feasibility assessment. The decision matrix presented in this chapter seeks to assist in getting a first idea of the suitability of potential technologies for specific contexts and the various aspects decision makers should look out for in discussions with technology providers. It summarises the general framework conditions as applicable to each of the five technologies covered in this guide. The matrix has three objectives:

- To provide an overview of pre-conditions for building and operating a WtE technology
- To compare the suitability of the five presented WtE technologies for different framework conditions
- To offer a first orientation of whether an intended WtE technology is applicable, if further improvements to the overall waste management system are required or if the WtE technology does not fit.

The matrix consists of 12 essential parameters to consider in the local context when looking at going ahead with a WtE project. These are:

1. **Overall level of waste management**
2. **Composition of waste**
3. **Calorific value of MSW for thermal processes, organic content**
4. **Suitable quantities of waste for WtE**
5. **Efficient operation of waste facilities**
6. **Additional transportation time and distance for MSW to WtE plant**
7. **Marketing and/or final disposal of process residues**
8. **Legal framework & environmental requirements for WtE**
9. **Financing the management of MSW**
10. **Access to foreign currency**
11. **Access to energy end-users from WtE or RDF**
12. **Incentives for low carbon energy generation**

The parameters are partly taken from the World Bank's decision makers' guide [15] and modified to meet the needs of this guide. Each parameter is described in more detail in Annex A.

HOW TO USE THE DECISION MATRIX

For each of the twelve parameters listed above, the readers should assess their local conditions according to the options given horizontally from left (highly advanced) to right (very underdeveloped) in the matrix. The potential suitability of the five WtE technologies is shown by a different colour for each of the horizontally given local conditions:

GREEN
the WtE technology is most probably suitable.

YELLOW
more information and/or some improvements to local conditions may be required for successful planning and implementation of a WtE project.

RED
the WtE technology is not suitable. It is strongly recommended to improve or change the specific local conditions.

After assessing for the **twelve parameters**, the reader will have an overview of the suitability of each of the technologies for their local conditions. As an orientation, the number of red, yellow and green fields for each WtE technology can be interpreted as follows:

Matrix Totals	Is the technology suitable for my context?
• Nine or more green fields • All others yellow	**In principal the technology seems applicable.** However, parameters in yellow should be investigated in more detail and improvements should be initiated
• Less than nine green fields • All others yellow	**The technology might be suitable but the given conditions do not yet favour its application.** Decision makers should assess the given conditions in more detail before initiating a WtE project or focus on a technology which has more green fields.
• One or more red field	**KNOCK OUT CRITERIA: there are severe deficiencies when applying this technology.** All red highlighted conditions must be improved before initiating a project for the technology or select a technology which appears only in yellow and green fields.

The application of the matrix allows users to build a first transparent assessment of realistic WtE options for the near future. It gives an overview of the preconditions that require fulfilment in the targeted region for a WtE project and of the information gap for a more comprehensive evaluation. To gain further details on each parameter and its different values, please refer to the Annex A.

4.2 Decision maker's matrix

1. Overall level of waste management

1	Advanced waste management system which is based on waste streams (e.g. biomass, hazardous waste, recyclables) exists.	Systematic waste collection is organized. Some waste fractions (e.g. tyres, recyclables, biomass) are directed towards recycling and composting.	Systematic waste collection and disposal on landfill exist. Recycling is not organized systematically.	Absence of systematic waste collection, recycling and disposal.
	Incineration	Incineration	Incineration	Incineration
	Co-processing	Co-processing	Co-processing	Co-processing
	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion
	Landfill gas collection	Landfill gas collection	Landfill gas collection	Landfill gas collection
	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification

2. Composition of waste

2	Organic and non-organic fractions are collected separately. Hazardous & bulky mineral waste is treated separately	MSW or separate collected waste fractions are sometimes mixed with small fractions of mineral and hazardous waste	MSW is regularly mixed with fractions of minerals or hazardous waste	MSW is mixed with large amounts of mineral and hazardous waste
	Incineration	Incineration	Incineration	Incineration
	Co-processing	Co-processing	Co-processing	Co-processing
	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion
	Landfill gas collection	Landfill gas collection	Landfill gas collection	Landfill gas collection
	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification

3. Calorific value of MSW for thermal processes, organic content

3	The calorific value of MSW is on average > 8 MJ/kg.	The calorific value of MSW is on average between 7 and 8 MJ/kg.	The calorific value of MSW is < 7 MJ/kg. High biomass content with high average humidity.	The calorific value of MSW is < 7 MJ/kg. The content of inorganic fractions (e.g. ash, dust, sand, glass, metals) is high.
	Incineration	Incineration	Incineration	Incineration
	Co-processing	Co-processing	Co-processing	Co-processing
	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion
	Landfill gas collection	Landfill gas collection	Landfill gas collection	Landfill gas collection
	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification

4. Suitable waste quantities for WtE

4	> 150'000 metric tonnes of suitable waste fractions are available per year	50'000 to 150'000 metric tonnes of suitable waste fractions per year	10'000 to 50'000 metric tonnes of suitable waste fractions per year	< 10'000 metric tonnes of suitable waste fractions per year
	Incineration	Incineration	Incineration	Incineration
	Co-processing	Co-processing	Co-processing	Co-processing
	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion
	Landfill gas collection	Landfill gas collection	Landfill gas collection	Landfill gas collection
	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification

5. Efficient operation of waste facilities

5	Public and private actors are experienced in efficient running of waste management facilities, also in cooperation	Public or private actors are experienced but require capacity building to manage WtE facilities efficiently	Public actors have limited experience with WtE and recruitment of qualified national staff is difficult for public and private sector	Neither public nor private actors have experience with the operation of WtE systems.
	Incineration	Incineration	Incineration	Incineration
	Co-processing	Co-processing	Co-processing	Co-processing
	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion
	Landfill gas collection	Landfill gas collection	Landfill gas collection	Landfill gas collection
	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification

6. Additional transport time and distance for MSW to WtE plant

6	Distance or transport time will hardly change compared to the current situation.	Transport time will increase < 1 hour, additional distance < 50 km.	Transport time will increase >1 hour. Additional transport distance > 100 km.	Additional transport distance > 200 km and rail transport is not available.
	Incineration	Incineration	Incineration	Incineration
	Co-processing	Co-processing	Co-processing	Co-processing
	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion
	Landfill gas collection	Landfill gas collection	Landfill gas collection	Landfill gas collection
	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification

7. Marketing and/or final disposal of process residues

7	A market for process residues exists. Hazardous residues can be disposed of safely at a controlled landfill close to WtE plant.	No market for process residues. All process residues can be disposed of safely at a controlled landfill close to the plant.	No market for process residues. Safe disposal requires large transport distances	No market for process residues and safe disposal of process residues cannot be made available
	Incineration	Incineration	Incineration	Incineration
	Co-processing	Co-processing	Co-processing	Co-processing
	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion
	Landfill gas collection	Landfill gas collection	Landfill gas collection	Landfill gas collection
	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification

8. Marketing and/or final disposal of process residues

8	A comprehensive legal framework which considers all types of WtE exists. Laws are enforced & a national waste management strategy also covers WtE	A national legal framework for WtE exists. Any deficiencies on the level of enforcement, ordinances and by-laws are being addressed.	National legal framework for WtE is non- or only partially existant. It can be ensured that international standards are respected in specific projects.	The existing legal framework forbids thermal WtE or there are indications that sufficient emissions standards cannot be enforced.
	Incineration	Incineration	Incineration	Incineration
	Co-processing	Co-processing	Co-processing	Co-processing
	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion
	Landfill gas collection	Landfill gas collection	Landfill gas collection	Landfill gas collection
	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification

9. Financing the management of MSW

9	Collection and disposal costs of MSW are always fully covered. Financial means to cover additional costs of WtE are accessible.	Collection and disposal costs of MSW are always fully covered. Additional costs for WtE might be difficult to cover.	The costs for collection and disposal of MSW cannot be covered on a regular basis.	There is frequently a lack of financial means to cover operating costs of SWM services.
	Incineration	Incineration	Incineration	Incineration
	Co-processing	Co-processing	Co-processing	Co-processing
	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion
	Landfill gas collection	Landfill gas collection	Landfill gas collection	Landfill gas collection
	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification

10. Access to foreign currency

10	Spare parts can be purchased locally. No restriction on purchasing spare parts in foreign currency.	Most spare parts can be purchased locally. Sales offices for spare parts to be imported are locally available.	Key technology of the WtE plant must be imported. Delays in access to purchases in foreign curreny	No access to foreign currency
	Incineration	Incineration	Incineration	Incineration
	Co-processing	Co-processing	Co-processing	Co-processing
	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion
	Landfill gas collection	Landfill gas collection	Landfill gas collection	Landfill gas collection
	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification

11. Access to energy end-users of WtE

11	WtE or RDF facilities are located close to an industrial area with power and heat / gas demand. Good transport and energy infrastructure exists.	WtE or RDF facilities are located in an area with moderate heat demand. Good transport and energy infrastructure exists.	WtE or RDF facilities are located close to a large power transmission network. No heat demand in the area.	WtE or RDF facilities are located in an area which is poorly connected to energy consumers.
	Incineration	Incineration	Incineration	Incineration
	Co-processing	Co-processing	Co-processing	Co-processing
	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion
	Landfill gas collection	Landfill gas collection	Landfill gas collection	Landfill gas collection
	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification

12. Incentives for low carbon energy generation

12	Economic incentives for low carbon heat and power are already successfully applied	Economic incentives for low carbon electricity from waste are regulated by law but not yet applied	Introduction of economic incentives is most likely within one year	No economics incentives exist
	Incineration	Incineration	Incineration	Incineration
	Co-processing	Co-processing	Co-processing	Co-processing
	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion	Anaerobic digestion
	Landfill gas collection	Landfill gas collection	Landfill gas collection	Landfill gas collection
	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification	Pyrolysis & Gasification

4.3 Recommendations

Some questions may arise after going through chapters 1-3 and using the matrix of chapter 4.2. The following recommendations may provide some further orientation.

For decision makers at national and local level:

- **Assess whether WtE is the best solution in terms of the waste hierarchy and circular economy**: Waste reduction through prevention should take priority, followed by preparation for re-use and the material recycling of waste. Evaluate your waste stream and identify additional potential for reuse and recycling of specific waste fractions.

- **Make decisions on the basis of an MSWM plan**: decisions should only be taken on the basis of an integrated MSWM plan which is based on material flow analysis and which respects the concept of the waste hierarchy. WtE is not a stand-alone solution but a potentially interesting element of the waste treatment system.

- **Get an answer to all fields marked in yellow in the decision matrix**: Even if your internal appraisal with the help of the matrix favours WtE there might be still weak points which need further clarifications. Ask an independent advisor or expert for help to get your questions answered.

- **Ensure that international emissions standards are met by the project**: Emissions monitoring systems must be in place before going ahead with projects (particularly for incineration, co-processing, alternative technologies). Ensure that enforcement of the emissions standards can take place by independent authorities. This may require changes to the legal framework.

- **Set-up a financing system that allows cost-covering operation of WtE plants**: As WtE plants need additional financial sources to recover full costs, additional financing mechanisms must be applied. Beside direct revenues from households through taxes and waste tariffs, there are three additional sources for income: subsidies, gate fee or feed-in tariffs for electricity.

- **Assure smooth inter-institutional cooperation**: In many developing countries WtE is often associated with ministries or agencies from the energy sector. However, their interest should not be to maximize energy production from waste but to optimize the recovery of energy from those waste fractions which cannot - from a technical or commercial point of view - be recycled. Close cooperation with the authorities responsible for waste management and/or climate protection is therefore essential.

- **Promote and offer capacity building**: The shortage of experts for planning, operation and monitoring of WtE plants has a strong impact on the MSWM. Give municipal staff from the waste department the chance to increase their knowledge and support academic and scientific initiatives which foster education in the sector.

» **Assess opportunities for landfill gas collection from existing landfills**: It is important to reduce climate impacts of landfills. Landfill gas collection facilities require a realistic projection of the future quantities of landfill gas production taking into account increased future rates of waste diversion from landfill.

» **In the case of limited experiences with thermal treatment of waste, start with co-processing**: As co-processing of waste in cement kilns is already widely employed across many developing countries, this WtE option can be realised at short notice. Cement plants are available in almost all countries worldwide and can be upgraded for the use of RDF with limited investments. To start with co-processing also helps to practice cooperation between municipalities and the industrial sector and to make use of substantial international experience in co-processing in developing countries. The potential limiting factors are low gate fees for waste disposal, the distance between the place where waste is generated and the site of the cement plant and low prices for fossil fuels (coal, pet coke etc).

» **Promote waste segregation at source and decentralized anaerobic digestion plants for separately collected biomass**: Do not start on a big scale. Give your municipality and citizens the chance to gain experience with waste segregation and planning and operation of biogas plants.

» **Increase cooperation with the private sector**: Municipalities will not be able to shoulder the MSWM challenges of the future alone. Therefore the local authorities have to create an environment of trust and reliable legal and financial framework conditions so that the waste sector becomes attractive for private investors and operators.

For national and international companies:

» **Develop incineration techniques that fit local conditions**: Incineration plants installed in industrialized countries are too expensive for most cities in developing countries. There is a global need to develop new and appropriate technologies which respond to waste composition in cities in developing countries so that investment and operation costs can be financed.

» **Avoid the creation of a bad reputation for the sector**: Mid and long term success of WtE depends on the reputation gained by well-operated plants. Industry associations and individual companies should minimize the risk of WtE plants becoming a costly ‘white elephants’.

Annex A: Description of the decision matrix parameters

1. OVERALL LEVEL OF WASTE MANAGEMENT

- A basic requirement for successful implementation of WtE is the existence of an advanced waste management system which is based on the separate collection and treatment of different source separated waste streams. Biomass such as kitchen and garden waste are digested and/or composted. Recyclables such as paper, card-board, PET, glass, metals etc. are sorted and directed to the recycling industry. The management of hazardous waste is controlled. Remaining MSW fractions which cannot be recycled are disposed of in a controlled landfill.

- International experience indicates that the implementation of state of the art co-processing and landfill gas collection can be successful if a systematic waste collection exits and some selected waste streams such as tires or biomass can be directed to the facilities. Anaerobic digestion requires separate collection of biomass because any contamination with other MSW fractions may cause problems with the process and the use of the digestion residues in agriculture. On this waste management level the suitability of incineration should be assessed in detail before a project is initiated - some improvements of the waste management system might be required.

- If systematic recycling is missing, landfill gas capture might be a viable option that does not require substantial improvement of the overall MSWM level.

- Due to limited experiences and the high capital and operation costs, the applicability and planning of pyrolysis & gasification projects should be considered very carefully at all levels of MSWM.

2. COMPOSITION OF WASTE

- Separation of MSW at the source in households is the best precondition for recycling and also for WtE. Hazardous & bulky mineral waste should be collected and treated separately.

- As already mentioned, for anaerobic digestion separate collection of organic waste is a necessity. Anaerobic digestion is not an option if separately collected waste is mixed with mineral or hazardous waste, even in small amounts.

- If MSW is regularly mixed with hazardous and mineral fractions the suitability of each WtE technology must be assessed frequently. Measures to improve waste separation at source should be initiated (e.g. separate collection and treatment of construction & demolition waste and batteries).

- Landfill gas collection remains relevant where sanitary landfills contain significant levels of organic waste.

3. CALORIFIC VALUE OF MSW FOR THERMAL PROCESSES, ORGANIC CONTENT

- Autothermic combustion (self-sustaining combustion without additional fuels) of MSW must be ensured throughout the year for incineration and co-processing. Co-firing of oil, gas or other fuels is expensive and should be applied only to start up the combustion process or in emergency. For incineration and co-processing calorific value is one indicator to decide if MSW is suitable for the process. A high mineral content from construction and demolition waste, glass or ash, a high metal content or a high humidity from kitchen and garden waste reduce the calorific value. Calorific values > 8 MJ/kg indicates that all combustion technologies are suitable options for WtE projects.

- Incineration technologies with an advanced integrated drying stage are able to combust wet MSW with a calorific value of about 7 MJ/kg. For co-processing the minimum acceptable humidity should be clarified and drying technologies assessed before starting a WtE project.

- If the calorific value is < 7 MJ/kg due to humidity, for all combustion technologies the minimum acceptable humidity should be clarified and drying technologies assessed. When mineral waste is the main reason for a low calorific value, overall waste management should be improved first before starting with WtE options.

- The LCV for thermal processes cannot be directly compared with LFG collection and anaerobic digestion. However, the energy content of organic feedstock for an anaerobic digestor has an impact on the energy content of the biogas yield. Higher energy content feedstocks can increase the quality of the biogas. The efficiency of landfill gas collection is dependent on the existing landfill conditions, including the proportion of organic waste deposited and the way this is layered.

4. SUITABLE QUANTITIES OF WASTE FOR WTE

- The choice of a WtE technology also depends on the available waste quantities and the related minimum requirement of economically sound operation. In this context "available" refers to suitable waste fractions that can be supplied at acceptable costs to the facility and cannot be economically recycled. A WtE plant should also not cause an infrastructure lock-in effect that disincentivises building recycling infrastructure for the affected waste streams.

- If more than 150,000 metric tonnes of waste are available per year all technologies are suitable. However, due to limited international experiences with pyrolysis & gasification, other technologies are more favourable.

- For waste quantities between 50,000 and 150,000 metric tonnes per year the cost-effectiveness of incineration should be assessed carefully. Co-processing, landfill gas collection and anaerobic digestion are more favourable.

- Below 50,000 metric tonnes incineration is too expensive. Cost-effectiveness of co-processing might be impacted by low prices for coal and pet coke. If waste quantities are below 10,000 metric tonnes per year anaerobic digestion might be the only favourable technology if the quality of the biomass is acceptable.

- Landfill gas collection depends on the amount of organics in the landfill and may still be suitable as a retro-active measure after the landfill is closed, making this parameter less relevant - provided that enough methane can be collected to make the technology cost-effective.

5. EFFICIENT OPERATION OF WASTE FACILITIES

- Waste management facilities can be operated by the public sector, the private sector or in cooperation. National experience with well-managed landfill sites, large wastewater treatment plants (public sector) and large chemical or cement plants (private sector) indicate that complex systems can be handled locally. Nevertheless for foreign WtE technologies long term support from technology suppliers should be contractually ensured. Learning from past failed waste management projects, it is clear that WtE requires experienced management and well-trained technical staff. Good communication between the public and private actors is an essential precondition. Under these preconditions, all technologies might be successful candidates for a WtE project except pyrolysis & gasification due to limited international experience with heterogeneous MSW.

- Most actors require capacity building for WtE even if they have experience in managing waste treatment infrastructure. Cement plants are often owned by international companies with in-house knowledge of co-processing which they can provide. Landfill gas collection is technically the simplest approach. These two technologies are more favourable until knowhow about the other technologies is locally available.

- If public actors have limited experience with WtE and recruitment of qualified national staff is difficult, landfill gas collection is the most favourable technology. The need for capacity building for co-processing and anaerobic digestion should be assessed carefully; it is easier to cover than incineration and pyrolysis & gasification.

- If neither public nor private actors have experiences with the operation of WtE systems landfill gas collection is the only opportunity after some basic capacity building.

6. ADDITIONAL TRANSPORTATION TIME AND DISTANCE FOR MSW TO WTE PLANT

» In addition to the access to end users for the generated energy, the economic and environmental impact of additional transportation effort to WtE facilities must be taken into account. Each additional kilometre of road transportation of waste increases costs for collection, as well as congestion and greenhouse gas emissions in metropolitan areas. Ideally, distance or time for road transportation of waste will be the same as for the existing waste management situation or less.

» An increase of transportation time of less than 1 hour or additional distance of less than 50 km is seen as tolerable for WtE. For an increase of additional transportation time of >1 hour or additional transport distance of > 100 km the energy content of the transported waste should be high to be economically and environmentally worthwhile. For additional transportation distance > 200 km rail would be the only legitimate transport means, but it is difficult to manage and possibly unrealistic for MSW.

» The use of landfill gas collection at existing landfills implies that waste will be transported the same distance. New SLFs must also take distance considerations into account in order to maximise collection efficiencies.

7. VIABLE MARKET AND/OR FINAL DISPOSAL OF PROCESS RESIDUES FROM WTE

» Except for co-processing in cement plants and landfill gas collection, all other WtE technologies generate process residues. If in the current situation a market for similar process residues exists and hazardous residues can be disposed of safely in a controlled landfill close to the WtE plant, all technologies can be considered as a candidate for a WtE project.

» If no market for process residues is developed but all process residues can be disposed of safely at a controlled landfill close to the plant, then the economic feasibility of incineration, anaerobic digestion and pyrolysis & gasification needs to be carefully assessed. Co-processing and landfill gas collection are more favourable in this situation.

» Anaerobic digestion is not feasible if there are large transportation distances for the sale of compost and no long term market prospects. High quality compost resulting from well segregated and controlled organic waste streams is an important determinant of this.

8. LEGAL FRAMEWORK & ENVIRONMENTAL REQUIREMENTS FOR WTE

» An existing comprehensive legal framework for waste management is a precondition for WtE success. Legislation needs to include high environmental standards for emissions to air, water and soils, odours and noise as well as health and safety requirements. It also should define the role of WtE within an integrated waste management system. Legislation should be tailored for the national circumstances and not just be copied from an industrialized country.

» Effective enforcement mechanisms should minimise illegal waste management practices to ensure functioning waste supply chain to WtE facilities. However, legislation should aim for cooperation with the informal sector for collection logistics rather than to further marginalise them. International standards on emissions limits, monitoring and enforcement must be guaranteed. Public authorities must be sufficiently trained and equipped for ensuring adherence to environmental standards.

» While co-processing and landfill gas collection mainly build on existing facilities which are often already regulated, anaerobic digestion, pyrolysis and waste incineration require more specific regulation, e.g. with regards to the options of re-using process residues. The current legal framework may still show some deficiency. Changes to permit state of the art co-processing and landfill gas collection often need only the modification of ordinances and by-laws, which tends to be easier than the political process for new laws. Under such conditions state of the art co-processing and landfill gas collection should be considered as easier technologies to implement, while other WtE technologies require the development of more extensive legal frameworks before going ahead.

» In some countries a political consensus exists to adapt the legal framework towards WtE. Depending on progress with the elaboration of a comprehensive legal framework it may make sense to initiate the process for formulating or amendment of laws and by-laws for co-processing, landfill gas collection and anaerobic digestion as favourable technologies.

» In some countries the thermal treatment of waste is forbidden which excludes co-processing, incineration, pyrolysis and gasification. WtE technology can only be considered as appropriate if it does not contradict the waste hierarchy or the overall waste management strategy of a country or state.

9. FINANCING THE MANAGEMENT OF MSW

» The consistent availability of financial means is crucial for long term application of WtE technologies. It must be assumed that WtE projects will lead to higher treatment costs than for sanitary landfills. Tables 2-6 show the significant net costs per tonne of waste for typical WtE projects in the five technologies.

» Before considering WtE as an opportunity, municipalities must be able to fully cover the costs for MSW collection and disposal in a controlled landfill; further financial means to cover additional costs should be easily accessible. In the long-term a fee for waste generators based on the polluter pays principle is desirable, whereas current management costs may be primarily covered from the municipality budget. In particular, increasing the fee for landfilling can make other waste management options more feasible.

» If increasing the waste fee is not enforceable or municipalities do not want to or cannot increase budget, a detailed cost assessment by independent experts and/or the search for alternative long-term funding through alternative financing instruments is essential before initiating a WtE project. Where long-term financing options are not established, municipalities are likely to be left with the bill – resulting in either operations shutdown or unwanted additional costs for the municipality.

10. ACCESS TO SPARE PARTS & FOREIGN CURRENCY

» Access to foreign currency is essential for all spare parts which are not locally available, as part failure will otherwise lead to shut down of operations – or failure to meet operating standards.

» If spare parts can be purchased locally and no restriction exists for the purchase of spare parts in foreign currency, all WtE can be considered.

» When most of the spare parts can be purchased locally and sales offices are locally available for spare parts to be imported, the expected cost and access to foreign currency should be assessed before initiating a WtE project. Landfill gas collection is seen as less critical.

» If key technology of the WtE plant must be imported or delays in getting access to purchases in foreign currency can be expected, incineration, pyrolysis & gasification should not be chosen. Without access to foreign currency landfill gas collection might be the only option but will also require a cost assessment.

11. ACCESS TO ENERGY END-USERS FROM WTE

- The choice of a location for a WtE facility depends amongst other things on the access to end-users for the energy. The choice of the location and the incomes should be reviewed before starting the project. Industrial areas can benefit from the generated power, heat or biogas. Investments in district heating for process steam supply are high but also generate a valuable income. Landfill gas or biogas from anaerobic digestion facilities can be fed into a gas network if a pipeline is close by. The substitution of diesel with biogas or LFG as fuel for transportation is also a valuable option. The location for landfill gas collection and co-processing are normally pre-defined by respective existing landfills, cement or power plants.

- If the project is located in areas with no or only moderate heat or gas demand, revenues from energy sales will be lower. The transformation of all the heat into electricity is an option but not the most economical, as the efficiency rate is much lower than a direct use of gas or steam. Locations with a poor connection to energy end-users are substantially disadvantaged for WtE as this implies limited use of recovered energy and increased net operating costs.

12. INCENTIVES FOR LOW CARBON ENERGY GENERATION

- The sale of energy from waste i.e. power, gas and heat are subject to being competitively priced out of the market by fluctuations in price of conventional fossil fuels such as oil, coal and gas. When this happens the economic feasibility of the plant is endangered, making a secure income for energy from WtE plants necessary to ensure stable long-term income for waste management. Regulatory incentives (such as feed in tariffs) for low carbon energy generation will not only support WtE but can also contribute to national targets defined in NDCs (Nationally Determined Contributions) of the Paris Agreement on Climate Change.

- An already successful application of incentives for low carbon energy indicates good potential for all WtE technologies. If they exist but are not yet applied, the effectiveness of incentives for incineration, anaerobic digestion, pyrolysis & gasification should be assessed first.

- Without a realistic perspective for incentives, all WtE plants should be classified as risky.

Annex B: Further Reading

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Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn

Friedrich-Ebert-Allee 36 + 40
53113 Bonn, Germany
T +49 228 4460-0
F +49 228 4460-1766

Dag-Hammarskjöld-Weg 1 - 5
65760 Eschborn, Germany
T +49 6196 79-0
F +49 6196 79-1115

E info@giz.de
I www.giz.de

On behalf of

Federal Ministry
for Economic Cooperation
and Development