ISWA White Book on Energy-from-Waste (EfW) Technologies

Working Together
for a Cleaner, Healthier Planet

ISWA
International Solid Waste Association

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Front cover image:
Copenhagen (DK) Amager Energy-from-Waste plant
Photo credit: ARC

1 Preface

Johnny Stuen
Working Group Chair

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As Chair and Vice Chair of **ISWA's** Working Group on Energy Recovery, we are proud to present, after nearly two years of dedicated efforts from the whole Working Group, this new report, "**ISWA** White Book on Energy-from-Waste (EfW) Technologies"

This White Book is a comprehensive overview, looking at technical, economic, legislative, institutional, social and most importantly, environmental aspects of the available thermal technologies which produce energy from waste (EfW).

The idea behind this document is to assist those involved in the development of waste management, especially decision makers in countries where EfW is not yet familiar or implemented, particularly for the increasing number of large cities. Therefore, the intended users of the guidelines are primarily decision makers, waste management authorities and institutions involved in the financing of public infrastructure required by urbanization. The overall objective is to give an overview of the key pre-conditions which must be fulfilled in order to ensure short and long-term feasibility of Municipal Solid Waste (MSW) energy recovery facilities building and operation. The guidelines also include an overview of waste combustion and thermal treatment technologies as well as the necessary infrastructure and financing.

Waste-to-Energy (WtE) (or Energy-from-Waste (EfW)) is the thermal treatment of residual waste. The ideal role for the technology is to recover the energy and materials that cannot be recycled, and reduce the need for landfill, in some countries almost to zero.

Waste thermal treatment is a clean and compact technology that can be adopted in central areas of cities. It diverts residual municipal waste from landfills or worse options, provides locally available and sustainable energy, reduces dependence on fossil fuels and contributes to climate protection by avoiding methane emissions from landfill. It contributes also to environmental protection by avoiding huge pollution from worse options such as open dumps or open burning. Installed as close as possible to urban centers, EfW facilities respect the proximity principle for our cities "metabolism". They offer a hygienic, safe, and reliable solution for residual municipal waste treatment, combined with non-intermittent renewable energy production and mineral & metals recovery.

As a final sink, Energy-from Waste is an integral part of an efficient and sustainable waste and resource system, going hand in hand with recycling and biological treatment of waste when it comes to reducing the amount of waste landfilled and to eliminating open dumping and open burning and thereby protecting the environment and human health as well as mitigating climate change.

With this in mind, the Working Group has prepared this White Paper, which will serve as a roadmap for the industry from operators to owners and consultants in the field of EfW/WtE who seek to implement the technology as part of a balanced, integrated waste management system.

Our gratitude goes to the chief author of the report; **Mr. Frederic Aguesse** (EfW consult), whose vast experience and wealth of knowledge has provided the backbone of this report and who really made it happen. Our special thanks also go to the rest of the contributors, including;

- **Ms. Judith Harper**, CIWM (United Kingdom)
- **Mr. Frans Lamers**, DNV GL (Netherlands)
- **Mr. Peter Simões**, Harvest Waste (Netherlands)
- **Mr. Fabio Poretti**, CEWEP (Belgium)
- **Mr. Amit Pandey**, Geocycle (India)
- **Mr. Daniel Purchase, ISWA** (United Kingdom)

As well as those mentioned above, we are incredibly grateful to all of the **ISWA** Working Group on Energy Recovery who have dedicated uncountable hours of volunteer time in reviewing, commenting, editing, and revising many drafts of this report. Whilst we were not able to meet physically, we continued to work together to ensure that we produced a report which will serve the sector well. Further appreciation also to the efforts and contributions of **ISWA's** Scientific and Technical Committee, and General Secretariat.

Copenhagen (DK) Amager Energy-from-Waste plant
Photo credit: ARC

2 Introduction

As part of the overall **ISWA** Mission to promote sustainable Waste Management worldwide, the Working Group on Energy Recovery (WGER) has prepared this White Book on Energy-from-Waste (EfW) Technologies. This is a follow up of the "**ISWA** White Paper on Alternative Waste Conversion Technologies" and "Guidelines: Waste to Energy in Low and Middle-Income Countries" documents issued by the same **ISWA** Working Group in 2013. The terminology Energy from Waste puts more emphasis on energy than 'Waste to Energy' and is preferred to 'incineration', which originally did not have any energy recovery and is therefore no longer considered a viable option.

This document is intended **to assist stakeholders involved in the development of Municipal Waste Management solutions, especially decision makers** (mostly Public Authorities) in countries where EfW is not yet well-known or implemented, particularly where sustainable solutions are required for the increasing number of large cities and densely populated areas where waste collection, transport to the treatment site, land availability, health and climate change aspects are becoming major concerns.

It is considered that the wastes suitable for EfW treatment are **residual Municipal Solid Waste** (MSW) (or similar) and associated wastes. Consequently, this paper does not cover the treatment of separately collected recyclable wastes such as packaging (which are then generally processed in dedicated sorting and recycling facilities), separately collected organic waste (which is then processed in composting and / or anaerobic digestion plants) or hazardous waste. It is essential to remember that 70% of such residual MSW is currently going to landfill or worse options such as open dumps or open burning.

This White Book is based on existing documentation and the knowledge of the **ISWA** Working Group on Energy Recovery (WGER) and refers to a number of official publications listed in chapter 9 "References", in particular the *"UNEP 2019 Waste to Energy – Considerations for Informed Decision – making"*.

The objective of this White Book on EfW Technologies is therefore to:

- Review the experience in different areas around the world where Waste Management has developed over decades towards industrial technologies.
- Look at the possible evolutions in waste management and treatment in the targeted countries and identify the main Policy/ Regulation issues to be developed at Country level
- Address Public Health, Environment and Climate Change aspects which are crucial.
- Introduce the technical basics of EfW and, when required by some technologies, the need for Waste Preparation.
- Provide an update on the status of the different technologies currently marketed covering not only the technical aspects, but also the inputs and outputs, the current experience and dissemination and costs trends.
- Identify the pre-requisites for EfW implementation.
- Evaluate the different technologies and make general recommendations to ensure successful development of EfW.

3 Executive Summary


Torino (It) EfW Credit: TRM

Key Findings and Recommendations

- Many areas in the world do not have a satisfactory waste management system, and that often causes the use of open dumping or uncontrolled landfills and open burning of waste. This is more or less completely without control and is by far the most harmful way of treating waste. Open dumps cause additional large problems with groundwater, soil contamination, pollution, and significant health hazards. Many of these sites also contribute significantly to marine litter.
- Open burning is often practiced recovering disposal space on site. This main source of air pollution should unquestionably be avoided for its very strong environmental impact (especially with carbon particles and dioxins).
- Landfilling (controlled and managed) is in very many areas the most prominent method of waste management worldwide, as there is a lack of investment funds and/or infrastructure to support other solutions.
- The above-mentioned solutions have all a large land footprint, either close to large residential areas or located further away with associated transport and contribute significantly to greenhouse gas emissions, even though significantly lower from managed landfill than the more uncontrolled solutions.
- To move away from open dumps and uncontrolled landfills will give benefits to urban development taking place in low- and middle- income countries coupled with increasing consumption of goods and associated waste generation. The preliminary action is to implement an effective collection system to harness the material and energy content of waste.
- The first step that should be implemented is to eradicate open dumping and to develop sanitary landfills with proper and safe reception of collected waste, leachate collection and treatment, air (with methane capture and treatment) and ground protection.
- As a next step and as implemented in a number of areas, low-to-middle income countries are encouraged to "move up the Waste Treatment Hierarchy" including Reduction, Reuse, Recycling and Organic Waste separate collection and treatment and Energy from Waste - the combination of such treatments being based on the local waste characteristics.

The preparation of a comprehensive and performance-based waste management practice is a pre-requisite to such development.

- **Energy from Waste is the recommended waste treatment for residual household and similar waste that remains after waste prevention, recycling and organic waste treatment**.
- The main advantages of EfW are:
  - Being the safe and clean treatment of the residual waste thanks to efficient overall design, combustion process and flue gas cleaning, efficient operation complying at all times with stringent emissions regulation and permitting, with specific lower limits to be defined at the local level.
  - Being the final sink for mixed, dirty, or degraded materials
  - Enable recycling and material recovery by treating hazardous substances and preventing contamination of the recyclable waste streams.
  - Enabling the recovery of the energy embedded in the residual waste to provide local, non-intermittent, reliable, sustainable and mostly renewable energy which contributes to reduction of dependence on fossil fuel imports.
  - The material recycling of metals and use of bottom ash as construction aggregates.
  - The considerable reduction of the fraction to be landfilled.
- **With this diversion from landfill or worse options such as open dumps or open burning, EfW is a significant contributor to GHG mitigation in the waste management sector**. The waste sector represents a significant part of the total GHG emissions of countries with poor waste management.
- However, EfW requires significant funding capacities to build and operate the plants. The most common way to cover such costs is through a general waste collection and treatment contribution by the citizens which are the waste producers and taxpayers.
- The development of such large infrastructure also requires long-term planning based on a structured legislative framework including clear responsibility of public entities and commitment to delivery of large quantities of waste (minimum 100k to 150k tons per year) for 25 to 30 years, energy sale, the re-use / treatment of residues, and public determination for the plant location to be as close as possible to the residential and industrial areas.
- Some countries started to develop EfW many decades ago and have developed a wide range of skills together with companies, which enables them to split construction and operation contracts. Public / Private Partnerships (PPPs) provide an integrated approach and enable sharing of the risks from the Public Authority perspective. They also benefit from competences and knowledge from private sectors. This is therefore recommended for the development of new plants in the targeted countries.
- The most developed and therefore preferred technology for unprepared residual waste is "Advanced Moving Grate Combustion", given the extensive experience across all continents, the large number of incremental improvements developed over the years, its simplicity to operate, and its considerable flexibility and availability without any pre-treatment.
- Although not always made clear by promoters, a complex and costly waste preparation is required for a number of alternative technologies.
- Alternative technologies for prepared waste or non-hazardous Refused Derived Fuel (RDF) include fluidized beds but otherwise have not proven high reliability and generate high operational cost, but "can possibly make sense for specific and limited waste fractions. However, this requires significant efforts for waste pre-treatment, additives, higher CAPEX and OPEX." (RWTH Aachen University QUICKER, 2015)

4 **Definitions** and Context

4.1 Acronyms and abbreviations

APCR:	Air Control Residues
ATT:	Advanced / Alternative Thermal Treatment
BA:	Bottom Ashes
BOT:	Build Operate Transfer contractual scheme (concession in Public Private Partnership)
BREF:	Best available techniques Reference document
CAPEX:	Capital Expenditure
CHP:	Combined Heat and Power
EfW:	Energy from Waste
EPC:	Engineering Procurement Construction
GHG:	Green House Gases
IED:	European Industrial Emissions Directive
LCV:	Lower Calorific Value
MSW:	Municipal Solid Waste
NIMBY:	Not In My Backyard
OPEX:	Operational Expenditure
PPP:	Public Private Partnership
RDF:	Refuse Derived Fuel
SRF:	Solid Recovered Fuel
WtE:	Waste to Energy (similar to EfW)

Organizations:

CEWEP:	Confederation of European Waste-to-Energy Plants (Trade organization)
DEFRA:	Department of Environmental, Food & Rural affairs (UK Ministerial department)
EPA:	United States Environmental Protection Agency (National regulator)
ESWET:	European Suppliers of Waste to Energy Technologies (Trade organization)
GIZ:	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (German development agency for international development co-operation)
ISWA:	International Solid Waste Association
UNEP:	United Nations Environment Program

4.2 Waste Management Practices Worldwide

As can be seen from the figure below (Mavropoulos, 2020), there were 2 700 million tons of MSW generated worldwide in 2019 which is expected to further increase, together with population and GDP increases, to more than 3 billion tons by 2030. This waste generation increase will be most important in large cities, becoming even larger with associated consumption increase.

Seventy percent of these 2 700 million tons were disposed in landfills and open dumps. From that amount, 11.5 % are disposed in controlled landfills and 58% in uncontrolled landfills or dumps. Approximately 630 million tons were destroyed in open burning within the latter as confirmed by the World Bank. (World Bank, 2018).

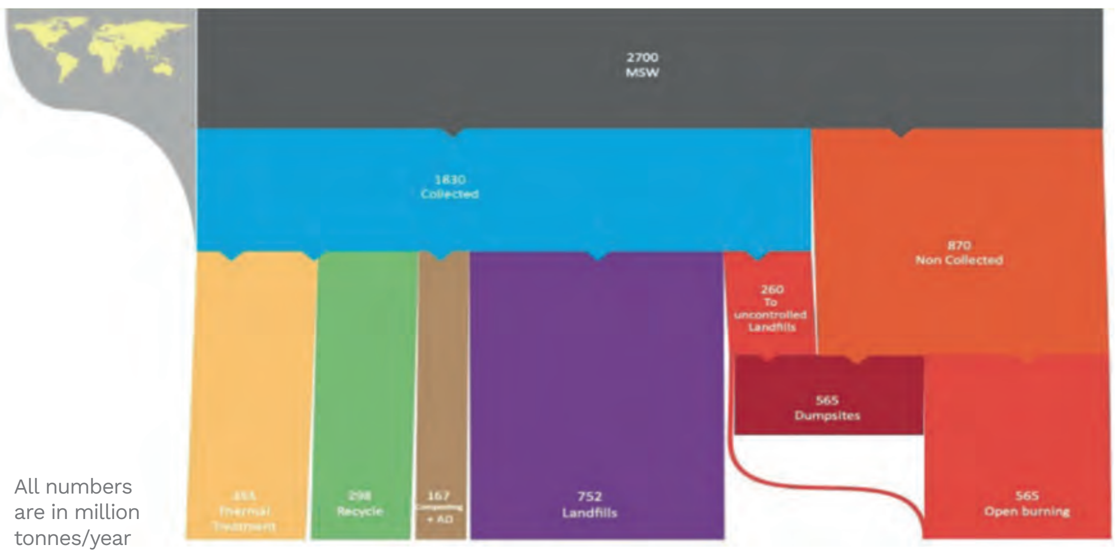
EfW represents 23% of the total amount of controlled waste management (excluding open dumps and open burning) whilst Recycling represents 20% and Composting/Anaerobic Digestion 11%.

There is therefore a huge potential to "move up the Waste Treatment Hierarchy" (refer to the waste treatment "pyramid" in §4.4.2).

There are approximately 2,450 EfW plants that are operational worldwide with a total waste input capacity of around 350 million tons per year. (ADB, 2020). Forty-nine percent of these EfW plants are based in Southeast Asia (mainly in China, Japan, Korea, Singapore), 48% in EMEA (Europe, Middle East and Africa) and the rest in America (mainly the USA).

Figure 1

Source: D-Waste



Waste disposal globally

4.3 Municipal Waste characteristics

Before contemplating the evolution of existing waste treatments, it is essential to understand the main characteristics and composition of the waste.

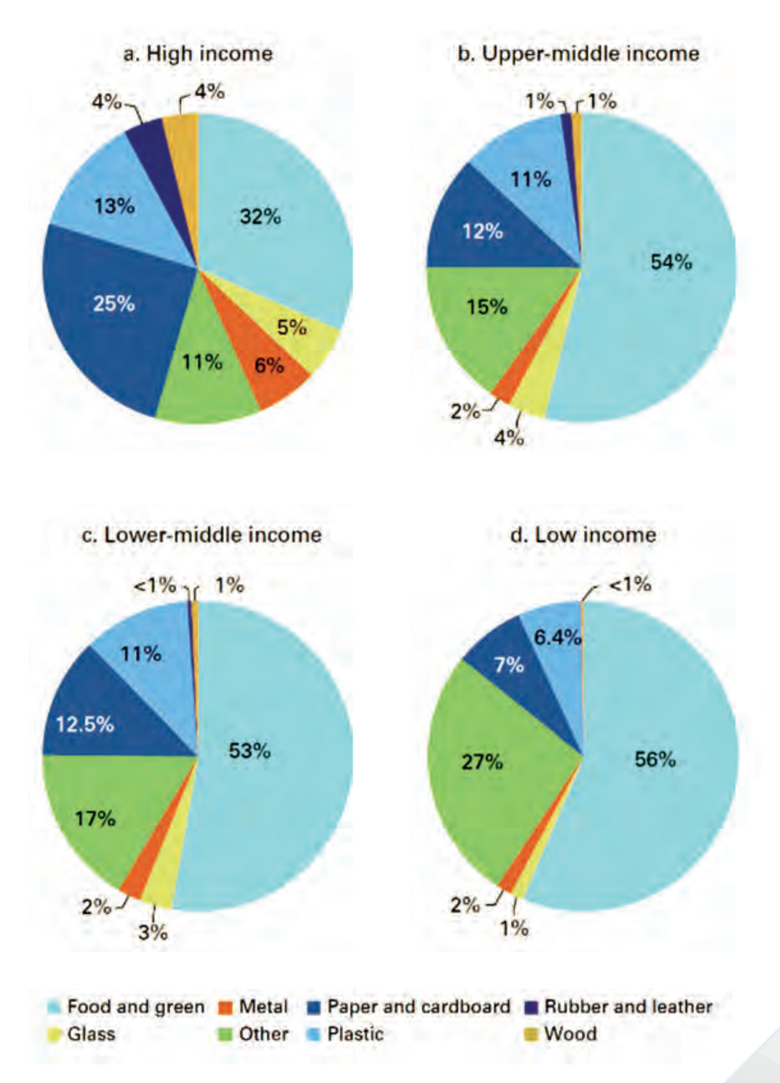
With increase in income levels the food and green fraction of MSW, which is the major fraction in low-income countries, reduces significantly and is replaced by a recyclables fraction as shown in the attached figure (World Bank, 2018). This composition evolution means that appropriate treatments must be developed for the specific composition.

The disposal of 1.5 billion tons of MSW worldwide in open dumps and uncontrolled landfills therefore initiates the decomposition of this organic fraction and in turn generates methane which is a very high GHG contributor (see §4.5.5).

This also means that the energy content in MSW is proportionately lower when the food and green fraction is high (increase of water content), unless these fractions are extracted before treatment. The moisture content may also significantly vary with the seasons (in the case of monsoon for example).

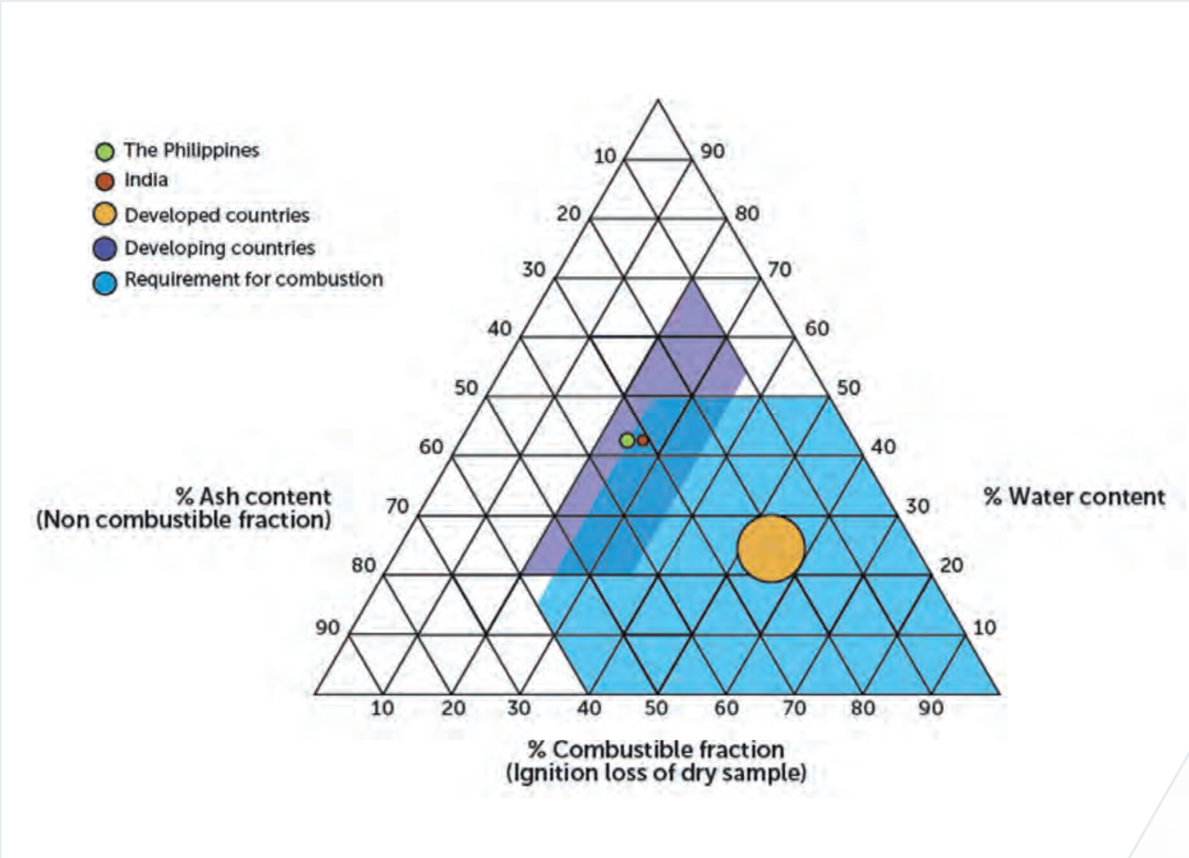
Figure 2

Source: World Bank



Waste Composition by Income Level (percent)

Figure 3
Source: UNEP



Tanner triangle for combustibility assessment of MSW (in percentage by weight)

The ternary diagram or Tanner triangle below (UNEP 2019 Waste to Energy – Considerations for Informed Decision – making) considers the combustible, ash and the moisture contents and the corresponding zone of self-combustion of MSW. It shows for example that Philippines' or Indian MSW have much higher water and less combustible contents than in high-income countries. This is also the case for most of the hundreds of EfW Plants in China where the average LCV can be as low as 5 to 6 MJ/kg (compared with 8-10 MJ/kg in developed countries).

In specific situations, a more acceptable LCV may be achieved by gravity drainage, separate organic waste collection and/or simple organic fraction separation. This enables the combustion of MSW in a treatment/EfW plant without any additional fuel.

Additional fuel may only be required by regulation for start-up and shutdown of EfW plants to ensure a sufficiently high temperature in the furnace to destroy air pathogens and pollutants as soon as the waste is introduced.

Many analyses have shown that LCV and waste quantities increase with the average income per capita, which means that most MSW from fast growing cities have high enough LCV for EfW.

Some countries have developed the preparation of Refuse Derived Fuel (RDF) and / or Solid Recovered Fuel (SRF) from non-hazardous MSW with the objective to enhance the calorific value for a better combustion efficiency. A more detailed description can be found in the introduction to the different technologies. Waste preparation details will however be included in the discussion where required by Technology.

A good knowledge of the current and anticipated waste characteristics is essential in order to develop the most appropriate and efficient combination of waste treatments.

4.4 Waste Management Policy

4.4.1 General Waste Management Policy

In most Countries, MSW Management is the responsibility of local Public Authorities (cities, intermunicipal organizations, counties, etc), to be in line with bespoke targets- Legislation and regulations developed at state or country level. Human health and pollution topics are the first topics addressed by government policies, to avoid diseases and hazardous compounds transmission to the environment.

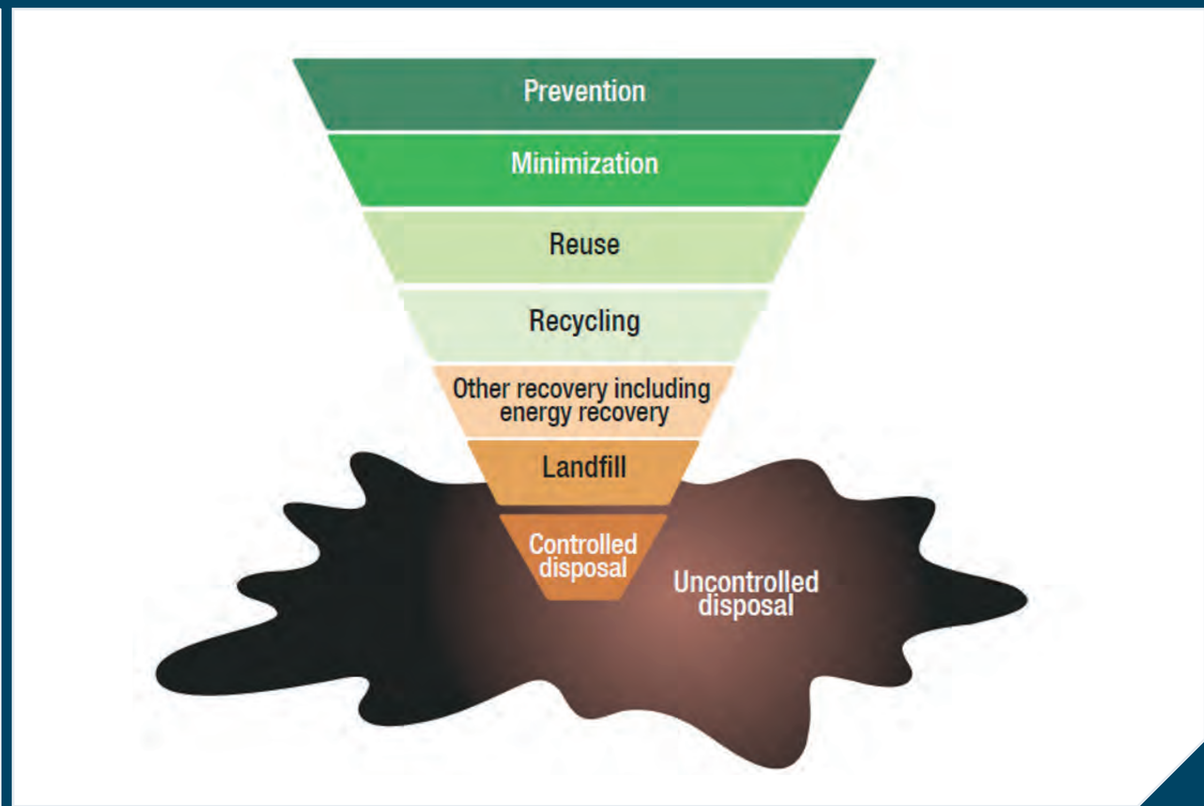
Such local legislation and regulation must cover the waste collection and treatment, including site planning and the decision-making process - which is notoriously difficult and can be influenced by public opposition (NIMBY). Good communication to all stakeholders is key to the success of all waste management operations.

4.4.2 European Union (EU) Experience

As The EU is often considered as "state of the art" in terms of overall Policy, Regulation and reduction of Climate Change impacts, so it is interesting to summarize its approach and current objectives:

The waste management hierarchy (see diagram (**ISWA** UNEP, 2015) is part of the Waste Framework Directive (2008) which aims to protect the environment and human health. All efforts should first be made to prevent, minimize, re-use or recycle the waste. Residual waste should then be used to recover energy in EfW plants and as a last resort should be disposed of in landfills.

Figure 4
Source: UNEP



Waste management hierarchy

The Circular Economy concept has also been developed in the early 2000s – it was described early in the 2000s in Chinese and European documents and later implemented extensively in Europe. The EfW role is well described as part of the circular economy in the **ISWA** Task Force report on Circular Economy 2015. It emphasizes its main quality as a final sink keeping the circular economy clean from hazardous substances pollution.

The **Circular Economy action plan** was adopted by the EU in 2015. The derived directive on waste (2018/851) sets a **minimum target of 65% of MSW recycling and maximum 10% landfill by 2035**.

According to CEWEP, there are currently +/- 500 dedicated EfW Plants in the EU treating +/- 90 Mt/year of residual MSW and non-hazardous commercial and industrial waste. Approximately 10 Mt/year additional are treated by co-incineration in cement kilns. More than 400 plants from 23 countries are represented in the Confederation of European Waste-to-Energy Plants (CEWEP) which focuses on contributing to European environmental and energy legislation, and to participate in many on-going studies internally and with international organizations such as UNEP, OECD, EU "...all members are committed to ensuring high environmental standards, achieving low emissions and maintaining state of the art energy production from remaining waste which cannot be recycled in a sustainable way". As indicated in the CEWEP Waste-to Energy Sustainability roadmap to 2035: *"EfW will continue to provide essential Waste treatment where Recycling is not appropriate and to offer a source of secondary raw materials and Renewable Energy for the Circular Economy and contribute to the EU's 2030 targets for Greenhouse Gas Emissions ..."*. CEWEP's prediction is that when the EU complies with the above ambitious targets, there will still be a gap of +/- 40 Mt/year EfW capacity as shown on the attached waste flow diagram. It is worth noting that several countries have prepared white books on EfW such as Austria and Italy, see the reference list.

Figure 5

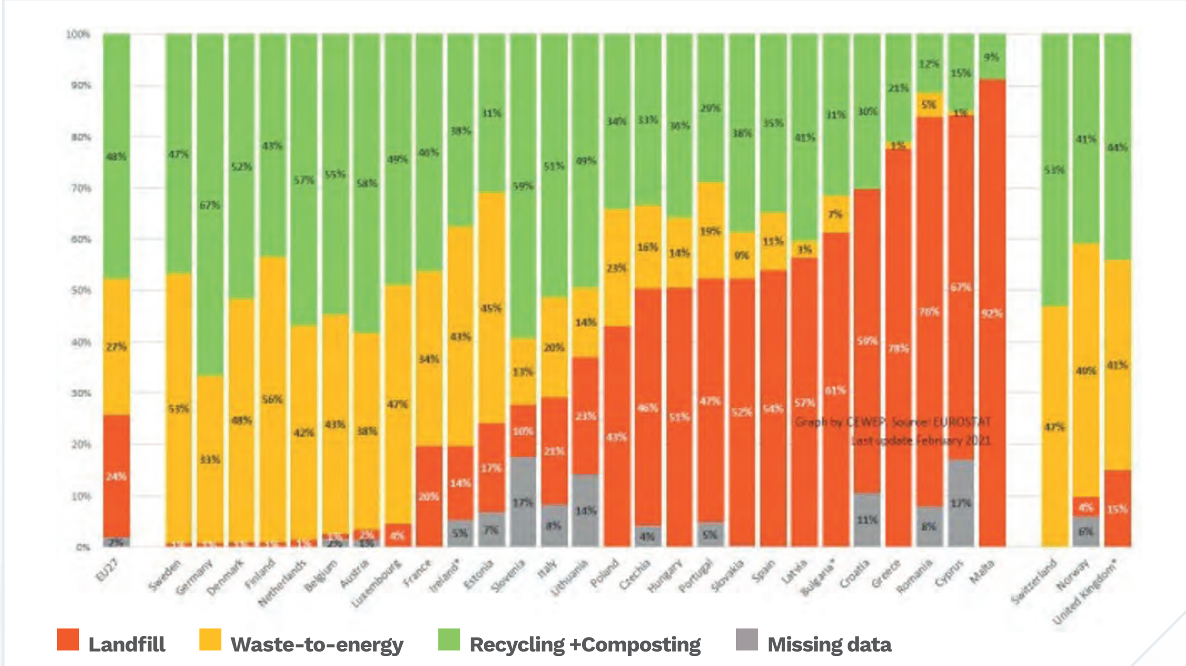
Source: CEWEP

The circular economy package scenario with ambitious targets for commercial waste: 2035

The summary of the different waste treatments in each EU country in the below figure (data source Eurostat, formatted by CEWEP) shows huge differences with countries having well below 5% landfill and others having more than 80%. This also shows that **the countries having the highest percentage of recycling** (Scandinavian Countries, the Netherlands, Germany) **also have the highest percentage of EfW which confirms the complementarity of the two treatments**.

Figure 6

Source: EUROSTAT/CEWEP

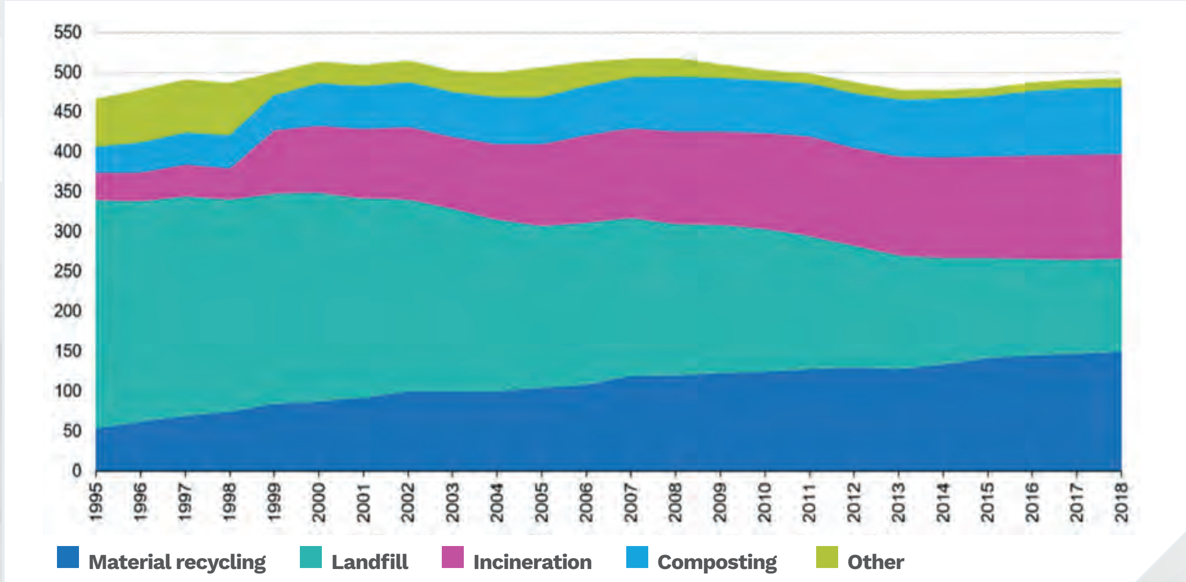


Municipal waste treatment in 2019 (EU 27 + Switzerland, Norway and the UK)

The evolution of waste treatment in EU-27 between 1995 and 2018 (see attached graph from Eurostat) also shows an important reduction in landfill (-60%) together with steady growth in recycling (tripled) and increasing use of EfW.

Figure 7

Source: EUROSTAT



Municipal waste treatment, EU-27, 1995-2017 (kg per capita)

It is also interesting to note that a number of other regulations impacting waste treatment have been published over the years:

- The Landfill Directive was issued in 1999, setting up progressive targets to divert up to 65% of the biodegradable municipal waste going to landfills,
- The Waste Incineration Directive (WID) issued in 2000 defined the maximum emission limits of all pollutants. It was replaced by the Industrial Emissions Directive in 2010. The emissions levels were updated in 2019 by the Best available Technique Reference document (BREF). This BREF update was completed following comprehensive analysis of the actual performances of existing plants, review of all recent health studies and extensive consultations with all stakeholders. This update has been performed in a consistent approach to all industrial sectors in line with the Industrial Emissions Directive (IED).
- The Waste Framework Directive lays down basic waste management principles.

This package of regulations makes EfW the industrial activity which has to comply with very strict industrial emission levels (well below those of power plants or cement kilns for example) and has to report monthly to the relevant authorities with continuous pollution control.

Each EU Member State has developed its own strategy to reach these common targets and comply with the Directives. To reach the objective to reduce the landfill proportion, the countries have often used strong regulation leverages such as Landfill ban or Landfill tax. For example, the UK decided in the late 1990s to drastically divert waste from landfilling. It successfully put in place a Landfill tax with long-term significant increases (+10% / year during between 2004 and 2014). This has demonstrated effectiveness to the whole waste sector and incentivized the necessary investments required for EfW as an essential component of the waste hierarchy. This policy enabled the UK to reduce the landfill proportion from more than 70% down to 15% in the last two decades with the implementation of a mix of Material Recovery Facilities (MRF) and EfW facilities.

As a summary, the 2035 targets concerning recycling and landfilling have been confirmed in the "Green Deal" announced in 2020, and the current implementation shows the **complementarity between Recycling and Energy Recovery (treating Waste which cannot be reused or recycled)**. To further increase the Energy Recovery efficiency, it is strongly encouraged to develop Combined Heat and Power (CHP) schemes whereby steam and / or hot water will be used in parallel to the production of electricity, thus increasing the Energy efficiency and reducing the GHG impacts accordingly.

In order to further enhance the efficiency in energy recovery, the EU has introduced an efficiency criterion called "R1" with a threshold above which the treatment is considered as "recovery" and below which the treatment is considered as "disposal". This has pushed the industry towards more sophisticated process concepts to reach that threshold which may not be cost effective in areas where the energy price remains low (e.g., below 50 € /MWh).

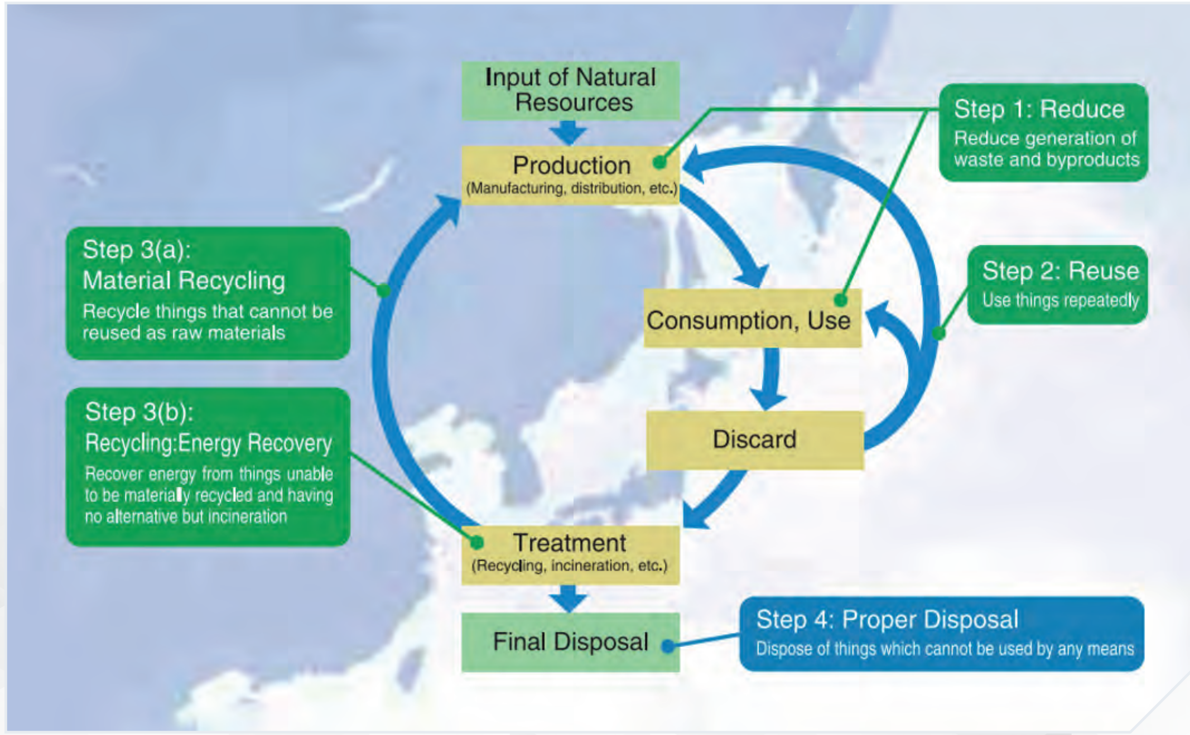
4.4.3 Experience in Japan

As indicated in report issued in from The World Bank in 2018 - What a Waste 2.0: "Japan manages its waste through comprehensive governance and advanced technologies. Of the nearly 44 million tons of waste generated annually, only one percent is landfilled. The remainder is either recycled or converted to energy in state-of-the-art waste-to-energy facilities." The different treatments are considered as complementary to each other.

"All local governments are required to develop a local solid waste management plan that looks ahead about 10 years". "The national government published guidelines to assist the local governments and ensure consistency. The national government also provides subsidies to develop and improve waste treatment facilities." Japan's efficient solid waste management practices can be largely attributed to effective cooperation between its national and local governments. In 2005, Japan started to develop and implement the 3R policy: Reducing waste, Reusing and Recycling resources.

Figure 8

Source: MOEJ



Japanese 3R policy

As shown in the diagram, material recycling and EfW for residual waste go hand in hand for the MSW treatment. With more than a thousand small-scale facilities, EfW is highly developed in Japan. Space for landfilling has always been short on the densely populated Japanese islands and climatic conditions also required a rapid sanitary waste treatment. Landfilling of untreated waste is almost abolished (<1%).

In terms of technologies, more than 90% of these plants are based on grate combustion process.

But due to the guideline of slag melting to safely dispose the ashes (which cannot be used for road construction), Japan has also developed alternative technologies such as fluidized beds and gasification to facilitate the ash vitrification, which was necessary to obtain government subsidies up to 2005. Since 2010, the operation of the ash smelters was no longer required, which significantly reduced the waste treatment costs.

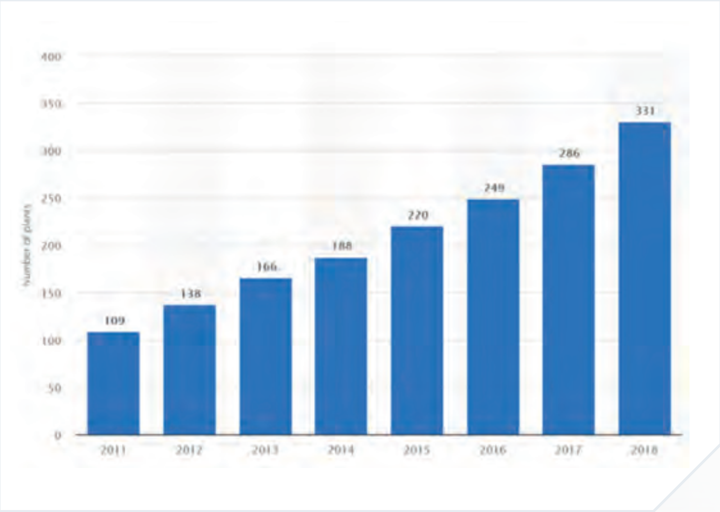
4.4.4 Experience in China

As a result of China's economic growth, the urban growth rate generates a fast-increasing number of very large cities.

The correlated waste amounts have resulted in a growing awareness for the necessity for safe waste disposal in these urban areas. EfW has become an essential part of the Waste Treatment strategy as a key element of the circular economy law issued in 2008 (one of 1st in the world). It has been put in place with very ambitious 5-year plan objectives (especially in the 12th & 13th plans).

Figure 9

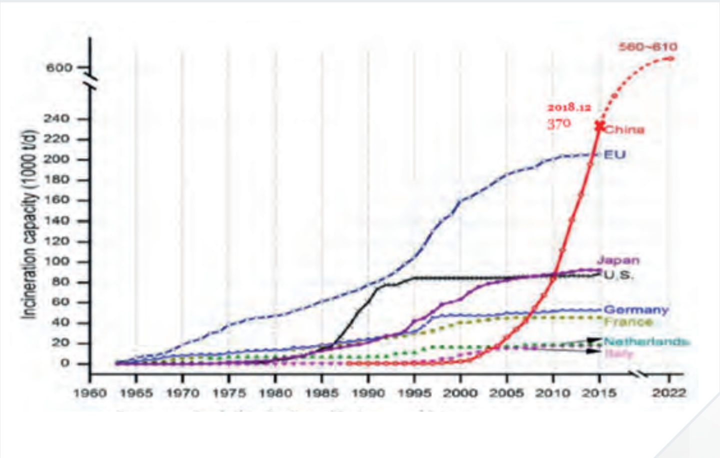
Source: Statista



Number of waste incineration plants in China from 2011 to 2018

Figure 10

Source: South China Institute of Environmental Sciences



Waste-to-energy processing capacity of major countries

Plants were initially based on European technology with license agreements, and are now locally designed, built and operated, with the support of China's central government for the development of EfW for the MSW treatment. China is the world's largest market for the new construction of EfW plants.

The following graph shows the very impressive development of new EfW plants across the country, many of them having a yearly capacity above 500 kt/year. After only 15 years of effort, the total EfW capacity installed in China has now overtaken that in Europe and is expected to double in the next 10 years. This new infrastructure network has already enabled ca. 50% of the MSW generated in China to be properly treated by the 400 EfW facilities.

4.4.5 Plastic Waste

Plastic waste is increasingly of concern with dramatic rise of pollution in the oceans.

The report of the dedicated **ISWA** Task Force on Marine Litter highlights the importance of comprehensive waste collection and treatment to reduce marine litter.

This is confirmed by the World Bank in What a Waste 2.0: "Before pursuing dedicated plastics management solutions, **governments must first focus on holistic management of waste**. Cities need consistent collection services, safe and environmentally sound disposal, and consistent enforcement of policy before targeted interventions for plastic can be fully effective. Without strong basic waste management systems, plastic is likely to continue to be dumped when uncollected."

Plastic recycling / chemical recycling is developing rapidly, and this has been even more necessary since China (and later India) stopped accepting plastic bales coming from Europe for treatment as from January 1st, 2018 (National Sword). The difficulty of recycling plastic is a very wide variety of plastic qualities and a that proper recycling in the chemical industry is dependent upon very clean and homogeneous flows of recycled plastics. To achieve the necessary sorting recommends very sophisticated sorting, which is often not feasible at acceptable economic costs. It also results in low yield of recyclables and high yield of mixed residuals, which still need treatment.

EfW can act as a sink for non-recyclable plastics (not including compostable plastics) and for the pollutants they contain which are effectively treated in the flue gas cleaning systems.

4.4.6 Organic Waste

As mentioned in the §4.3 on waste characteristics, most low- and middle-income countries (even more in the rural areas) have more than 50% food and green waste in the residual MSW. It is possible to separately collect organic kitchen waste to obtain a rather "good quality" non-contaminated stream (this means in particular that pollutants and plastics have to be removed and hygienic precautions should be taken to avoid smell or pathogens' spread). This may be converted to usable compost either as a direct treatment or after Anaerobic Digestion followed by the composting of the digestate, which increases the investment requirements in the facilities.

This approach has already been implemented at local level (ie. mostly in rural areas) and enables us to reduce the need of chemical fertilizers for soil improvement and tends to increase the average LCV of the residual Waste which is beneficial to the energy efficiency of EfW Plants.

NB: one should not confuse biogenic fraction of residual waste and bio-waste/kitchen waste concerned by this separate collection. This flow is much more limited.

4.5 **Evolution** of Waste Management

4.5.1 Initially - uncontrolled Landfill and Dumpsites

Historically, the first collected waste has been transported to open dumps where people manually extracted the materials which could have some value. As mentioned in §4.2, this still represents 40% of the total Worldwide generated MSW.

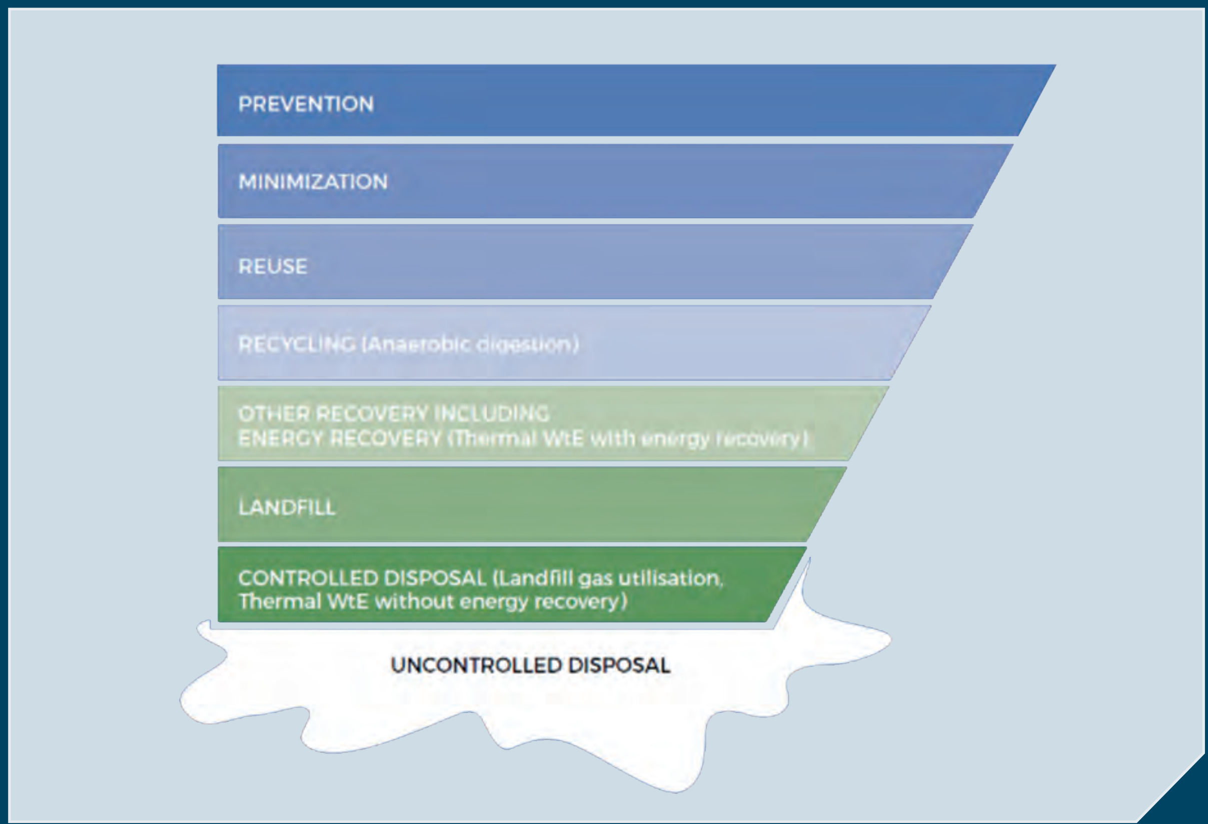
It is considered (**ISWA** Closing Dumpsites, 2016) that 1 million deaths / year are related to poor waste management and that 64 million people health is affected by the 50 biggest dumpsites.

These uncontrolled landfills or dumpsites often contaminate surface water, ground water and / or soil and emit large quantities of greenhouse gases (mainly methane) and also air pollutants such as acids, carbon particles or dioxins due to open burning. This pollution is becoming less acceptable to the public.

In fact, UNEP has defined in 2019 an alternative waste treatment hierarchy whereby landfills are split into different categories to highlight the possible improvements, separating uncontrolled disposal from controlled. The objective is to eradicate catastrophes such as the landslide on the Koshe dump site near Addis Ababa which killed 114 people in March 2017.

Figure 11

Source: UNEP



Waste treatment hierarchy (UNEP 2015; European Commission 2017)

4.5.2 Controlled Landfill

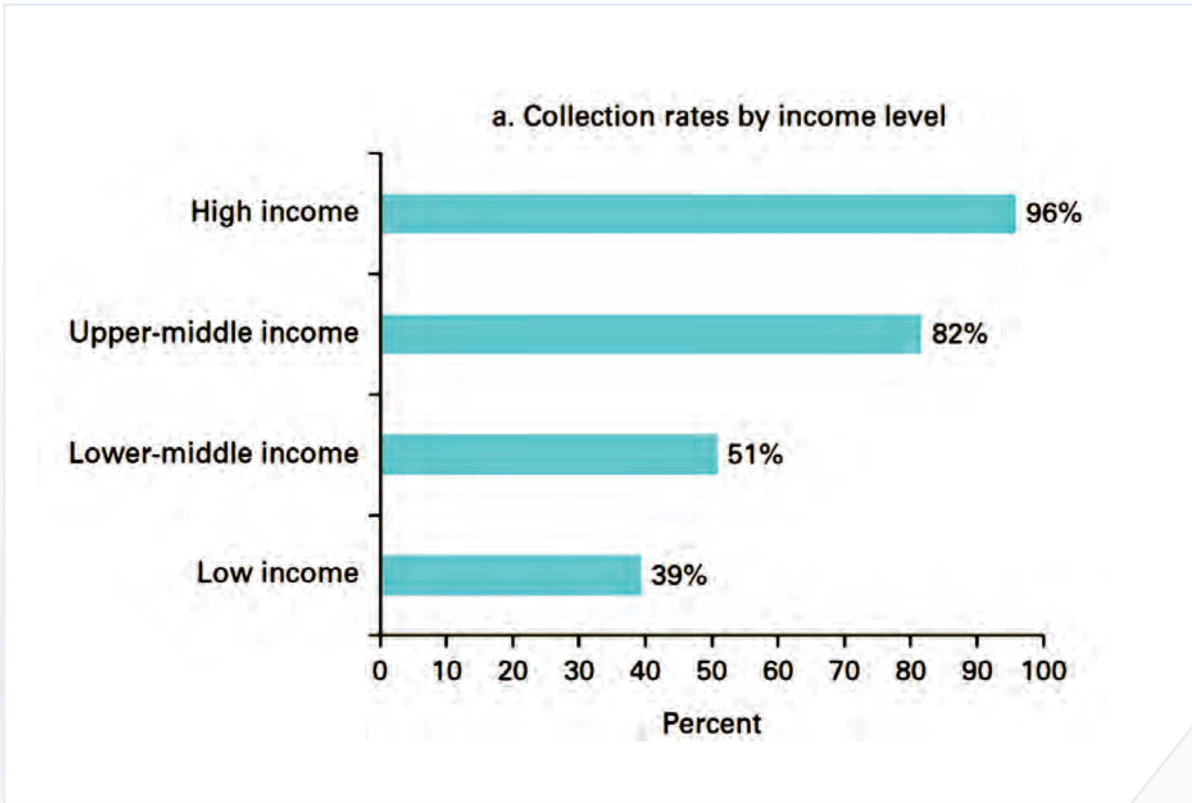
The **first improvement** in waste management is therefore to **eradicate the dumpsites** and replace them with **sanitary landfills**. These often need large new land areas, and these are rarely available near metropolitan areas due to protests, conflicts in land use and rapidly increasing land prices where the cities are growing.

The typical footprint for a landfill able to receive 200 kt/y (ie. less than 1 million inhabitants) for 15 years will be 30 to 50 ha whereas an EfW of similar or even larger capacity will only need an order of magnitude of 4 to 6 ha depending whether there is ash treatment on site. Even smaller sites can be seen at a higher CAPEX.

The improvement of a proper waste management system begins with increasing collection rate (see What a waste attached fig 2.10).

Figure 12

Source: World Bank



Waste collection rates

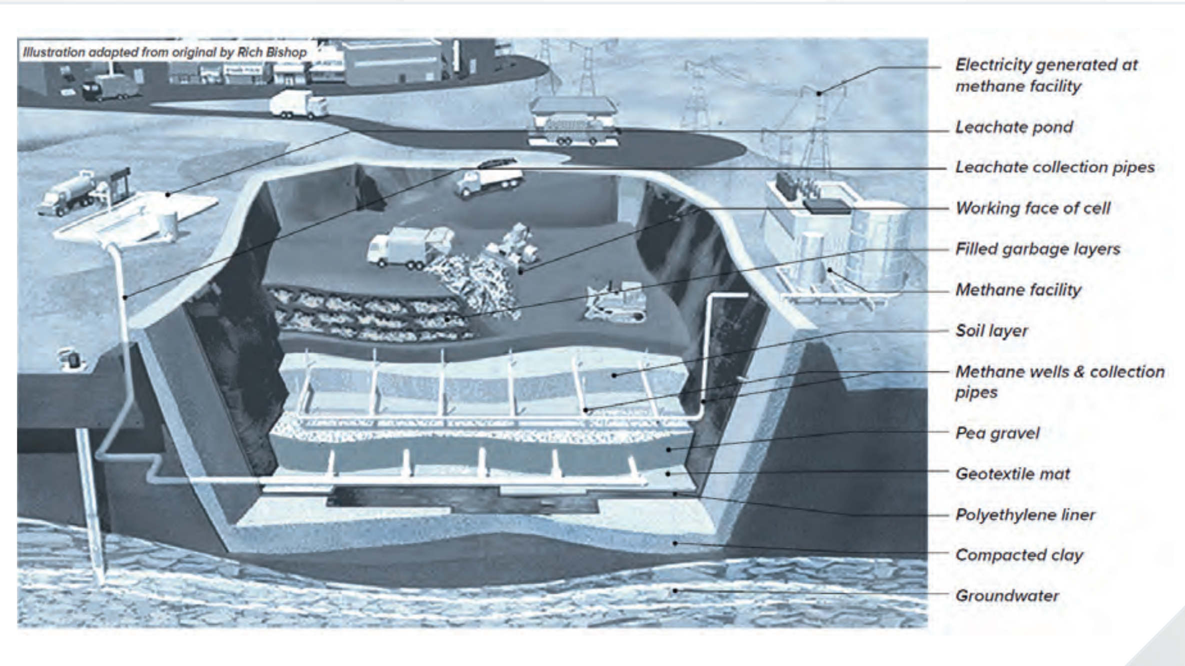
The simplest way is then to transport the waste to a sanitary landfill and use transfer stations and heavy bulk haulage vehicles in case of distances beyond 30 km, as is done in Mexico City for example. A sanitary landfill should preferably be located on a low permeability base, e.g. clay to mitigate the risks of water table pollution. It should have sealing liners at the bottom of the cells, have a controlled waste delivery area to ensure safe access by the trucks, transfer to the waste cell by loader and compacting, daily cover with inert material, leachates collection and treatment (all the more when the waste has a high moisture content or in high rainfall areas), biogas collection and its energy recovery when the volumes are large enough (biogas flaring being the minimum requirement), post-closure monitoring (at least 30 years).

In some cases, separate unloading areas can be implemented to allow for manual sorting on ground or on simple conveyor belts prior to the transfer to the waste cell.

See the schematic diagram from the World Bank:

Figure 13

Source: World Bank



Schematic diagram of a sanitary landfill

4.5.3 Going up the Waste Treatment hierarchy

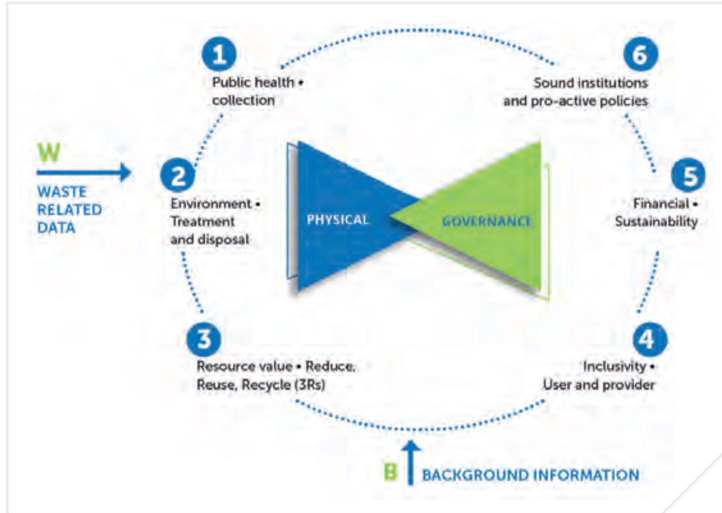
Large urban areas often lack enough space to implement appropriate sanitary landfills, and all intend to improve their carbon footprint. They want to “move up” the waste treatment hierarchy and implement an Integrated Sustainable Waste Management in line with the UNEP schematic framework attached.

This approach implies in the long term a reduction of residual waste volumes, more recycling and the development of a local energy source through EfW preferably (when possible) with heat offtake / CHP. The different and complementary treatments can also be progressively implemented (potentially / preferably on the same landfill site for optimum logistics) as with the “smart treatment” chart in the figure adjacent.

It is important to keep in mind that EfW will not get rid of all waste in the cities, that the energy recovered will not finance the Operational costs (OPEX) and only cover a fraction of the city energy needs and that, overall waste treatment costs become significantly higher than those of a sanitary Landfill and of course significantly higher than those of an open dump. This cost difference can be considerably reduced or even reversed depending on land availability, distance and transportation costs and environmental taxation.

Figure 14

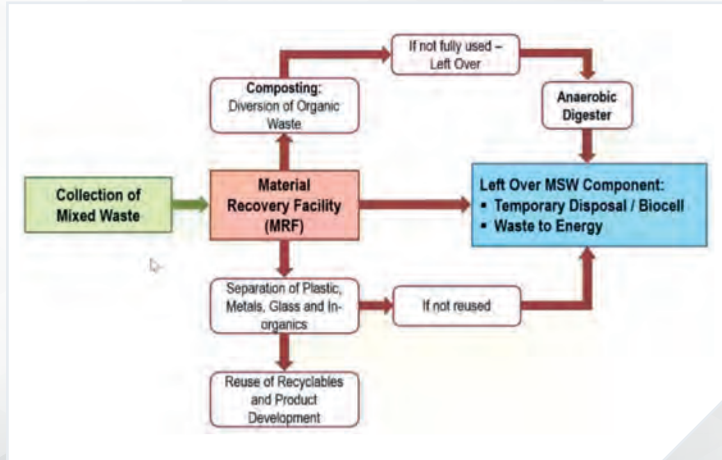
Source: UNEP



Schematic framework of Integrated Sustainable Waste Management
(UNEP 2015)

Figure 15

Source: ISWA

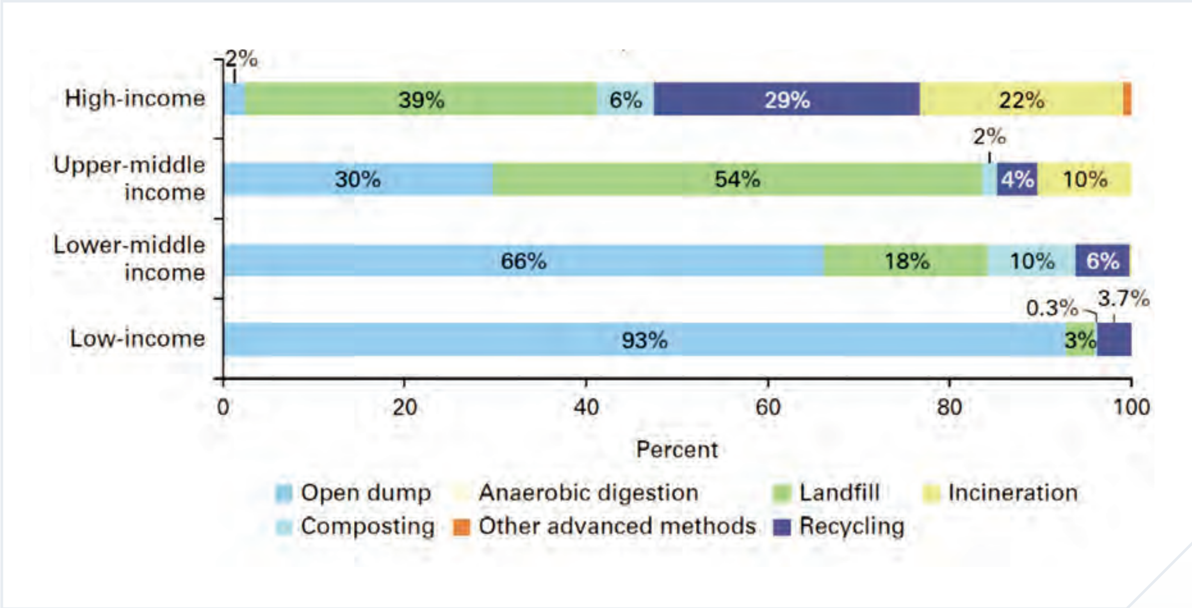


"Smart treatment" chart example for Belgrade waste management

See the disposal methods by income from the World Bank report “What a Waste.”

Figure 16

Source: World Bank



Disposal methods by income

EfW approach can be developed by diverting waste from landfill and at a later stage or in parallel with the implementation of a recycling strategy. An exception could be made for bulky items which cannot be introduced in EfW furnaces except after coarse shredding. At least the impact of a future recycling strategy should be considered in the projection of waste characteristics and quantities, bearing in mind that there will in the foreseeable future be a significant fraction of the waste that still remains non-recyclable and EfW is the best solution for such residual waste.

Recycling strategies need to ensure that there is a market for recyclables (paper, cardboard, glass and metals being the easiest to re-use) and that pollutants are removed from recyclables (as mentioned above, China decided in 2018 to refuse imported recyclable plastics due to their pollutant content). The most efficient recycling is done by the users which means that separate collections have to be developed, preferably in voluntary collection points of single streams which ensures best quality of recyclables or through door-to-door separate collection of recyclables delivering to waste sorting facilities. Intermediate and interim solutions enable progressive change of the cultural view of waste treatment which is necessary to obtain public acceptance of the long-term strategy and its related facilities.

A number of Mechanical and Biological (MBT) plants were developed in Europe to extract recyclables and “stabilize” the organic fraction from residual waste. The quality of the recyclables has in many cases not been good enough to direct recycling and has generated an overall increased residual waste treatment cost.

The development of “EfW is associated with a cross section of stakeholders and includes strategic health, environmental, socio-economic, technical and legal aspects”. UNEP 2019 Waste to Energy – Considerations for Informed Decision – making).

The major drivers of thermal EfW growth in developing countries include:

LAND CONSTRAINTS
Thermal EfW can reduce waste volume and mass by 75-90 percent, thus reducing the demand for landfill space.

ENERGY GENERATION
The energy value in waste can be utilized to generate electricity and heat during the thermal EfW process. The biogenic fraction of waste in thermal EfW can contribute to a portion of a country’s renewable energy.

CLIMATE CHANGE IMPACT
Thermal EfW plants reduce greenhouse gas emissions by diverting waste from landfills and open burning and by replacing fossil fuels, leading to incentives for developing countries to achieve climate goals.

PUBLIC HEALTH AND ENVIRONMENTAL CONCERNS
In many developing countries, waste is often disposed of in open dumpsites. A shift to thermal EfW could improve hygienic and environmental conditions in these countries.

4.5.4 Health aspects

Human health should be the highest priority, and this is for example included in the EU Waste Framework Directive 2008/98/EC which requires Member States to take the necessary measures to ensure that waste management is carried out without endangering human health.

Uncontrolled dumpsites are a health hazard in many respects with contaminants and pathogens in decomposing waste and leachates which can pollute the underground and the ground water, plus regular uncontrolled fires and occasional landslides. The first priority is therefore to eradicate all dumps and non-controlled landfills and replace them where possible with sanitary landfills avoiding direct contact between waste and people and thus drastically reduce the figure of 64 million people affected by the 50 biggest dumpsites (**ISWA** Closing Dumpsites, 2016).

Until the 1990’s incineration was also an air pollution source due to the lack of regulation and control on emissions, leading to basic flue gas cleaning systems and a number of cases with high dioxins emissions. Increasingly stringent regulation / control and efficient flue gas cleaning systems were progressively developed and implemented. In Europe, the EU Waste Incineration Directive in 1989 was a pioneer step for this pollution control regulation. It has been reinforced in 2000 and then in 2010 with the Industrial Emissions Directive.

The CEWEP website https://www.cewep.eu/review-health-studies/ provides an abstract of "Environmental and health risks related to waste incineration" published by Waste Management & Research in 2019: *"In summary, there is no known scientific evidence that EfW plants designed and operated in order to comply with the emission standards in force in developed countries have a significative impact on the environment and the health of people living in their environment. Therefore, the establishment and compliance of emission standards should be sufficient to ensure their safety for the environment. The realization of a previous socio-environmental impact assessment and a participatory follow-up process of their operation are sufficient guarantees for the authorities and the community that the operation of the EfW plant is a virtuous step in the management of waste with the added value of contributing to the reduction of greenhouse gas emissions."*

Many countries have performed various extensive studies which confirm the above and EfW is for example approved by Public Health England following the results of a major study by Imperial College London published in 2018 and 2019. A comprehensive collection and analysis of epidemiological studies conducted in different areas of the planet where EfW plants are present has also been conducted in the "White Paper on Municipal Waste Incineration" by Utilitalia (2021). With regards to emissions into the atmosphere, the impact of the EfW is found to be marginal or insignificant, as reported with various case studies. It is highlighted that there is no evidence about the presence of cancer risk factors or negative effects on reproduction or on human development.

Today, EfW facilities have to comply at all times (i.e. including start-up, shutdown and transient conditions) with the strictest emission standards in the EU Industry. This makes EfW a very safe and clean waste treatment.

In addition to the regulation, it is worth noting that incineration has originally been intended (in the 1900's) for the **safe destruction of pathogens** at high temperatures. Also, from the beginning it was focused on preventing the spread of diseases from waste dumps and uncontrolled landfills through infectious animals (like rats). The delivered waste is put directly into the bunker, and then discharged into the furnace through the feeding chute by an overhead crane, thus avoiding human or animal contact with the contaminated waste. Within a pandemic period, EfW provides an optimal means to prevent unnecessary human contact with any infected waste and in that way presents a high safety margin against viruses and other pathogens.

It is much more important to establish hygienic precautions for both biological treatment (that does not destroy viruses) and all kinds of mechanical separation processes necessary for recycling.

4.5.5 Climate Change

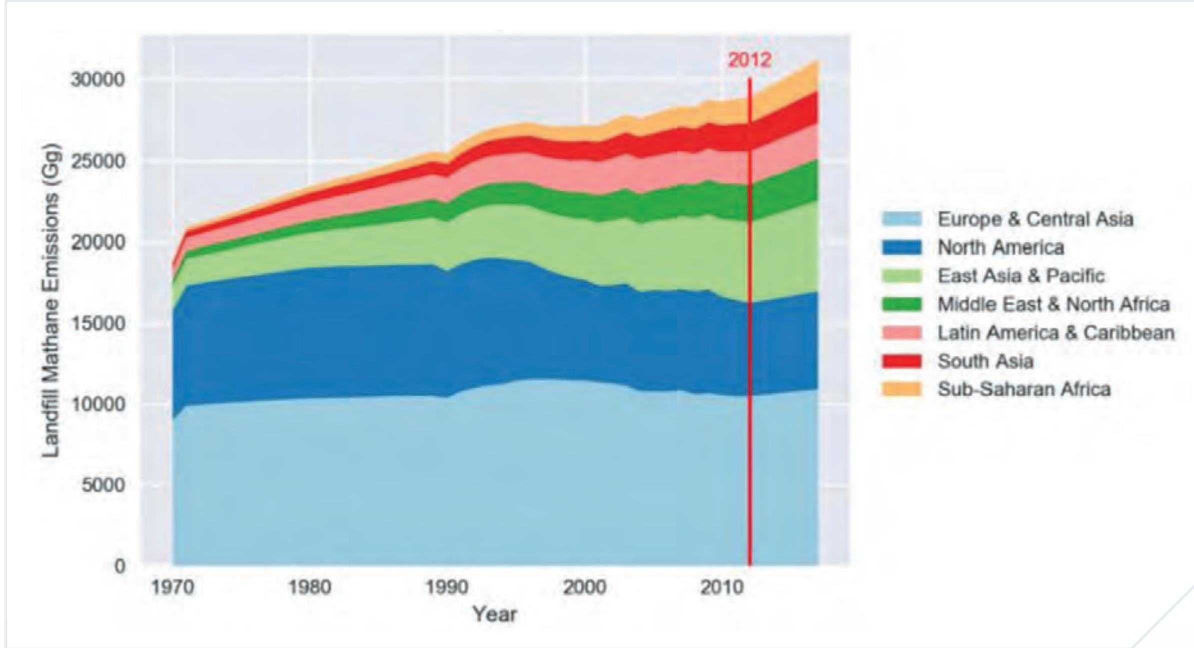
Waste treatment has a significant impact on Climate Change and Greenhouse Gas (GHG) Emissions. The UK considered that waste management emitted 10% of total GHG in the UK in 2000 (Department for Business, Energy & Industrial Strategy,2021) before starting with the development of modern EfW, whereas the EPA from USA assessed that landfills account for almost 26 % of total US anthropogenic methane emissions, the largest contribution of any single CH_4 source in the United States (USEPA, 2016). In Europe, waste landfilling represented 28% of the methane emissions in 2017. (Eurostat) This GHG emission from waste landfill in EU28 represents more than 5 times the GHG emitted by air transport. (CGDD, 2020) This confirms the importance of selecting waste treatment method.

A critical factor regarding the landfills relates to the organic fraction of the waste which generate methane and has a Global Warming Potential (GWP) 28 times higher than CO_2 when looking at 100 years' time horizon, and 84 times higher than CO_2 when looking at 20 years' time horizon (CGDD, 2020).

As the population grows and becomes more urban, more waste is produced and consequently, the potential for more methane to be released into the air increases. As can be seen in the figure (Global methane budget, 2020), volumes of methane have been increasing over the years, contributing to climate change.

Figure 17

Source: CGDD



Landfill Methane Emissions by World Region 1970 - 2017

Also, in the UK, DEFRA Carbon modelling 2014 considered that well managed UK Landfills capture 75% of the methane being generated, versus 60 to 85% estimated by the EPA in the USA, and often below 50% in developing countries due to reduced technical standards and costs limitations (GIZ report 2017).

The worst situation is dumpsites, uncontrolled and uncovered landfills with no capture of the methane generated. In addition, uncontrolled landfills also have a vital impact at local level, since they are prone to large spontaneous fires where all pollutants are released in the atmosphere. In most cases, such landfills do not collect nor treat the leachates which also release pollutants in the ground water and / or in the subsoil.

Collecting and treating the leachates and capturing the methane produced in landfill and flaring such gas is therefore the first most efficient step in reducing waste related GHG emissions by converting methane in CO_2. Energy Recovery from captured methane then enables generation of some renewable energy (up to 150 kWh/t of waste).

The problem of methane emissions from landfills has also been assessed in October 2020 by the European Commission through the Methane Strategy. The Commission recognizes that more stringent compliance with standard landfills operation and diversion of biodegradable waste from landfills are needed to further reduce methane emissions from waste.

In comparison, EfW ensures a complete waste combustion which converts the carbon in CO_2 and the recovery of non-intermittent energy:

- The **"Biogenic"** fraction (50 to 60% in Europe, more in developing countries - refer to waste characteristics in § 4.3) of the carbon in the waste being considered as **GHG free (Biomass)**. This has been confirmed by various studies including the project "UIOM 14C" in France.
- The **"Fossil"** fraction of the carbon ion the waste generating energy which replaces existing energy generation. The **offset CO_2** can be calculated using the local energy mix or more appropriately the marginal energy production (generally using fossil fuel). It can also be considered that this "fossil" fraction would be lost in the waste if landfilled and as such is a "fatal" source of energy to be used before extracting fossil fuels to generate energy.
- EfW therefore contributes to the decarbonization of electricity production which is key to reduce the overall CO_2 emissions.

- Furthermore, MSW is a stable/ non-intermittent and locally produced “Energy Source” and thus avoids fuel / energy transport-related emissions and reduces the dependence on fossil fuel imports and impact of fuel market price fluctuations.
- EfW enables the generation of 600 kWh/t (in case of electricity generation) to 1000 in case of CHP and up to 2000 kWh/t of waste in case of 100% heat recovery. EfW therefore contributes to the production of significant local baseload renewable energy.
- EfW enables recovery and recycling of ferrous and highly valued non-ferrous metals from the ashes.
- In many countries, the local regulation defines the regulation to be complied with to use EfW bottom ashes as construction aggregates replacing virgin materials, which may also be considered as recycling. In most cases only a very small fraction of bottom ashes is landfilled.
- This material recycling (metals and aggregates) is also avoiding important GHG emissions emitted during their production.

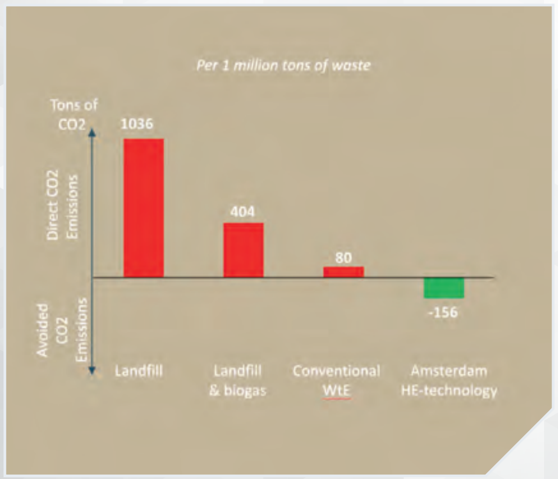
Many studies have tried to evaluate the actual impact of different waste treatments, and the results depend on numerous factors such as the waste composition, the ratio between the export of heat (which is more effective) versus electricity and country energy substitution mix. It is generally considered that savings in the range of 200 to 800 kg of CO_2 per ton of waste (or even more than 1000 kg as stated by the UN) will be realized if EfW replaces landfilling by avoiding the methane emissions (see attached graph from Amsterdam comparing different landfill and EfW cases). The increase in plastic recycling rate will be a way to further reduce the fossil CO_2 emissions of EfW.

About 60 million tons of municipal waste are still landfilled in Europe (Eurostat 2018, data of 2016), and almost 200 million tons considering all the waste streams (except mineral waste).
To divert these waste streams to Waste-to-Energy instead would prevent around **875 kg of CO_2 eq/ton** (German environment agency – UBA – The Climate Change Mitigation potential of the waste sector – 2015). Considering that a significant part of it could be also recycled, a total saving of more than **175 million tons of CO_2 eq** (more than the annual CO_2 emissions from fossil fuels of the Netherlands) could be achieved every year by shifting waste from landfilling to a higher treatment in the waste hierarchy (CEWEP - ESWET, 2018).

In conclusion, EfW is therefore an environmentally safe and sustainable treatment of waste. EfW has in any case a smaller GHG impact than any landfill solutions. Note (landfill CH_4 emissions are very difficult to measure).

Figure 18

Source: Unleashing the power of waste -Amsterdam



Overall Greenhouse Effect

4.5.6 Introduction to costs of different Waste Treatment approaches

As mentioned above, moving up the waste treatment hierarchy entails increasing waste management costs.

As explained by the World Bank in ‘What a waste 2.0’ (see tables 5.2 and 5.5 attached), the financing of waste management systems is often one of the greatest concerns for municipalities. Capital costs (CAPEX) associated with infrastructure and equipment are often at least partially supported by subsidies or donations. Operational expenditure (OPEX) typically requires “a solid cost recovery system for long-term sustainability”, often based on a standard user fee / waste collection and treatment tax which may be variable depending on the income of the residents.

Figure 19

Source: World Bank

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

Typical Waste Management Cost by Disposal Type (US$/tonne)

Figure 20

Source: World Bank

	Average fees, US$ per year	
Income group	Household	Commercial
High income	$168	$314
Upper-middle income	$52	$235
Lower-middle income	$47	$173
Low income	$37	$155

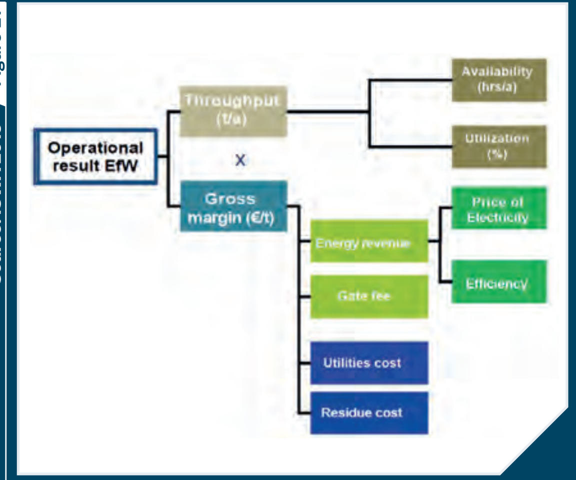
Waste Management User Fees by Income Level (All currency amounts are in US$)

EfW CAPEX and OPEX ranges will be provided later in this paper for advanced moving grate technologies, but a ballpark figure of 50 to 100 US$/ton should be considered for the total costs in “low- or middle-income countries”. There are not enough alternative technology plants in commercial operation being proposed by reliable contractors to obtain / provide associated meaningful CAPEX and OPEX figures.

Figures 19 and 20 show the typical cost breakdown to check the balance between income (gate fee and energy revenue) and costs (utilities and residues) to reach a positive operational result of the EfW plant (source (**ISWA**, 2013). Reliable quantities and costs are required to demonstrate the bankability of a project.

Figure 21

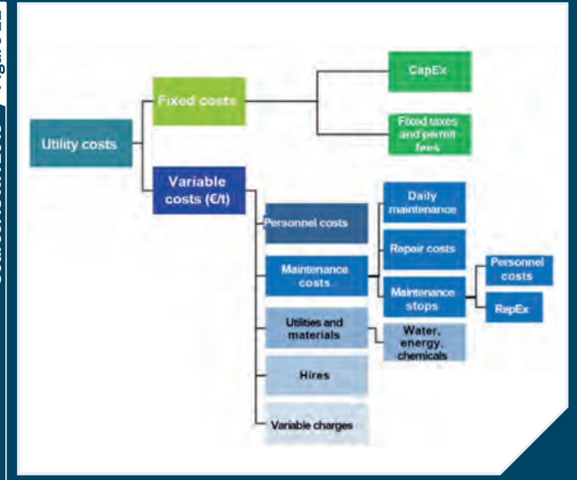
Source: ISWA 2013



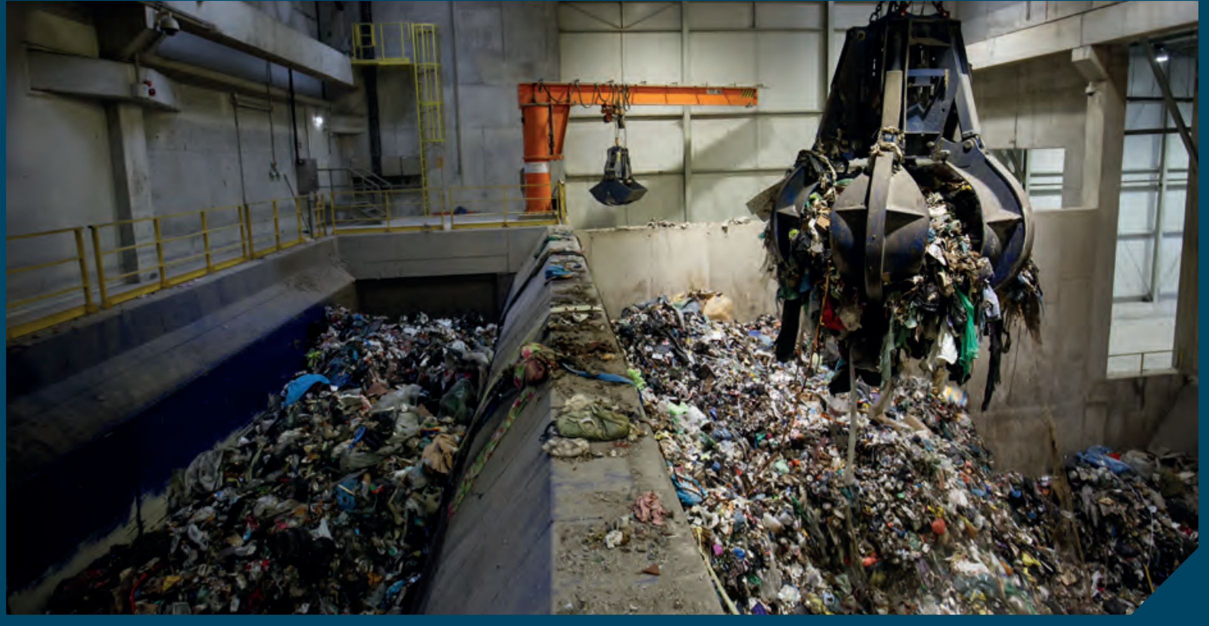
Overview of the value chain for a thermal waste conversation installation

Figure 22

Source: ISWA 2013



Overview of utility cost items within a thermal waste conversation installation



5 EfW technologies

5.1 Introduction to EfW

An EfW plant/facility has to comply with a number of constraints as required in a related permit for operation granted by the authorities to achieve a high level of protection of human health and environment.

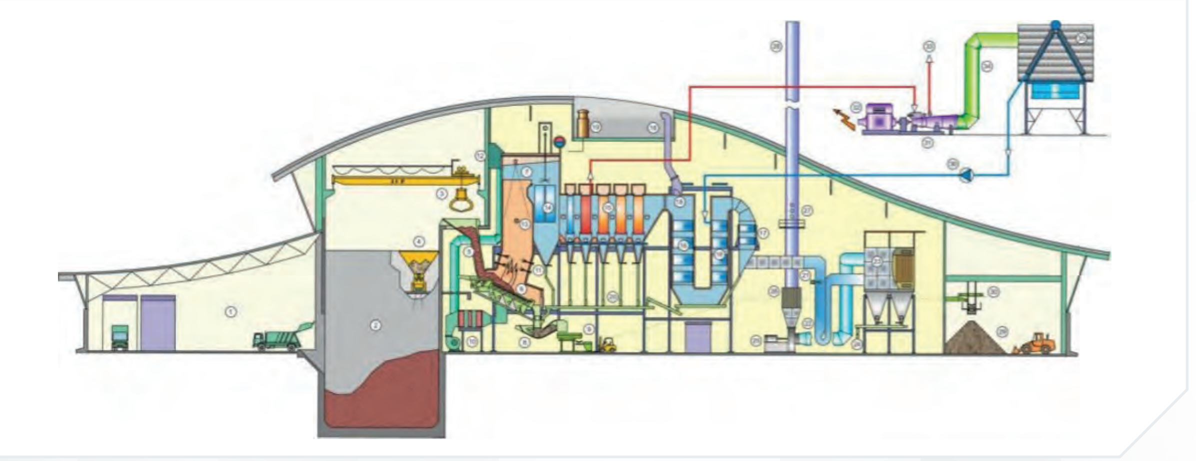
The most scrutinised topic is the **Emissions to air**: the EU Industrial Emissions Directive (IED) has set a comprehensive list of emission limit values to be permanently monitored at the stack outlet. As mentioned in §4.4.2 these limits have been recently updated in the BREF Revision.

The permit also defines the other acceptable residues and operating conditions, and in more and more cases, no water is allowed to be discharged into the environment.

An EfW can typically be split in several main areas:

Figure 23

Source: CNIM/Martin



Typical EfW cross section

- Waste delivery and storage. The waste is brought to the plant directly by collection trucks if the plant is close enough to residential areas, or by larger transportation vehicles loaded in transfer stations. The waste is first deposited in a large concrete bunker and then fed into the combustion chamber using remotely driven overhead cranes. This ensures that there is no direct contact between the plant workers or the truck drivers and the waste.
- Combustion. Once automatically fed into the furnace via the hopper, the waste is generally dried out by the surrounding heat and then burned.
- Energy recovery. The combustion heat is recovered in a boiler to produce steam which may be exported for industrial use and / or district heating and the complement is to generate electricity through a steam turbine and generator.
- The flue gas cleaning (FGC) systems are designed to inject various reagents to neutralize all acids formed during the combustion by the chlorine and sulfur contained in the waste and capture all residues which are gathered in Air Pollution Control Residues (APCR) to be disposed of in hazardous waste landfill. These represent an average of 3% of the incoming waste tonnage. One of the State-of-the-Art flue gas cleaning process is a SNCR (Selective Non-Catalytic Reduction) + “Dry” FGC which means an injection of ammonia-based solution in the upper part of the boiler to reduce the NOx (Nitrogen oxides) plus an injection of a dry reagent downstream the boiler to neutralize the acids with a bag filter to capture and collect all fine particulates. This process is relatively simple, efficient and therefore adequate for many countries.

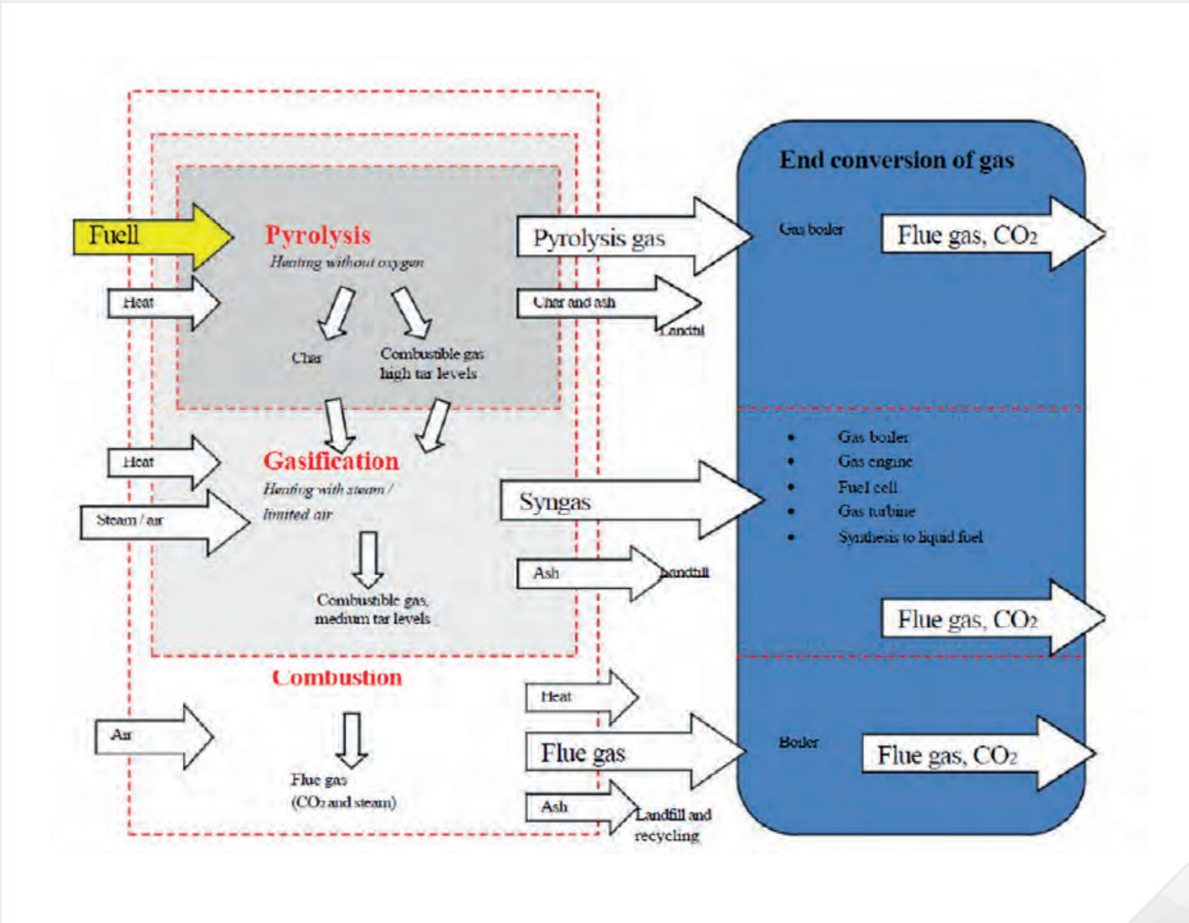
5.2 Principles of combustion

Complete thermal conversion of waste consists of a sequence of pyrolysis, gasification and/ or combustion steps. Within a conventional EfW combustion system, these three steps are integrated, whereas in the case of alternative conversion systems, an intermediate product is generated, and the combustion step is carried through later. The figure below presents an overview of the steps and processes within waste conversion. It shows that any thermal treatment begins with a pyrolysis process. If heat and steam, or in limited amounts air, is added then gasification occurs. If excess amount of air is admitted then complete combustion takes place." (**ISWA**, 2013)

The incomplete combustion obtained by pyrolysis or gasification generates intermediate products with a significant carbon content which cannot be easily disposed of. This is why many alternative processes add heat and / or air as a second (and sometimes separate) step to complete the carbon oxidation. This means that in most cases, the alternative processes end up in complete although staged combustion.

Figure 24

Source: ISWA 2013



Overview on conversion steps within total thermal waste conversion processes and end uses of intermediate product

5.3 Introduction to Waste Preparation

As the purpose of this paper is to review the technologies to treat **residual MSW**, we will first look at the **proven technology able to treat waste as delivered**, i.e. without any pre-treatment.

We will then address the technologies which require a **pre-treatment** before the conversion process with a split between **"proven"** and **"unproven technologies"**.

Such mechanical pre-treatments generally include a minimum of waste shredding (typically in 2 stages) and metal separation (ferrous and non-ferrous) to prepare a Refused Derived Fuel (RDF).

Some technologies require a higher fuel quality with a specification to define the detailed characteristics such as granulometry, acceptable chemical and moisture contents, calorific value (LCV). This often includes a maximum chlorine content which means that PVC removal may be required. The prepared fuel in compliance with such specification is called a Solid Recovered Fuel (SRF) and generally has higher LCV than RDF. In Europe, the standard EN15359 has been issued to define a classification scheme, quality requirements and compliance rules, since the preparation is mostly not done by the process user.

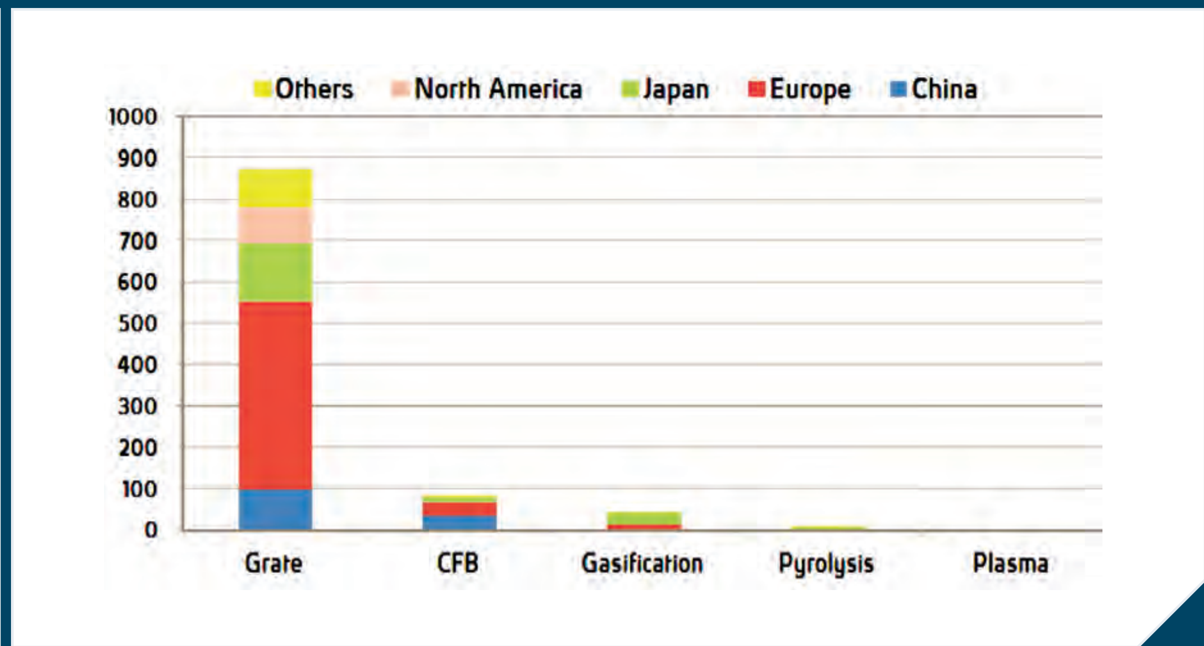
The preparation of RDF or SRF implies double storage and handling, complex and dusty pre-processing plants generating significantly higher costs.

As a matter of principle, we consider a technology to be proven when it has reached the commercial stage for a capacity appropriate to its use and when several plants have been built under such commercial conditions and have been in continuous operation for a number of years with MSW as main fuel.

At this stage, it is important to know the split of the different technologies in the world. See below a graph with data from the 2016 ECOPROG report which show that nearly 90% of the plants in commercial operation (with capacity > 5t/h) worldwide are using grate combustion systems, less than 10% are using fluidized beds, and a few % only are using gasification, mainly in Japan. Pyrolysis and plasma are "not visible" at this scale.

Figure 25

Source: Ecoprog data



Number of EfW plants (>5t MSW/h) in commercial operation broken down by world region and by thermal technology

5.4 Unprepared waste: Advanced Moving Grate Combustion

5.4.1 Principles

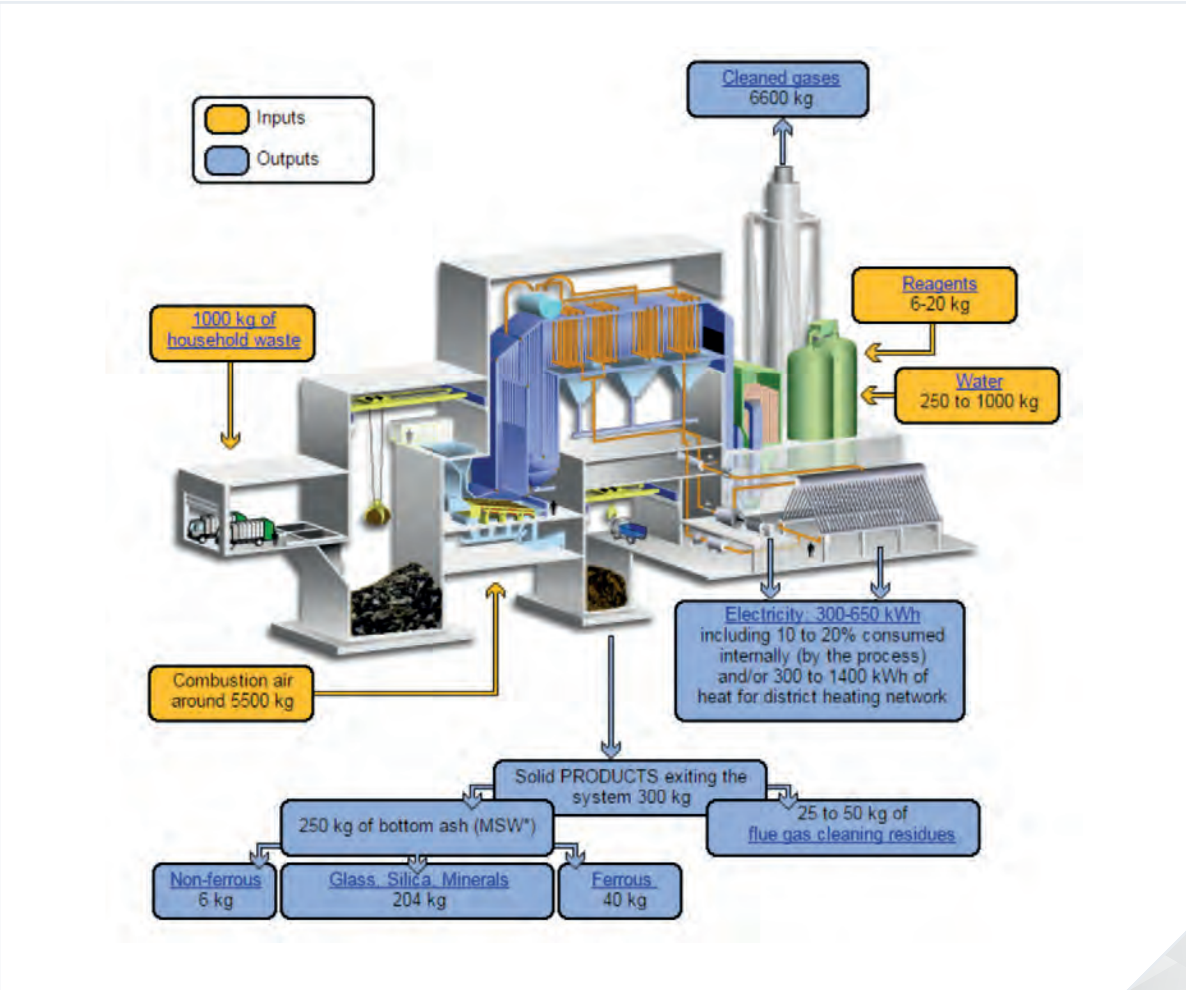
The figure below shows the basic inputs and outputs of an EfW with an advanced moving grate combustion process.

The first combustion plants were developed more than a century ago. Considerable incremental improvements have been made since then in their design, pollution control, automation, monitoring and overall performances, hence the definition of "Advanced Moving Grate Combustion" comes in place of obsolete incineration of the past (without energy recovery or flue gas treatment) which was considered a highly polluting activity.

The key feature compared with other technologies is that waste can be treated "as delivered".

Figure 26

Source: CNIM



EfW Combustion plant - Typical inputs and outputs for 1t of waste

5.4.2 Waste input

Advanced Combustion moving grates enable the direct treatment of a wide range of unprepared wastes to be efficiently burned, with some specific features in extreme cases such as very wet / low LCV waste: this can include the drainage of the waste bunker and appropriate treatment of leachates (with possible introduction above the furnace) are then implemented as it is the case in many Chinese plants. Some specific features can also be implemented to improve the drying of waste and improve combustion such as the increase of combustion air temperature, and a longer than usual combustion chamber.

Large items of non-combustible waste should however be avoided to prevent feeder, grate or ash extraction blockages. Burnable bulky waste could be shredded before their introduction in the furnace. Some other types of specific waste could be co-combusted mixed with MSW such as commercial & industrial non-hazardous waste and clinical waste or sewage sludge in limited quantities (ca.10%).

Advanced combustion moving grates can also efficiently burn higher LCV fractions and RDF.

5.4.3 Output

- **Energy**: Given the standard high availability rate (> 90%), the most efficient concept is when all heat produced can be exported to a nearby outside consumer, which reduces the losses to a minimum. Alternatively, a "Combined Heat and Power" production will enable use of as much heat as possible through district heating networks or industries located in the vicinity and generate electricity with the remainder steam. When no heat users are available, the plant can be designed for 100% electricity production. For such cases, there have been many developments to optimize the export of electricity with, in particular, increasing steam pressure and temperature. To maximize the energy recovery, new plants should preferably be installed near large heat consumers.
- The **"bottom ashes"** generally represent 20-25% of the incoming waste tonnage and are collected, cooled down and temporarily stored on site. They represent the incombustible inert part of the waste with important quantities of metals and minerals which offer opportunities for recycling. They can then be treated to recycle metals (with today separation of ferrous and non-ferrous metals to increase the corresponding revenues) and to prepare aggregates which can be used as sub-base material in road construction or the like when complying with the local regulation. Depending on land availability, such treatment and preparation may take place on the same site, or the bottom ash can be transported to a remote place for treatment before use as secondary material.

5.4.4 Experience / development

The design of combustion grates allows for efficient and complete combustion thanks to increasingly more automated control systems that permanently analyze and adapt an increasing number of operating parameters and take into account the variations in waste characteristics. The modern grates also ensure a very high availability with 1 annual planned outage of 2 to 3 weeks to inspect and repair / replace the necessary components.

The boiler design has also been drastically improved to provide better availability (temperature control, material selection, online cleaning etc.) and increased efficiency.

The flue gas cleaning process has to meet constantly decreasing emission limits without compromising the availability of the plant nor its energy recovery. Hence the dry process ticks all the boxes in general.

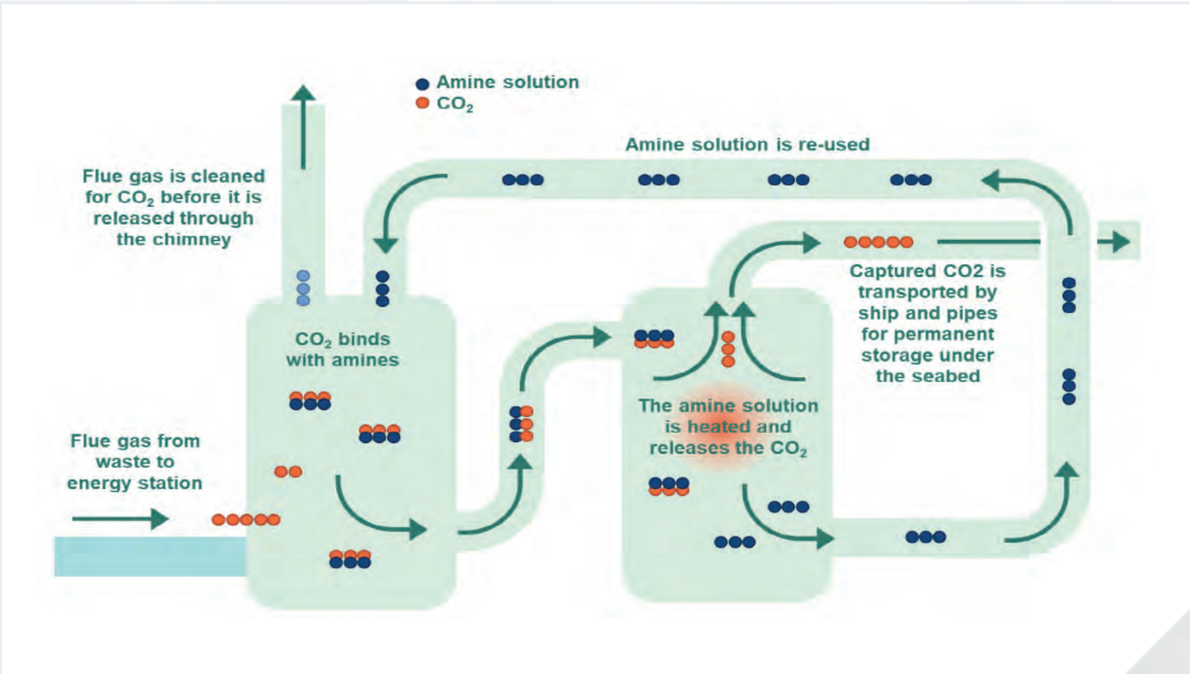
The electricity generation is a somewhat more conventional island which has nevertheless been also the center of optimizations (steam cycle, condensing systems etc.) and more reliable performances.

Although the principle of technology was initiated a century ago, innovative technologies are continuously developed to improve overall performances and reduce emissions, leading to modern very efficient and reliable plants.

In order to further reduce its GHG impact, the CO_2 capture from the Flue Gas is also under development and is likely to be implemented on some existing EfW plants. The captured CO_2 should then be sent to a deep underground storage area as part of a Carbon Capture and Storage scheme (CCS). Some technologies already exist but the overall costs remain very high at this initial stage, and they could only be contemplated for large plants.

EfW is becoming more recognized as a reliable safe and clean energy source. Its renewable but non-intermittent characteristic is also interesting for the production of emission free Hydrogen to feed local vehicles such as buses. (Examples of this can be seen at the Wuppertal EfW in Germany and in Creteil in France as from 2022).

Figure 27



Source: Fortum Oslo Varme

Technology - CO_2 - capture

5.4.5 Contractors

Most renowned construction contractors originate from Europe. The European EfW market has undergone some consolidations and is still evolving, but there remain a significant number of EPC contractors, capable of providing a complete plant and taking the associated budget, delay and performance risks. This is often a pre-requisite to set up a project finance scheme.

The operation of EfW Plants is much more complex than the operation of a sanitary landfill since this is a fully industrialized process plant with many mechanical, chemical, electrical components as well as high pressure parts. This means that such an operation requires a well experienced organization with fully trained management and technical personnel, preferably with a strong back office. In some European countries where there is a long-standing experience of EfW, some plants are operated by public companies. This approach is not recommended for countries which begin the implementation of EfW, as reputable private companies can provide long-term commitment with associated price and performance guarantees, which is essential to ensure a long-term success (see more details in §6.6)

5.4.6 Capacity / Costing

This advanced moving grate technology can be tailored to suit a very large range of capacity per line from 6t/h to 50 t/h i.e. 50 to 400 kt/y per line, with thermal input now potentially exceeding 120 MWth/line. Concerning the plant as a whole, its total capacity is recommended to be at least 150 kt/y for scale effects for the investment amortization and 300 to 500 kt/y capacity is the most sensible.

In the past, EfW plants had a minimum of 2 or 3 lines to ensure a continuous service all year round. Nowadays, the high availability which is obtained on this reliable technology (+92%) allows building plants with only one line with an optimized maintenance program.

Below some orders of magnitude for **costs in Eastern Europe** or similar based on:

- Fuel: typical Residual Municipal Solid Waste
- No land costs (considered as provided free of charge by the Authority), and ground conditions allowing conventional foundations
- Project development and Permitting costs to be added
- “Standard” architectural requirements
- Emissions requirements in line with the Industrial Emissions Directive
- BOT contract whereby the contractor finances the CAPEX and is paid back with tipping fee per tonne of waste over 25+ years.
- Well established bankability of the project with payment guarantees limited currency risk.
- Energy sales: electricity only at 40- 50€/MWhe

This estimate provides some reference data which should remain valid in principle in different countries. The OPEX figures (and to a lesser extent the CAPEX) could however be significantly lower in low-income countries.

The gate fee covers CAPEX and OPEX expenditures minus the revenues from the energy selling and material recycling.

This table shows the significance of the “scale effect” when developing larger plants.

Plant capacity kt/y	CAPEX in M€	OPEX €/t	Energy rev. €/t	Gate fee €/t
150	150	40 to 50	20 to 30	80 to 100
500	300	30 to 40	20 to 30	50 to 80

Rather than the annual mass capacity, the “size” of an EfW plant for its design and its CAPEX amount are mainly fixed by the thermal power input of the plant, which is the product of its hourly capacity by the calorific value of the fuel.

For example, a facility designed to treat 10t/h of residual MSW with an LCV of 8MJ/kg will develop a thermal power of 8x10x1000/3600 = 22MWth.

It will cost and produce the same energy quantity as a facility designed to treat 8t/h of residual MSW with an LCV of 10MJ/kg with the same thermal power input of c.22MW.

This means that:

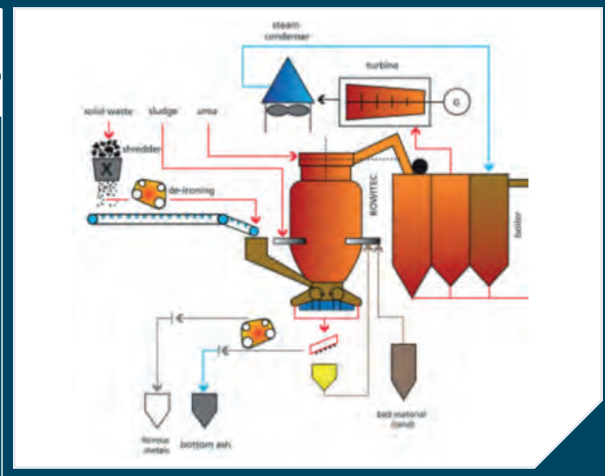
- The pre-treatment in order to increase the LCV up-stream the EfW is in general not viable (except for very low LCV to improve the self-combustion of the fuel)
- With an increase of the LCV for example from 8 to 10MJ/kg (+25%), the size of a facility with an hourly capacity of 10t/h will increase from c.22MWth to 28MWth (+25%), the CAPEX will roughly cost 15% more, the OPEX will be roughly the same and the energy revenues will increase by 25%.

5.5 Prepared waste: Proven technology

As indicated in the split of different technologies in operation in the world, the second most common technology is the fluidized bed combustion process. This technology requires a significant upstream waste preparation as explained in § 5.3.

Figure 28

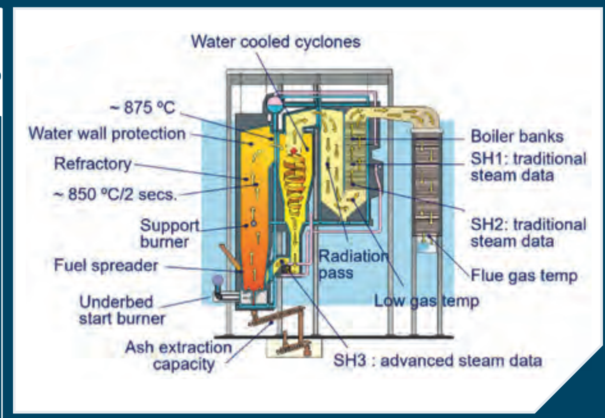
Source: EBARA



Bubbling Fluidised Bed typical cross section

Figure 29

Source: Valmet



Circulating Fluidised Bed typical cross section

5.5.1 Fluidised Beds combustion (FB)

5.5.1.1 Principles

The prepared waste is mechanically introduced to the furnace, where a large quantity of sand is maintained in suspension by a significant air stream at a temperature of around 700°C. The waste can then burn in a +/- minute compared with +/- 1h in an advanced moving grate. The combustion part is mechanically simpler than the advanced moving grate, but the preparation, operation, waste and residues handling are more complex and average yearly availability is 7500 to 7800h as opposed to 8000 to 8200h for advanced moving grates.

Most fluidized beds in operation burning waste (RDF) are “bubbling bed” where the flue gases exiting the generally not cooled furnace are at a relatively low temperature (hence limiting the steam characteristics and thermal efficiency) with a high load of dust (typically 10 times more than advanced moving grate). Size is somehow limited for this process.

Only a few plants are equipped with a “circulating fluidized bed” which enables larger capacity per line and higher steam characteristics but also need chlorine removal during the preparation stage (SRF) and are more complex and sensitive in operation. This technology is used more for specific waste streams and biomass.

5.5.1.2 Waste Input

Most waste burning plants with fluidized bed technology use "bubbling beds" which require some MSW fuel preparation (RDF type) but not as stringent criteria as the "circulating fluidized bed" (SRF type). In both cases, a mechanical waste pre-treatment is necessary to ensure a significant size reduction (to allow the fluidization of the waste) and the removal of most metals (large parts in particular). This means that residual MSW needs to go through a double stage shredding (preliminary shredding plus granulator). Some providers sometimes claim that a single shredding stage is sufficient, but experience has proven that this is not the case because the mechanical feeders and ash extraction, mostly with screws, become a weak part in the system with associated unavailability and high maintenance costs. The metal separation should include ferrous and non-ferrous extraction machinery.

Some plants receive residual MSW and integrate the preparation on the same site.

This technology is of interest when significant quantities of sewage sludge (from Wastewater Treatment Plants) have to be burned together in the same furnace rather than in 2 separate plants thanks to the heat inertia of the bed which maintains a constant temperature.

5.5.1.3 Output

- **Energy**: the bubbling beds net efficiency is **lower than advanced moving grates** due to lower steam characteristics, the much higher parasitic load (waste preparation but also the high air pressure needed for fluidization), more heat losses (not cooled furnace, sand extraction at high temperature) and therefore achieve a less favorable GHG impact than advanced moving grates.
- **The bottom ashes recovered under the bed** are not usable in general in road construction because it is dry, not compactable, and more heterogeneous, but remaining metals can be efficiently extracted for recycling.
- There are much more **APCR** than with advanced moving grates (3 to 4 times) due to the quantity of dust entrained by fluidization. These are hazardous wastes to be disposed of in specific landfills at a high cost.
- The overall result is much more residues.

5.5.1.4 Experience / development

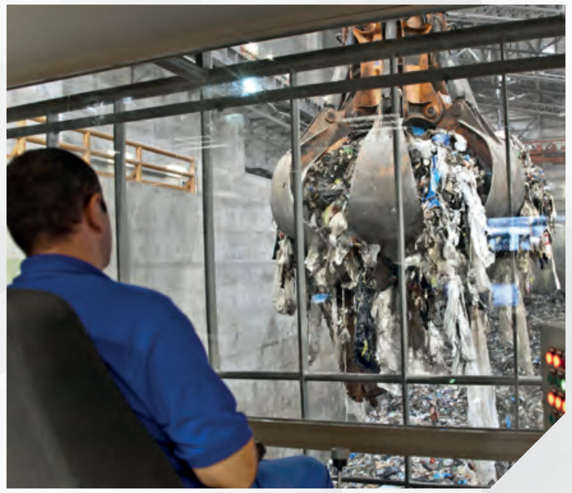
As shown in the table §4.3 the fluidized bed technology is the second most installed technology (+/- 10%) but there are few EPC contractors available and only a very limited number of technology providers such as Valmet (formerly Metso) mostly active in Northern Europe, Andritz or Japanese companies such as Nippon Steel, Ebara, JFE, Kobelco and Takuma.

The **operation is also more complex**, and it is more difficult to find suitably trained operators. The overall staffing is also more important.

5.5.1.5 Capacity / Costing

Costs have historically been higher with the fluidized bed technology than with advanced moving grates:

- CAPEX with the preparation plant and associated double storage and footprint, plus necessary building air treatment.
- Fixed OPEX: personnel, maintenance (preparation, mechanical handling etc.)
- Variable OPEX: less energy revenues, more residues which cannot be reused.
- The only potential benefit is to burn in the same furnace large quantities of sewage sludge, but this is not enough to make it attractive for countries starting the implementation of EfW. The other alternative is to develop plants dedicated to burning biomass (to be adequately prepared as well).



5.5.2 Co-Combustion in cement kilns / large combustion plants

5.5.2.1 Principles

Cement plants use a lot of energy to generate the clinker at temperatures above 1400°C. Historically, all types of fossil fuels have and are being used, but the cement industry has been under pressure to reduce their GHG emissions, bearing in mind that 60% of their CO_2 emissions come from the calcium carbonate conversion to lime and CO_2. The cement industry is therefore keen to replace fossil fuels with various types of waste fuels and generally get paid to burn and dispose of such waste.

The substitution started with liquid hazardous wastes with significant calorific values and has continued with specific streams such as tires. A number of cement plants also use Solid Recovered Fuel (SRF) in co-combustion, either in the main burner (with stricter specifications) or in the pre-calciner for modern kilns.

5.5.2.2 Waste preparation

Substitution Fuels for Cement Kilns need to comply with bespoke specifications prepared by each cement plant, and which typically include:

- A minimum LCV of 12MJ/kg and preferably > 18MJ/kg up to 20 MJ/kg for main burner injection. Producing such a high calorific fraction when starting from residual MSW with LCV < 10 MJ/Kg is challenging and requires a high level of pre-processing, which is not practical in most cases. This extract only represents a small fraction of MSW meaning a high flow of residues from this pre-processing requiring separate treatment.
- Acceptable limits in terms of chlorine (removal of certain plastics such as PVC might be required), and to a lower extent mercury.
- Granulometry range (generally < 30mm for main burner injection and < 80mm for pre-calciner) and maximum moisture content to reach the required LCV.

This means that the waste preparation usually needs preliminary storage, a double stage shredding with chlorine removal which in itself is already an expensive process, blending, screening and a local laboratory for quality control. This also means that besides the SRF preparation plant, it is necessary to have treatment elsewhere for all remaining waste fractions.

5.5.2.3 Experience

Cement kilns in Europe mostly use SRF derived from specific high calorific industrial waste streams. While some plants preparing SRF from residual MSW have not been economically viable in the UK, there are also successful examples of production of RDF from raw MSW especially in China, but also Indonesia and Morocco. Many more examples of operations diverting higher-calorific but non-recyclable fractions from landfills to RDF for cement plants exist around the world, notably in Latin America, India and Eastern Europe.

A number of experimental tests have also been carried out in Germany and Benelux to use SRF as a small fuel fraction for substitution of about 2% in coal or lignite fired power plants. Due to a mechanical and chemical behavior very different to the coal, and the difficulty of chlorine removal to prevent corrosion of pressure parts (steam pressure is much higher in power plants than in EfW), this type of application is limited and is not expected to expand.

The conclusion is that co-combustion in cement kilns can be a technically viable option for emerging countries. It requires that the cement plants are prepared to accept some prepared waste as a fuel substitute (both in investment and operation), but this cannot handle all of of the Municipal Waste that needs to be treated, all the more when the average LCV of the MSW is < 10 MJ/kg. The remainder waste fraction still needs to be treated separately at a cost, so in addition to the specific preparation costs and the **payment** for the SRF delivered to the cement plants, this is a process that has a high total lifecycle cost.

5.6 **Alternative -** Technologies for prepared waste

As indicated in §5.3 and the split of different technologies in operation in the world, there are some “alternative” technologies: pyrolysis, gasification and plasma assistance.

Note: The European directive IED 2010/75/EU indicates in the definition that these other waste thermal treatment processes, such as pyrolysis, gasification or plasma process are not considered differently than combustion / oxidation processes if the substances resulting from the alternative treatment are subsequently incinerated.

5.6.1 Pyrolysis

5.6.1.1 Principles

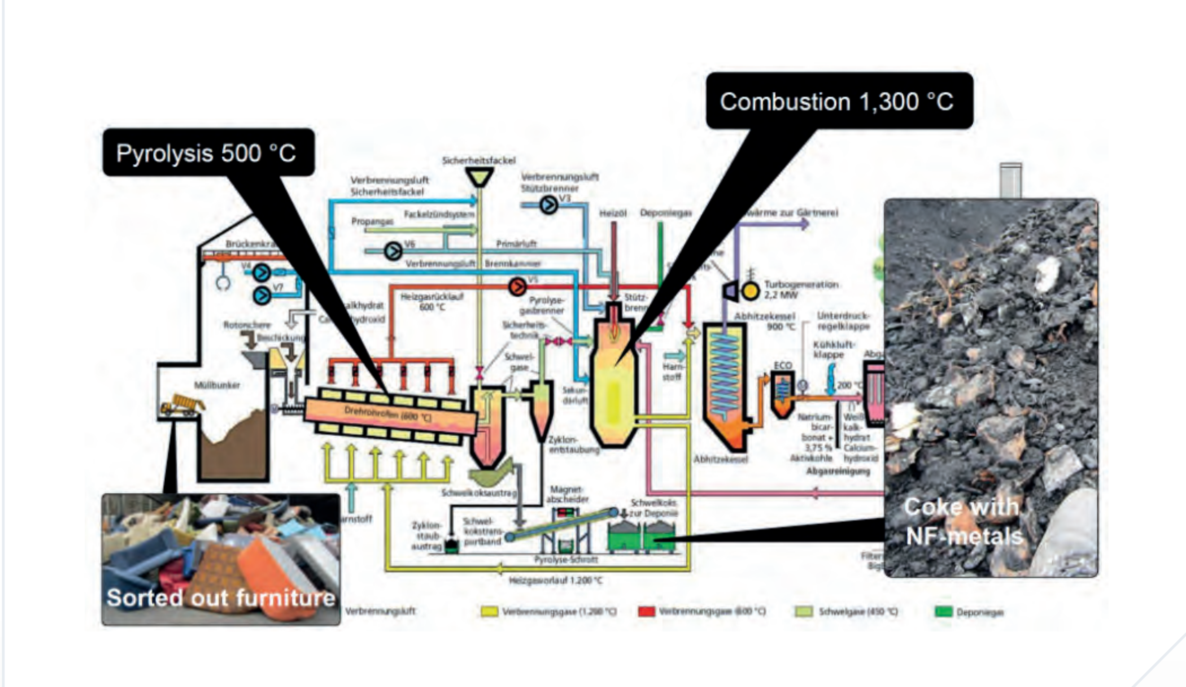
As shown on the diagram in §5.2, pyrolysis is the thermochemical decomposition of organic materials caused by external heat supply in the absence of air, at temperature between 500 and 800°C to produce char, pyrolysis oil and syngas (e.g., the conversion of wood into charcoal). The heat comes from an external source (oil or gas) typically in a rotating drum with double envelope.

It was claimed that pyrolysis oil and syngas can be utilized as high value fuels in more efficient conversion cycles (such as gas turbines or gas motors) and that metals and carbon black streams can be easily recycled with a high product value for the char. But this was never achieved with residual municipal waste in industrial operation, i.e., permanent and stable operation, despite some considerable developments, such as the Siemens Schwel-Brenn process developed in Fürth (Germany) which was eventually stopped in 1999 despite a few sister plants built in Japan.

The latest and only municipal waste pyrolysis plant in operation in Europe was in Burgau Germany which was commissioned in 1983 and treated +/- 26kt/year (i.e., very small capacity) but was stopped in 2015. Below the process scheme is shown.

Figure 30

Source: Meier 2014



Cross section of pyrolysis plant in Burgau

5.6.1.2 Waste Input

The Burgau plant drum being fed by mechanical screws, the input waste should have a particle size no larger than 300mm and with limited metals.

Due to the limited granulometry acceptable in a drum, the pyrolysis process is in principle more suitable for mono streams such as tyres but not appropriate for mixed wastes such as unprepared MSW. In addition, it can only accept small capacities.

5.6.1.3. Output

Neither the Syngas not the char can be used as a secondary fuel because of their pollution. They therefore have to be burned in the same location in line with waste combustion provisions or landfilled which is not acceptable in the principle of moving up the waste treatment hierarchy.

5.6.1.4. Experience

The plant in Burgau was the latest and only one of its kind in Europe and operated at a very high cost, so it does not appear to be an acceptable solution.

A number of pyrolysis technologies and plants were developed in Japan in combination with ash melting when this was compulsory. Since the ash melting is no longer required, no new plants have been built recently.

The small French company ETIA / Biogreen from Compiegne has developed a technology for small capacities (up to 5t/h) and specific flows (biomass fluff with high LCV 16 to 22 MJ/kg) suitable for areas where very high electricity prices prevail (typically in islands).

5.6.1.5. Capacity / Costing

Pyrolysis plants can only treat small quantities of waste at high prices. This is not a suitable solution for large cities.

5.6.2 Gasification

Given its very limited market share outside Japan, this paper will not review the numerous technologies which have been developed over the years. For more details, please refer to the documents issued by RWTH Aachen University in 2015: *“Status of Alternative Techniques for Thermal Treatment of Waste”* and by IEA *Bioenergy in 2018 “Gasification of waste for energy carriers- A review”.*

5.6.2.1. Principles

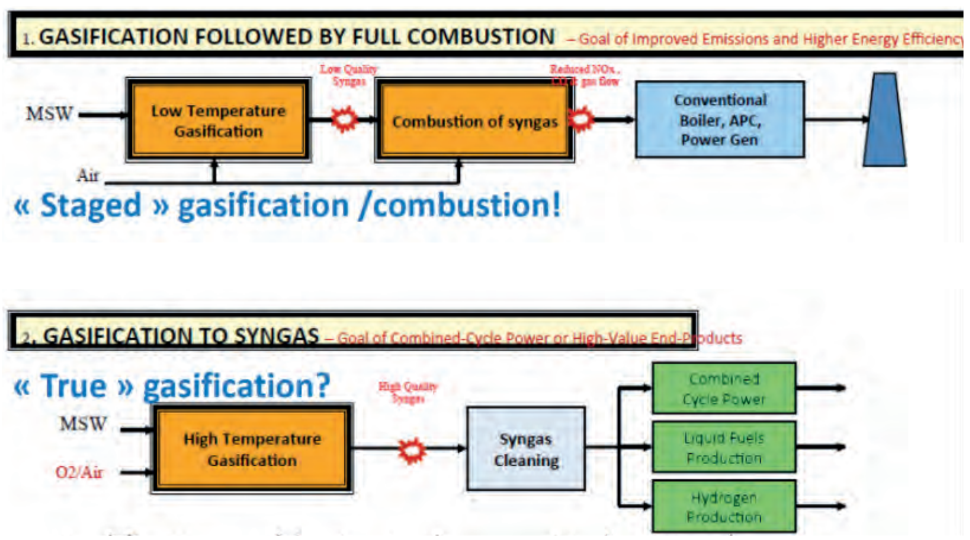
Gasification processes aim to convert mostly solid materials to a liquid fuel or synthesis gas with a high calorific value (ideally 10 to 18 MJ/Nm^3). The solid material is brought into contact with a re-active gasification agent which carries oxygen or – in the case of steam as agent – hydrogen into the process. Possible gasification agents are air, oxygen, steam, or carbon dioxide. The limitation of oxygen supply is crucial for gasification in order to prevent energy loss or complete oxidation of feedstock. Usual conditions imply an oxygen supply of 30 to 40 % of the total oxygen demand (stoichiometry).

Gasification directly followed by the produced synthetic gas combustion and the energy recovery in a steam boiler coupled to the same installation is in fact a "staged combustion" and considered as such in the European IED directive.

Gasification, subsequent syngas cleaning and supply of the syngas to a higher efficiency thermal process (gas turbine or a gas motor) or to production of liquid fuels could be considered as "true" gasification.

See the attached figure (Themellis).

Figure 31



Source: Themellis

The two different types of gasification

Note: Article 42 of the IED directive indicates this type of thermal process could be an exception to fulfil incineration provisions only in the case that *"the gases resulting from this thermal treatment of waste are purified to such an extent that they are no longer a waste prior to their incineration, and they can cause emissions no higher than those resulting from the burning of natural gas".*

The UK has encouraged the development of alternative waste treatment (pyrolysis or gasification) by awarding in the past Renewable Obligation Certificates (ROC), a government financial incentive which nearly doubles the electricity revenues. This was awarded only where the syngas produced and analyzed online has an LCV between 2 and 4MJ/Nm^3, and "double ROC" when the LCV exceeds 4 MJ/Nm^3 even if this gas was subsequently incinerated in the same plant. Most of the developed plants in the UK have a "staged combustion" process, but very few plants have managed to achieve this LCV target. They would not have been developed without this strong Government incentive.

According to the report "Advanced Thermal Treatment of Municipal Solid Waste" published in 2013 by DEFRA (Department for Environment, Food and Rural Affairs) from the UK Government, it is indicated that *"…most commercial gasification facilities processing MSW derived feedstock utilize a secondary combustion chamber to burn the syngas and recover energy via a steam circuit, and whilst this is not incineration, the differences between the processes in practical and efficiency terms are much more modest."*

Most gasification technologies are implemented in Japan and use either fluidized beds in gasification mode or shaft furnaces.

5.6.2.2 Waste input

Since most processes use a fluidized bed (FB), the waste preparation has to comply with FB requirements explained in §5.5.1.2 i.e. double stage shredding plus metals removal.

5.6.2.3 Output

- The initial objective of gasification is to produce syngas. To date, no waste gasification plant having reached the industrial stage is able to produce from MSW (even prepared) a clean syngas usable in a separate and more effective thermal or chemical process.
- This means that all currently operating waste gasification plants (mostly in Japan) have a staged combustion with similar outputs to an advanced moving grate plant, but with upstream waste preparation and generally **much reduced energy efficiency**.
- The **bottom ashes** at the furnace/ gasification reactor outlet contain in general a significant proportion of unburned carbon (due to only partial carbon oxidation) which is a serious issue, unless they are vitrified (at unaffordable costs) as in Japan.
- As for the fluidized beds, there are much more **APCR** than with advanced moving grates due to the quantity of dust entrained by fluidization. These are hazardous waste to be disposed of in specific landfills at a high cost.

5.6.2.4 Experience / Development

As already mentioned, most gasification technologies are implemented in **Japan** where the incombustible fraction is generally extracted at source. As indicated in §4.4.3, due to the guideline for slag melting for safe disposal of ashes which cannot be used for road construction, Japan has also developed alternative technologies such as fluidized beds and gasification to facilitate the ash vitrification which was promoted until 2010. They nevertheless represent less than 10% of the installed capacity in Japan.

The waste gasification plants are therefore coupled with ash vitrification systems with very high energy needs (and therefore high cost), the syngas being fully oxidized in separate adjacent post combustion reactors. This means that they are of "staged combustion type". It is also important to note that the Japanese plants have a reduced availability, typically < 7500h / year compared with > 8000h for advanced moving grates.

In Europe, the very large site of **Schwarze Pumpe** in the Eastern part of Germany was developed in the 70's and 80's with numerous attempts to convert waste to fuels after extensive preparation, but this eventually shutdown.

Thermoselect was the emblematic waste gasification process in the 90's with the plant of Karlsruhe commissioned in 1999 but it was shut down in 2004 for "commercial reasons". A few sister plants were built in Japan in the early 2000's.

There are very few commercial plants outside Japan, which are also of "staged combustion" type such as **Energos** or **Outotec**, but these companies are no longer offering to build municipal waste gasification plants.

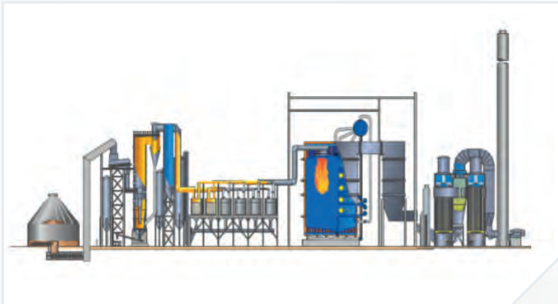
There is currently no "true" waste gasification process available and having reached an industrial stage i.e., several plants in operation and build under "normal" market conditions.

Lahti Energia in Finland has developed a 1st gasification plant with Foster Wheeler and a 2nd one with **Metso** (now **Valmet**) - see attached figure. The objective was to burn high quality SRF mixed with some biomass and to clean partially the hot syngas to feed a more efficient "gas boiler" operating at typical power plant steam characteristics. However, the plant is now mainly using biomass instead of SRF.

In Canada, **Enerkem** is still developing their "waste to fuel" plant near Edmonton with a gasification stage followed by cleaning and conditioning of syngas with the ultimate objective to produce methanol or ethanol by catalytic synthesis. At this stage, no figures have been published to show that this demonstration plant could be able to reliably operate at designed capacity after several years of commissioning. Track record and operation cost are not published but a waste to chemicals project is being developed in Rotterdam with this technology.

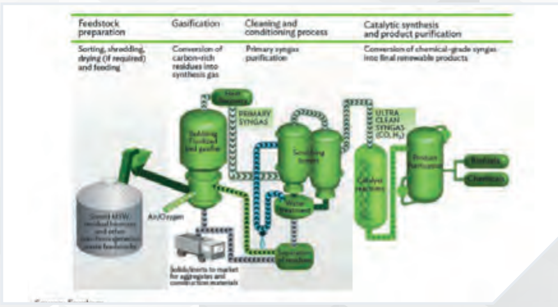
Numerous spectacular failures have occurred such as **Air Products** which had to write off ca.1 billion dollars investment in one plant in the UK.

Figure 32 Source: Valmet



Lahti gasification cross section

Figure 33 Source: Enerkem



Enerkem process principle

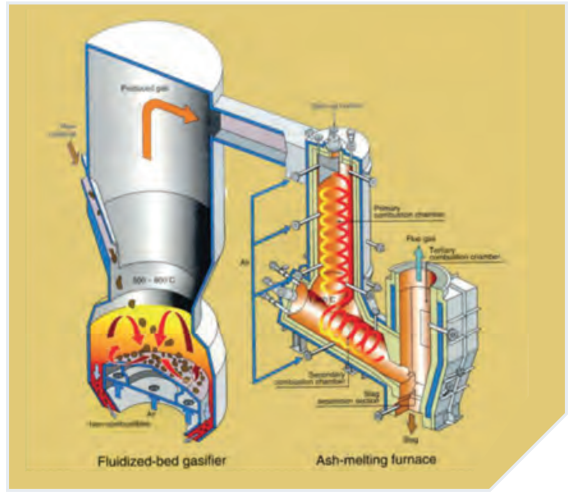
5.6.2.5 Contractors

In alphabetical order

Staged combustion:

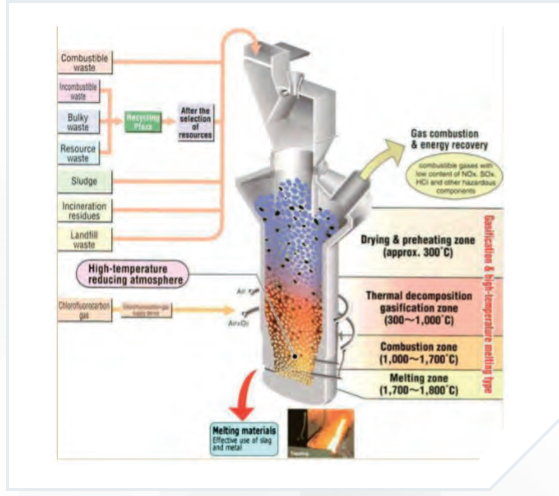
- Ebara (see figure) & Hitachi Zosen are Japanese contractors using fluidized bed technology in gasification mode for ash melting in Japan.
- Another one from Japan, Kobelco is building a fluidized bed plant in UK in gasification mode.
- With shaft furnace technologies, JFE had built a plant outside Southeast Asia in Italy near Rome, which stopped. See figure of the Fukuyama plant in Japan.
- Nippon Steel, one of main actors in Japan with shaft furnace process. But they did not succeed in selling any plant in Europe after 10 years of commercial activity and the take-over of Steinmüller Babcock. See figure of the shaft furnace.
- For European suppliers, Babcock Wilcox Volund has developed a biomass gasification, which is not applied for waste.
- Energos has built +/- 10 plants in Europe treating MSW after coarse shredding and metals extraction / RDF but had to stop their non-viable construction activity,
- Outotec (now part of Metso Group for this activity) has mostly developed "high quality RDF" staged combustion fluidized bed gasifiers, with 4-5 plants in UK, but decided to leave this MSW market.

Figure 34 Source: Ebara



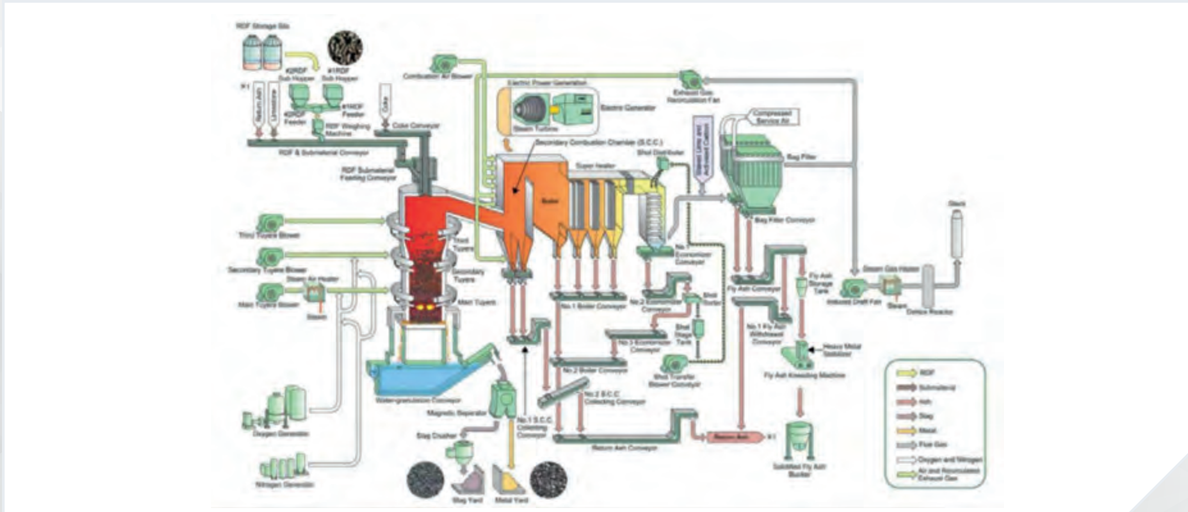
Schematic diagram Ebara process (Steiner 2002)

Figure 35 Source: Nippon Steel



Shaft furnace of the Nippon Steel DMS process with display of reaction zones

Figure 36 Source: JFE



Process schema JFE High-Temperature Gasifying and Direct Melting Furnace System in Fukuyama (Suzukji 2011)

"True" gasification:

- Air Products Gasification Plant in Tees Valley – this huge project of shaft furnace combined with plasma gasification was abandoned a few months after start up before commissioning with a loss of 945 M USD for Air Products.
- Rüdersdorf (gas to calciner of cement kiln), with Noell and Lurgi technologies, is not operating with waste anymore.
- Enerkem with development of methanol and then ethanol production from MSW RDF (the quality of these chemicals should enable end of waste status to be obtained and reach commercial products quality to be able to sell them on international markets. Only 1 demonstration Plant in Edmonton Canada is still under commissioning more than 5 years after completion of construction
- Thermoselect developed in Germany, stopped activity in Europe. JFE is licensed in Japan but do not offer this technology anymore.
- Valmet CFB main reference Plant in gasification in Lahti Kymijärvi II (Finland) which was to burn a mix of high quality SRF and biomass, now mainly biomass (granulometry required lower than for BFB)
- Europlasma in France has built a 50kt/y gasification fluidized bed facility with plasma assistance in South West of France. This has later been decommissioned due to largely failing performance targets for the installation.

5.6.2.6 Capacity / Costing

No auditable data are available, but the Japanese plants with ashes vitrification experience the highest waste treatment costs, and there are no other technologies having reached the industrial stage.

Energos was one of the only technology suppliers in a position to provide staged combustion / gasification at relatively low market price. This company is no longer offering to build new plants.

5.6.3 Plasma Technology

Plasma technology is sometimes considered as an alternative waste treatment, which is possible to treat small waste fractions with high hazardous potential (such as asbestos or dust) in a "single stage" process. Due to the high energy costs, there is more potential in "two stage" processes where syngas produced by a gasifier are treated with plasma which will remove remaining tars for a gas upgrade utilization, in a gas motor for example.

Plasma is therefore not a stand-alone technology but a potentially interesting add-on to "true" gasification plants. However, as stated above, there are no "true" gasification plants in operation and only 2 potential plasma technology suppliers with some "quasi-experience" on pre-treated MSW:

- Westinghouse / Alter NRG has developed a test plant in Madison (USA) and 2 small plants in Japan which have closed for technical and economic reasons. They also supplied the technology for Tees Valley Air Products plant, which has been a technical and economic disaster. It was scrapped after it failed to start up.
- Europlasma / CHO Power who built an innovative gasification + plasma plant in Morcenx (southwest of France), but it could not achieve the expected performances (in particular due to the gasification technology). Europlasma decided to stop this activity and dismantle the plant.
- Advanced Plasma Power is restarting the construction of a 8,000 ton/year "waste to gas" facility after going through administration.

Therefore, there is no plasma gasification technology available on the market with commercial operation experience for residual municipal waste even with preparation.

6 How to make EfW **a success story**

EfW is sitting after Reduce, Reuse and Recycle in the Waste treatment hierarchy, but before landfill. It is a recovery process (Energy and materials) and as such fits well in the "circular economy".

EfW is therefore a key solution to "move up in the Waste Treatment hierarchy" to treat all waste which cannot be reused or recycled. It is important to ensure that the development of such facilities is successful for the best use of large amounts of public money.

To reach this goal, many aspects have to be well taken care of as described in the UNEP figure to the right.

This also involves a number of stakeholders and contributors to the project as shown on the typical project structure below.

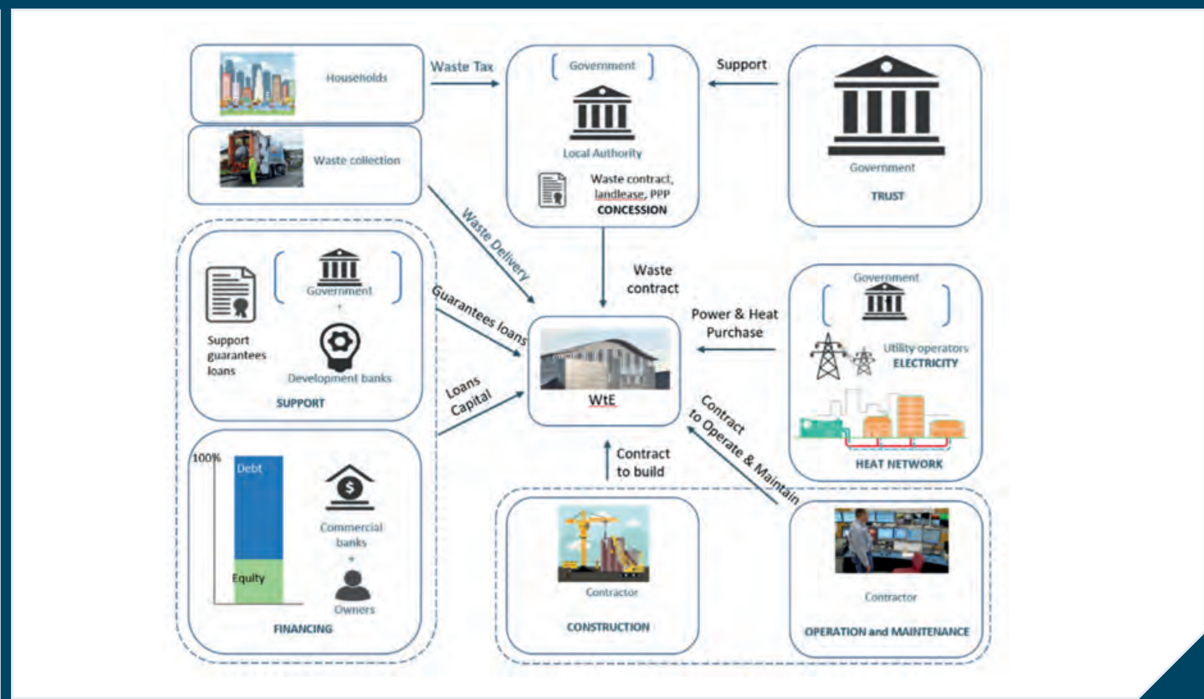
Figure 37

Source: UNEP

Implementation timeline of the four major considerations for the Integrated Sustainable Waste Management framework

Figure 38

Source: ISWA WGER



Typical project structuring with stakeholders position

6.1 Develop a **long-term waste treatment strategy**

When there is no National waste strategy and associated policies in place, these should be established prior to the development of new facilities.

The **National policies** should set up targets and principles in terms of waste treatments and environmental protection, also addressing regulatory matters such as:

- **Principles of waste treatment mix** with long-term targets for reduction, recycling, organic waste composting and potentially anaerobic digestion, so that appropriate **evaluations of waste quantities and qualities** can be made to size the required infrastructures. This should define the approach to evaluate the impact of different waste treatments on sustainable development and Carbon footprint.
- Set up a **long-term tax strategy** to drive the market towards the defined targets. It should be noted that increase in recycling can only be a result of segregating materials which have a viable end market for which quality is key whereas landfill diversion can be strongly influenced by a tax policy which will make alternatives such as EfW more cost effective (see the UK success story).
- Definition of the **waste categories** to be treated: at least residual MSW, but preferably together with (non-hazardous) associated Commercial & Industrial (C&I) waste, to ensure that these large quantities of waste will be mostly recycled and will not be delivered to landfills. In most cases, these C&I wastes provide additional revenues through a specific gate fee which could consider the LCV.
- Principles of **local public authorities' compliance** with such long-term targets.
- Site development and **planning with permitting** procedures to develop the required infrastructure.
- **Environmental standards** including emissions to air and water where EU standards can be used as a safe and solid baseline.
- **Management of residues**: Bottom Ashes (BA) and Air Pollution Control Residues (APCR). The EU or international conventions have not set international standards for these categories. So, each country has developed its own regulation defining the parameters to be complied with and the associated quality control. Specific regulation therefore needs to be defined. In addition to the very efficient extraction of ferrous and non-ferrous metals from BA to be recycled, the use of the mineral fraction of BA should be considered mainly as aggregates as a sub-base for road construction given its very good mechanical characteristics and the reduction of the use of virgin material, therefore considered as recycling (see CEWEP bottom ash fact sheet). These by-products' use should be acceptable and even encouraged after adequate quality control. The APCR are hazardous waste which means that appropriate treatment, generally in hazardous landfills should be defined.
- **Financial incentives** such as a clear and long-term Tax Policy to encourage the evolution defined in the Waste Management strategy. This should include the principles of standard user fee for waste treatment and **feed-in tariff** for the sale of Energy (electricity and heat) to utilities or industries together with the energy sector.
- Define **possible funding solutions** including the Public Private Partnership principles, since this is a very robust and proven answer for such a development.
- Definition of **principles heat and power offtake** with national energy players.

The **local Public Authority** responsible for waste collection and treatment has to develop a long-term strategy based on National policy. The first difficulty is to launch such a long-term reflection although most of the local elective mandates are short-term. The pre-requisite to develop waste treatment facilities is to have a well-structured waste collection system, so that waste quantities to be delivered to the facilities are "guaranteed" by the Authority.

The local Public Authority should also:

- Perform a **comprehensive analysis of the wastes** to be treated and make projections for the years to come considering the expected demography and economical evolutions and targeted waste treatment mix. Such projections should include LCV evaluation (usually higher in urban areas), potential seasonal variations and should be made for at least 10 to 15 years bearing in mind that project development and construction usually takes +/- 5 years and that EfW Plants are designed to safely and reliably operate over more than 30 years. It should be noted that EfW plants should treat at least 100 to 150 kt/year, and preferably 300 to 500 kt/year to optimize the CAPEX and OPEX with important scale-up effects.
- Select the **location of the different waste treatment facilities** and of their residues, possibly including transfer stations and trying to optimize the local use of heat and power in symbiosis with the current and future industrial infrastructure.

6.2 Communicate to the Public
and explain the Strategy

During the preparation of the overall waste treatment strategy, it is essential to implement a comprehensive Communication strategy towards all stakeholders. See the mapping proposed by **ISWA** in its document *"Waste to Energy in Low- and Middle-Income Countries"* 2013.

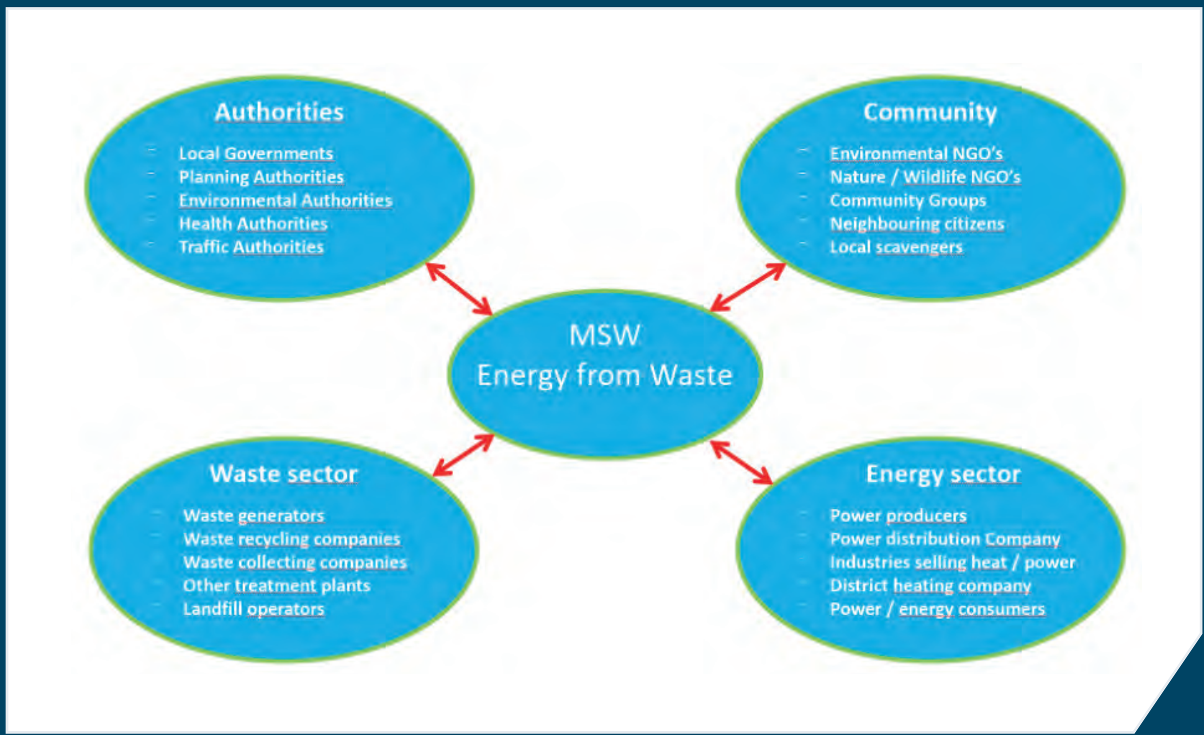
Waste treatment is a long-standing sensitive issue in many countries, where historical culture play an important role and NGO's take more and more assertive positions, often considering that we should move towards a World without waste which will at best take decades.

It is therefore important that the authority is proactive and explains how the proposed comprehensive solution will benefit the people and solve their problem. It is as important that the authority defines the solution after proper evaluation of the stakes and possibilities and select robust and well proven technology.

A good communication strategy should address and highlight all the benefits of the proposed treatment as well as considering the negative aspects, presenting a balanced view that the stakeholders can accept. Negative aspects can be countered by presenting a set of 'frequently asked questions' (FAQ) with answers that address concerns, misconceptions and incorrect information.

Figure 39

Source: ISWA



Stakeholders to be considered when planning and assessing the viability of MSW Energy from Waste

Sharjah (UAE) EfW Credit: EWTE

6.3 Identify suitable sites
for the development of waste treatment infrastructure and communicate with neighbours.

Once the national and local strategy is in place, as well as the necessary regulatory framework, it is necessary to identify suitable sites and launch the permitting process.

A continuous and efficient communication with the neighborhood needs to be developed to mitigate the protests very often based on the NIMBY syndrome. One solution is to look for remote sites so that there are no close neighbors. But this will increase the distance and transport costs and decrease the possibilities of implementing a Combined Heat & Power (CHP) scheme which would maximize the energy revenues. Sites in industrial areas are therefore very attractive in many respects.

An EfW will typically require 4 to 6ha depending on the capacity and location of bottom ash treatment to generate reusable aggregates. This remains extremely compact in area in ha/kt treated versus sorting or landfill which often needs more than 100ha.

The proposed site will provide good access for heavy vehicles during construction and collection trucks during operation, and the possibility to build a cooling system for the steam cycle. Air-Cooled Condenser – ACC – is installed in most cases, but a Water-Cooled Condenser – WCC – has a better efficiency in energy recovery if significant quantities of water are available nearby. It is also necessary to have a connection to the high voltage electrical grid and when it is possible to the heat network or heat consumers.

The potential risks of flooding, cyclones, hurricanes, earthquakes, rise in sea level and environmental impacts must also be considered during the selection of the site location.

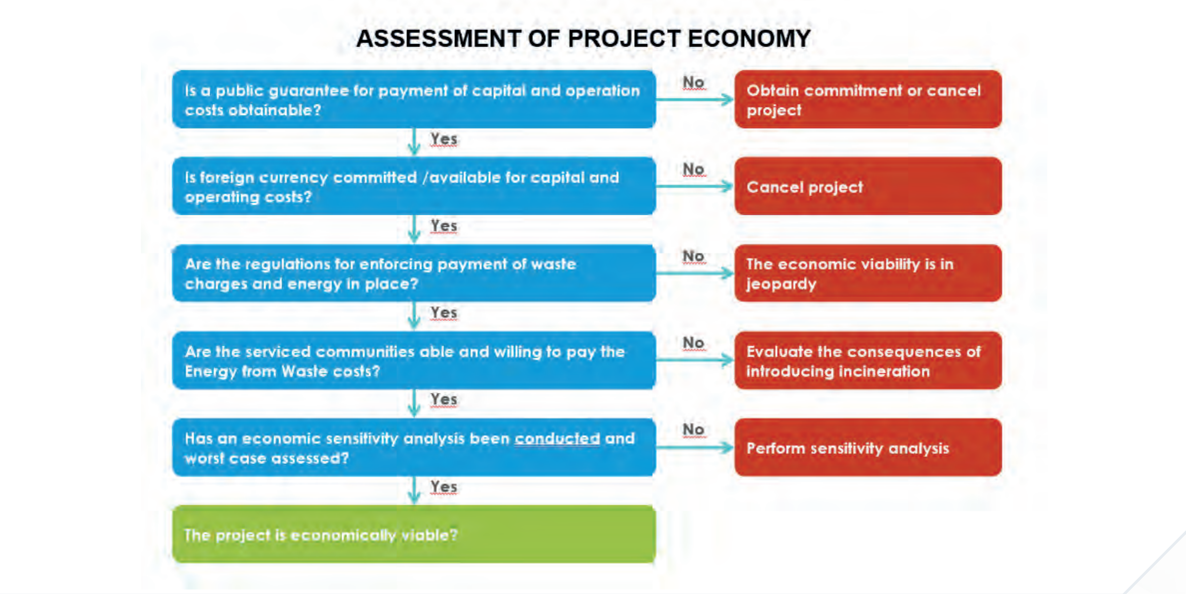
The Authority should buy the site and be committed to assisting the Planning and Permits applicant.

6.4 **Ensure Affordability** and Bankability of infrastructure

The following table shows the assessment of Project Economy from **ISWA** *"Waste to Energy in Low- and Middle-Income Countries"* 2013.

Figure 40

Source: ISWA



Assessment of Project Economy

A "standard" EfW plant has generally a lifetime of 30 years and more. Its CAPEX amortization can therefore take place during the first 20 years or more. In most cases, funders and lenders are called in to pay for the construction costs and be reimbursed over the years.

Funders need therefore a guarantee from the project sponsor or the Authority to provide regular and long-term payment. Since the Energy sale does not cover all the OPEX, the Authority also needs to guarantee the payment of the residual OPEX.

Funders will also look for:

- robust and proven technology delivered under EPC Contracts with full construction responsibility to cover potential time and costs overrun as well as potential performance shortcomings. This means that only advanced moving grate technologies qualify and that local authorities will bear the full risk if they wish to implement other technologies.
- well experienced operators to ensure long-term performance at fixed costs incorporating local workforce to be adequately trained.

As previously mentioned, there is a need to have a minimum quantity of waste to be treated for economies of scale, at least 100 to 150 kt / year but preferably 300 to 500 kt/year (corresponding to 500,000 to 1 million people MSW production). These quantities of waste will be delivered to the EfW plant under agreed commercial conditions (usually a payment through Tipping Fee, plus waste delivery regime according to a weekly schedule, truck size, etc.).

To ensure good availability of the plant to receive and treat the generated waste, it is generally best to have at least two independent combustion lines in the plant, even if plants with only one line could be built providing that a back-up solution is available.

6.5 Implement a **robust procurement approach**

The project success is based on an appropriate and detailed risk allocation between Authority and Private Companies. This should cover the site conditions (in particular the site selection with its underground conditions, access), the planning and permitting, the construction, the operation, the general regulation (potential change in law)

See the following table with different contracting models (World Bank, 1999).

Figure 41

Source: World Bank, 1999

Table 3.1 Applicable Tender and Contracting Models for Waste Incineration Plants

Tender Model	*Client's Obligations*	*Contractor's Obligations*	*Advantages*	*Constraints*
Multiple contracts	Financing. Function specifications, tendering, project coordination, and construction supervision. Ownership and operation.	Supply and detailed design of individual parts for the plant.	Full client control of specifications. Possible to create the optimum plant based on most feasible plant components.	Absolute requirement for project management and waste incineration skills in the client's organization.
Single turnkey contract	Financing. Function specifications, tendering, and client's supervision. Ownership and operation.	Responsible for all project design, coordination, and procurement activities.	One contractor has the full responsibility for design, erection, and performance.	Limited client control of choice of plant components.
Operation contract	Multiple or single turnkey contract. Ownership. Supply of waste.	Operation of the completed and functional plant in a certain period.	Limited strain on the client's organization.	Difficult for client to secure affordable tariffs, (put or pay contract), control finances, and monitor the contractor's performance and service level.
Build Operate	Financing, function specifications, tendering, and client's supervision. Ownership. Supply of waste.	Detailed design, project management, contractor's supervision, operation, and maintenance.	Contractor committed to well-functioning and effective solutions. Limited strain on client's resources.	Difficult for client to secure affordable tariffs (put or pay contract), control finances, and monitor the contractor's performance and service level.
Design Build Operate	Financing. Overall function specifications and tendering. Ownership. Supply of waste.	Detailed design, project management, supervision, operation, and maintenance. Ownership.	Contractor committed to well-functioning and effective solutions. Limited strain on client's resources.	Difficult for client to secure affordable tariffs (put or pay contract), control finances, and monitor the contractor's performance and service level. Limited client control of choice of plant components.
Build Own Operate Transfer	Overall function specifications and tendering. Ownership after transfer. Supply of waste.	Financing, design, project management, supervision, operation, and maintenance. Ownership until transfer.	Contractor finances, constructs, and operates the plant for a period after which the plant is transferred to the client. Very limited strain on client's resources.	Difficult for client to secure affordable tariffs (put or pay contract), control finances, and monitor the contractor's performance and service level. Limited client control of choice of plant components.
Build Own Operate	Overall function specifications and tendering. Supply of waste.	Financing, ownership, design, project management, supervision, performance guarantees, operation, and maintenance.	Client does not need to finance the project. Contractor committed to well-functioning and effective solutions. Very limited strain on client's resources.	Difficult for client to secure affordable tariffs (put or pay contract), control finances, and monitor the contractor's performance and service level. Limited client control of choice of plant components.

Applicable tender and contracting models for waste incineration plants

As indicated the multiple contract approach needs excellent knowledge and project management skills from the Authority which can only develop with time and many projects already in successful operation.

The most suitable way for countries which want to start the development of EfW is therefore either:

- Design & Build (DB) or Design, Build and Operate (DBO) in particular for very large plants for which the construction is better financed by the Authority because of the sheer amount at stake. This is the case for Istanbul (DB), Baku (DBO) or Hong Kong (DBO).
- For more common size plants, the Build, Operate and Transfer (BOT or PPP) is often chosen because it provides the best visibility for the funders and still requires a strong and long-term contribution from the authority. The main advantage for the authority is that the Contractor is responsible for both construction and operation and all related interface and potential mismatch which are difficult to manage for authorities who have no or little experience in this field. This is the case of Belgrade EfW and is recommended by the ADB in their 2020 Waste Energy circular economy handbook.

It is important to note that the so called "Advanced or Alternative Thermal Treatment" (ATT) technologies have not been implemented with the use of DB, DBO, BOT or PPP schemes, mainly because of lacking experience of long-term reliable operation of these technologies.

6.6 Ensure long-term safe, reliable, compliant and efficient operation

The long-term success of an EfW project depends on the consistent operational performance year after year: waste quantities treated (which implies the availability and the continuous operation at the maximum capacity), the energy produced (which implies the performance of the energy recovery), actual emissions levels in line with the permitted limit values, use of bottom ashes aggregates as planned. All these parameters should always remain in line with the modelled design parameters.

One prerequisite is that the design and construction is undertaken by recognized and proven technology provider(s) but the other prerequisite is to also have a recognized and proven operator who will in particular:

- Commit to a fixed price for the complete plant operation and maintenance potentially including energy sales and residues management based on agreed prevailing stable conditions (note this is basically impossible for ATT technologies given the lack of practical experience and feedback based on track record).
- Set up a comprehensive operational team and train the local staff ahead of the start of operation.
- Prepare the operational and safety procedures.
- Review the plant design and assist during the commissioning.
- Prepare all operation reporting procedures to local Authorities and stakeholders to demonstrate ongoing compliance with permit and contracts.
- Organize all supply chains for waste, chemicals & reagents, residues management.
- Define and implement all the maintenance procedures from routine to programming general overhauls (at least 1 / year generally lasting 2-3 weeks) together with good housekeeping to achieve the expected plant reliability and availability.
- Manage the waste which cannot be treated during the long outages in agreement with the Authority when alternative treatments are temporarily necessary.
- Obtain all necessary technical support to put in place appropriate Key Performance Indicators to monitor the performance and solve problems.
- Develop and implement a continuous improvement program and propose upgrades as necessary, for example in the case of variations in waste quality.
- Comply with all environmental and safety requirements and good practice.

Municipal waste is a very specific and complex fuel which justifies the appointment of an experienced operator (even more so when EfW is a new technology implemented for the first time in the country). He will maximize local resources depending on the prevailing industrial experience of the area where the EfW plant is built. For the same reasons and given the numerous problematic experiences in the start-up of new plants, it is highly recommended to combine construction and operation in one DBO or PPP Contract.

6.7 Case Studies

Beyond all the above explanation, it is essential to base the new development of a technology on past experiences. The recent years have seen a number of new flagship projects in various countries, using different contractual models such as:

- **Baku**, 1st EfW plant in Central Asia (Azerbaijan) with a capacity of 500 kt/year commissioned in 2012.
- **Addis Ababa**, 1st EfW in Africa (Ethiopia) with a capacity of 350 kt/year inaugurated in 2018.
- **Istanbul**, 1st EfW plant in Turkey with a capacity of 1 Mt/year and commissioned in 2022.
- **Belgrade**, 1st EfW plant in Serbia, with a capacity of 350 kt/year, to be commissioned in 2023.

The **ISWA** Working Group has collated specific data on experience summaries for each of these successful cases, which are available through the links to the **ISWA** website.

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7 Evaluation

Once the prerequisites in terms of waste management strategy and regulation have been fulfilled, it is possible to look at the different technologies available keeping in mind the key success factors related to bankability, procurement, and long-term operation, as well as the split of the different Technologies in the World introduced in § 5.

Baku (AZ) EfW Credit: Tamiz Shahar

7.1 Treatment costs

As mentioned in §4.5.3, going up the Waste Treatment hierarchy will significantly increase the waste treatment costs compared with controlled or sanitary landfill. In most countries, these costs are funded by specific Waste Collection and Treatment Taxes paid by the users, enabling a Gate Fee to be paid for waste delivered to an EfW plant.

As detailed in the review of the different technologies, only advanced moving grates can provide reliable data. Based on the assumptions detailed in § 5.4.6, the orders of magnitude are as follows:

Plant capacity kt/y	CAPEX in M€	OPEX €/t	Energy rev. €/t	Gate fee €/t
150	150	40 to 50	20 to 30	80 to 100
500	300	30 to 40	20 to 30	50 to 80

These figures are based on the CAPEX amortization over 25 years which reinforce the need for reliable technology to achieve this long lifetime with just ordinary maintenance. This also shows the importance of the “scale effect”, mainly on the CAPEX and to a lesser extent on the fixed OPEX. This scale effect was already highlighted in World Bank Technical Report dated 1999 with tables on “investments costs” and “cost of incineration per year” which have been updated with current figures.

When comparing different technologies, the actual hourly capacity and the yearly availability should be considered to ensure that actual costs and revenues are in line with the theoretical annual capacity. It is notoriously known that the so-called alternative technologies are unable to match the performances of the advanced moving grates which significantly distort the projected figures.

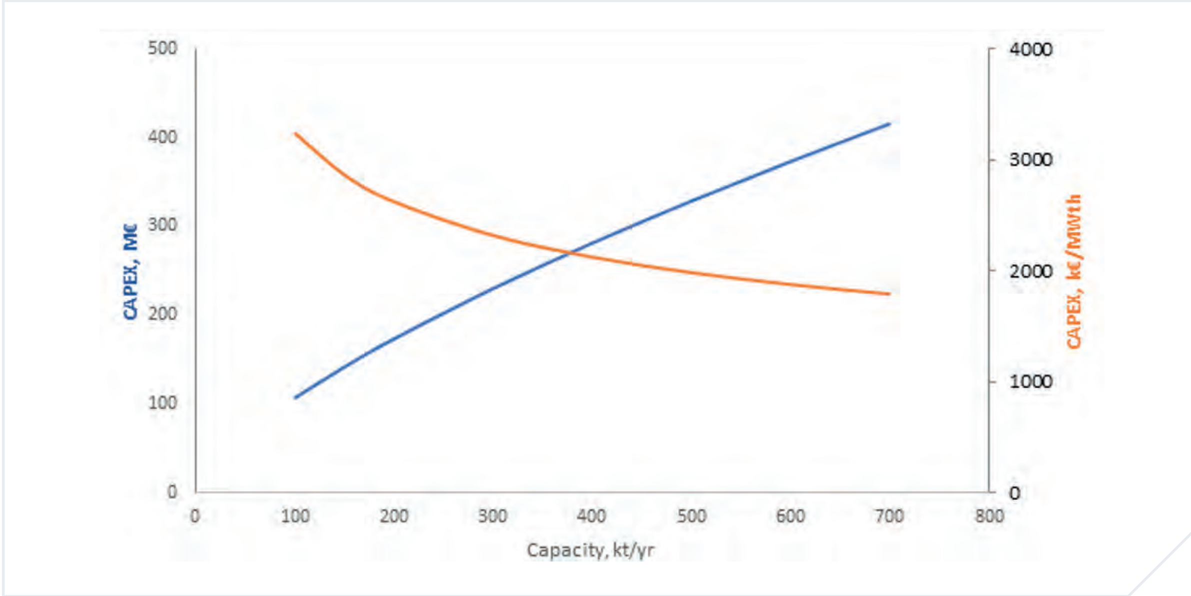
As an example, a plant with the same CAPEX and OPEX but being able to operate 7500h per year instead of the most common standard of 8000h will need a ca.10% increase on the gate fee to reach the same financial return.

It is important to keep in mind that:

- Each case is specific and the above only provides orders of magnitude, to be supported by feasibility studies which should consider the specific situation starting with local waste characteristics and quantities. As previously indicated, very organic / wet waste could make a simple pre-treatment worthwhile.
- Under normal economic conditions, the energy revenues will not compensate for the OPEX, and a gate fee is necessary even in cases where the Authority is financing the CAPEX (in case of DBO contract for example).

Figure 42

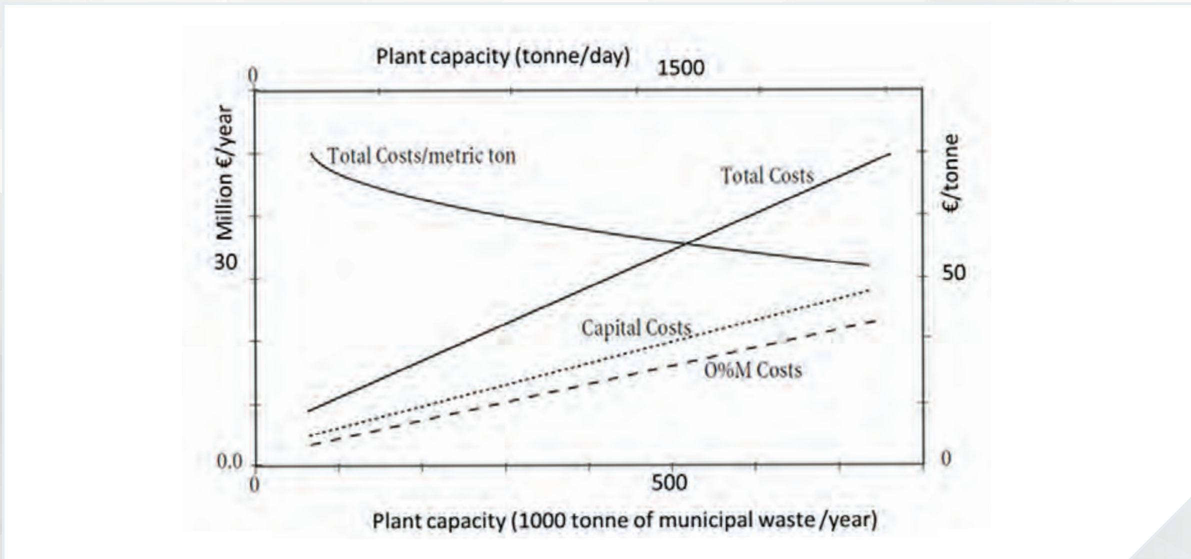
Source: ISWA WGER



EfW CAPEX variation towards capacity

Figure 43

Source: ISWA WGER



Evolution of EfW costs per tonne and per year towards plant capacity

7.2 Energy Recovery

Given the waste preparation necessary for all technologies alternative to advanced moving grates, the energy consumption of such preparation of RDF / SRF has a significant negative impact on the net energy efficiency and therefore reduces the energy export of such EfW. In addition, these preparation plants generate some rejects which have to be treated elsewhere after further transport and potentially some further process energy consumption, the minimum being landfilling and compaction.

The net process efficiency is difficult to compare between the different technologies due to the lack of references, but it is possible to look at trends using the advanced moving grates as a benchmark.

Bubbling fluidized beds have a lower efficiency due to the energy used for higher parasitic load (high air pressure needed to fluidize sand and waste), generally lower steam parameters (to avoid higher tubes erosion and corrosion), bottom ash quality unsuitable for processing to aggregates for road construction and higher APCR quantities due to higher dust content in flue gas.

Pyrolysis (Burgau reference no longer in operation) needs a separate treatment for the carbon residue (currently 40% of the input and being landfilled!) and has a poor energy recovery due to the low flue gas temperature remaining after the kiln pre-heating and despite the auxiliary fuel burner to burn the carbon left in the flue gas.

The gasification as implemented in Japan generally vitrifies the bottom ash to comply with specific local regulation, which need huge quantities of additional energy making the overall energy recovery much lower. Therefore, R1 threshold is unlikely to be fulfilled.

This problem was identified by the JRC of the European Commission in their report *"Towards a better exploitation of the technical potential of waste-to-energy" (JRC, 2016) . It indicates that: "Considering the requirement for extensive waste pre-treatment and the production of combustion support materials such as oxygen or steam, gasification and pyrolysis technologies (where the syngas produced is combusted in a boiler or gas engine) are unlikely to achieve higher overall net electrical efficiencies than conventional combustion plants."*

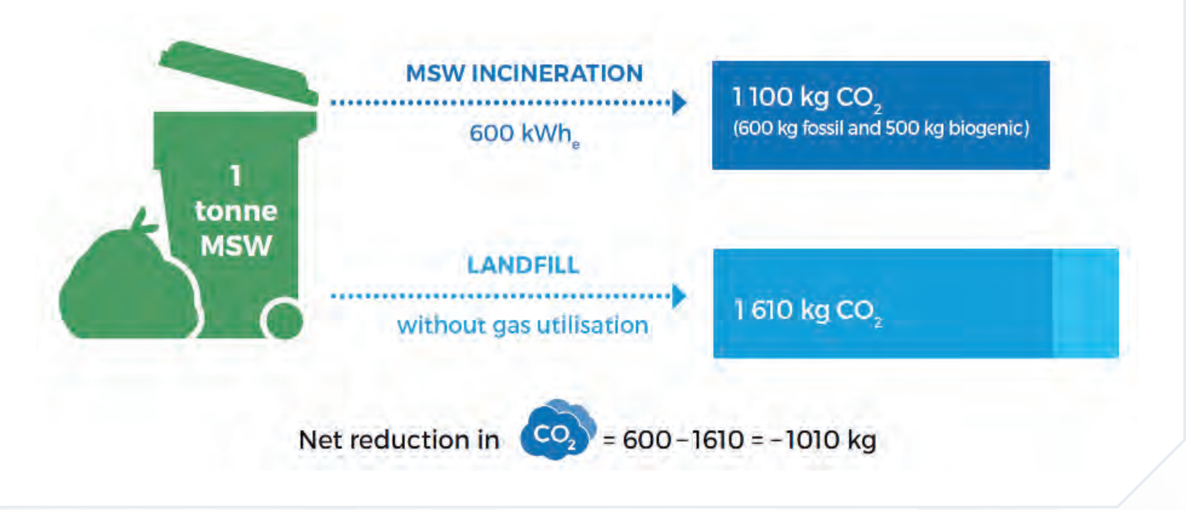
On the other hand, as stated in § 5.4.3, the export of energy should be maximized (at affordable cost) in particular through Combined Heat and Power (CHP) or even better 100% heat production. These schemes are more efficient than 100% electricity production and should be strongly encouraged, potentially with specific feed-in tariffs, carbon credits or the like. The difficulty is to find long-term (preferably permanent – all year round) heat users within a few kilometers from the EfW plant. These could be heat networks to feed heat demand of large cities (see very good examples in Malmö, Brescia or Barcelona district heating or even cooling) or various industries: pulp & paper, food & beverages being the best candidates.

7.3 Impact of EfW on Climate Change

As introduced in § 4.5.5, climate change and GHG impacts are a growing issue everywhere and that obviously include waste treatment at large.

The UNEP 2016 guideline on Waste to Energy states that *"a Thermal Waste-to-Energy is considered a climate mitigation measure because the biogenic waste in MSW is treated as carbon-neutral, and emission credits can be earned through fossil fuel substitution"* (depending on energy mix). They also summarize the net reduction of CO_2 emissions to be 1010 kg/ton of MSW when diverting from landfill without gas utilization to EfW in the attached figure.

Figure 44



Source: UNEP

CO_2 savings from thermal WtE

The Intergovernmental Panel on Climate Change (IPCC) says that *"Compared to landfilling, waste combustion and other thermal processes avoid most GHG generation, resulting only in minor emissions of CO_2 from fossil Carbon sources"*. The study *"The climate change mitigation potential of the waste sector"* from the Environment Ministry of Germany addresses the potential of the waste sector as a whole to help reduce greenhouse gas emissions. *"One of the key findings is that diversion from landfills is the main contributor to greenhouse gas mitigation in the waste sector. An integrated waste management system that prioritizes reuse, material recycling and otherwise energy recovery instead of landfilling can contribute significantly to national GHG mitigation goals."*

Avonmouth (UK) EfW Credit: Viridor

The exact figure depends on a number of basic assumptions and on the actual plant performances and the UNEP calculation only relates to the direct CO_2 emissions and does not consider the recycling of metals and the use of aggregates produced from the bottom ashes.

The main criteria to benchmark the different EfW technologies are:

- The direct CO_2 emissions from carbon combustion. Assuming that all the carbon contained in the waste is oxidized (not quite correct for pyrolysis and gasification but the carbon residues are generally oxidized separately), there is no significant difference in direct CO_2 emissions. One should consider separately biogenic emissions from fossil emissions.
- Energy recovery and fossil fuel substitution. As described in § 7.2 above, advanced moving grates achieve a better energy efficiency than the alternative technologies due to the need for waste preparation and lower intrinsic efficiency of their processes.

The advanced moving grate technology is therefore the most efficient in terms of GHG impact and continues to develop even more performing energy recovery systems.

It is worthwhile to know that the French association *"Entreprises pour l'Environnement"* (EpE) which gathers around 50 French and international large companies from all sectors to better integrate environment in their strategies and management have developed in 2013 quite a sophisticated protocol for the quantification of GHG from waste management activities.

7.4 Technology experience

Countries which have a long standing EfW experience have tested a large number of alternative technologies (Pyrolysis, Gasification). The most of these plants are either shut down or have undergone extensive remodeling to obtain acceptable reliability.

To date, there is hardly any plant with alternative technologies satisfactorily operating that treat residual MSW at an affordable cost, except in Japan for specific regulatory reasons and at the highest cost per ton experienced in the World. This is also the World Bank position: *"Pyrolysis and gasification are emerging technologies that have not yet been demonstrated at large-scale for treating municipal solid waste"*. The position of the Joint Research Centre, the European Commission's science and knowledge service is also similar. In their document *"Towards a better exploitation of the technical potential of waste-to-energy"* (JRC, 2016), it emphasizes that *"Gasification and pyrolysis of MSW and other mixed wastes have not been commercially proven to date, even with extensive pre-treatment of the waste to achieve better homogeneity. …There have been many costly failures of MSW gasification and pyrolysis plants throughout the EU-28 Member States in the past decades. A number of successful demonstration-scale plants using emerging techniques have also failed to make the jump to commercial scale."*

Given the high CAPEX required as well as years of Project development and many years of operation thereafter, emerging countries are therefore strongly encouraged to use **the only robust proven technology capable of directly treating residual MSW, that is to say "Advanced Grate Combustion"** when starting to develop EfW Plants.

7.5 Summary table – Impacts on fundability and risks

The summary table below has been established from the perspective of **Residual MSW Treatment in Countries where EfW is not yet implemented.**

In such Countries, **LCV generally ranges from 5 to 8 MJ/kg** compared with 8 to 10MJ/kg in Western Europe. This table considers technologies which have at least one plant in commercial operation with MSW. The color coding reflects the suitability of the technology to meet the above requirements, in particular in respect of bankability and fundability. **The conclusion is that only Advanced Moving Grate Combustion systems should be contemplated to ensure a successful development at long-term pre-determined costs.**

Figure 45

Source: ISWA WGER

Technology	Capacity kt/y	Waste input Waste preparation	Energy Recovery 100% Electricity	CHP	Operating hours / year	Envt Impact Emissions	Fundability & Bankability	CAPEX in M€	Costing in €/t over 25 years OPEX Fix + Var	Revenues	Gate fee €/t	Conclusion
Direct Treatment of Residual MSW : Advanced Moving Grate Technology												
Advanced Grate Combustion	**150** **500**	**Residual MSW** **No preparation required**	22 to 30% 22 to 30%	33 to 50% 33 to 50%	8 000 + 8 000 +	Most stringent Regulation	+++	**150** **300**	**40 to 50** **30 to 40**	**20 to 30** **20 to 30**	**80 to 100** **50 to 80**	**Basically the only proven and fundable Technology**
Comments	Range 50kt/y to 2 Mt/y	Hundreds of Plants in Operation with **Residual MSW**	450 to 650 kWhe/t of MSW (depending of LHV)					For info, order of magnitude of costs in **Eastern Europe** based on Compliance to WID emission limits - No specific architecture - no land cost -100% electricity production @ 40-50 €/MWh				
Since no figures are available due to very limited number of Plants in operation or in development, only comments related to Advanced Grate Combustion are reported												
Alternatives other Treatment Technologies												
Fluidised Bed	Range 50kt to 500kt/y	Need to have maximum particle size 200mm => shredding + Fe removal + treatment 10% rejects	Reduced efficiency due to high parasitic load + Energy to prepare Waste		+/- 7 500h due to bed maintenance	Most stringent Regulation	Possible since nb of Plants in Operation but lack of EPC Contractors	Higher than Adv Grate due to preparation required	Nb Plants in operation Limited figures available but OPEX also > Adv Grate due to more labour (preparation), high qualification required (BFB) and more APCR			**No advantage compared with Adv Grate except when large quantities of sludge to be burned in the same Plant**
Pyrolysis												
Burgau	**1 Plant < 100 kt/y**	Need to have maximum particle size 200mm (screw feeder) => shredding + Fe removal + treatment 10% rejects	Reduced efficiency due to poor thermal conversion + losses (coke) + Energy to prepare Waste		+/- 7 000h/y TBC	Comply with stringent emissions	In principle not possible since only one unit and stopped	No references	No real figures available			**Not available to developping Countries due to Plant complexity and lack of references**
ETIA	Only small capacity **max 25 kt/y - 25 Plants (none in MSW)**	Need to have **maximum particle size 30mm** + LCV min 16 MJ/Kg, Moisture < 20% => double shredding + Fe removal + treatment 50% rejects => **not well suited to MSW**	High thermal conversion due to high input LCV but much reduced when compared with MSW + losses (char) + Energy to prepare Waste		+/- 7 000h/y	Does not supply FGT	Possible when very attractive electricity selling Price + small units	Available on request but only partial scope. Containerized	Overall higher costs due to small capacity but can be economical when high electricity Price			**Available to developing Countries for specific streams, reduced capacities and very high electricity Prices (Islands)**
Gasification												
Valmet - CFB	1 Plant in Operation (Lahti - FIN) **mainly burning Biomass**	Need to have **maximum particle size 50mm** => shredding + Fe and non Fe removal + treatment 20% rejects	Good Energy Recovery efficiency due to high steam characteristics possible with CFB, but reduced by the Energy required for parasitic load, fuel preparation and Syngas cleaning		Lahti ref Plant **+/- 7000h (TBC)** but burns mainly biomass	Most stringent emissions with APC	In principle limited since no unit in operation burning 100% Municipal Waste	CAPEX > Adv Grate due to preparation and sophisticated non standard technology	No figures available but OPEX also > Adv Grate due to more labour (preparation) , high qualification required (CFB) and more APCR			**Initially indicated as suitable for MSW, but in practice biomass is much more suitable**
Japanese Techno BFB or Shaft Furnace (SF)	Many Plants only in Japan & Korea	**Extensive preparation (BFB)** Need to have maximum particle size 100mm => shredding + inerts, Fe and non Fe removal + treatment 20% rejects	Poor Energy Recovery (often **around 15%**) due to fuel preparation and vitrified slag required in Japan		Poor availability acceptable in Japan	Most stringent emissions with APC	Possible thanks to Bankable large Japanese Companies	CAPEX > Adv Grate due to preparation and sophisticated non standard technology	No figures available (**reports mention +/- 150€/t**) but OPEX also > Adv Grate due to more labour (preparation and process complexity), high qualification required and gasification reagents cost (coke, limestone, oxygen for SF)			**No Plants successfully in operation outside Japan & Korea despite many years of commercial development**
Enerkem	**1st Plant** in commissioning in Canada	Need to have **maximum particle size 50mm** => shredding + Fe and non Fe removal + treatment 30% rejects	Potential high Energy Recovery with **production of Methanol or Ethanol**, but reduced by the Energy required for parasitic load and preparation		**Very poor availability** after several years of commissioning	Most stringent emissions with APC	Not possible since 1st demo Plant not yet in full operation	No figures available but likely >> Adv Grate due to preparation and very sophisticated process.	No figures available but OPEX also > Adv Grate due to more labour (preparation and process complexity), high qualification required (FB) and refuse disposal cost			**1st demo Plant still in commissioning**
Co-combustion												
Cement kilns		Need to have **maximum particle size 30mm, strong limitation in Chlorine and mercury and minimum LCV 12 (preferred 18) MJ/kg** => shredding + Cl, Hg, Fe and non Fe removal + treatment 50% + rejects	100% Energy Recovery for the high Calorific fraction burned in kiln, but additional separate treatment required for the low calorific fraction so overall not attractive		Good availability of the preparation Plant and Cement Kilns	Cement Kilns have their specific regulation	Possible in principle for the preparation but solution for low calorific fraction ?	Relatively limited CAPEX for the preparation but solution for low calorific fraction ?	Overall costs mainly depends on solution for low calorific fraction			**It is virtually impossible to generate 18 MJ/Kg SRF from 6 to 9 MJ/kg MSW or this will represent such a small fraction of incoming stream that it does not make sense**

Summary evaluation of EfW technologies

8 Recommendations

8.1 Check list for decision-makers

As detailed above, rapidly increasing urban growth and environmental concerns push Authorities to “move up the waste treatment hierarchy”.

All authorities should as a first step **eradicate dump sites and open burning** and ensure that all landfills are **sanitary** with appropriate waste, biogas and leachates management.

The next step is to develop a **long-term waste management strategy** based on circular economy principles favoring the reuse and recycling and contemplate the implementation of **EfW for all waste which cannot be reused or recycled**.

See the attached UNEP document which summarizes most of the issues identified in this paper which have to be addressed to ensure the successful development of EfW.

Waste data and characteristics

- ☐ Does the waste quality and quantity meet thermal WtE requirements?
- ☐ Do seasonal waste variations and transboundary waste flow affect future waste projections?
- ☐ Is the MSW sorted at the source in the environs of the city or municipality, for both households and commerce?
- ☐ What percentage of the waste sent for disposal is recyclable or compostable?
- ☐ Are source recyclables and organics collected separately and sent to recycling and composting facilities?

Infrastructure

- ☐ Does systematic waste collection and transportation exist?
- ☐ Is a controlled landfill available for safe disposal of thermal WtE residues?

Environmental aspects

- ☐ Do emission standards for thermal WtE follow international standards?
- ☐ Are compensatory strategies available to mitigate environmental impacts?
- ☐ Is there installed capacity to regularly monitor emissions, including for persistent organic pollutants?
- ☐ What are the occupational health risks for workers and how can they be mitigated in everyday operations and in case of serious accidents?

Economic aspects

- ☐ Is the energy produced accessible to local users and/or available for sale in the market?
- ☐ Is there an available market for thermal WtE residues?
- ☐ Have long-term financial sources been secured?
- ☐ Is there access to foreign currency?

Legal aspects

- ☐ Does a comprehensive legal framework exist for all planned WtE technologies?
- ☐ Is there a decommission plan or decommission regulations in place for the thermal WtE plant?

Social aspects

- ☐ Can the working conditions of informal recyclers be improved?
- ☐ Are compensatory strategies available to mitigate social impacts?
- ☐ Are all relevant stakeholders being considered and consulted?

Risk assessment

- ☐ What are the flooding and tsunami risks, and what would the environmental and health impacts be if the plant was flooded?
- ☐ What is the hurricane or cyclone risk, and what environmental and health impacts would result if the plant was damaged by a hurricane or cyclone?
- ☐ What is the seismic risk, and what environmental and health impacts would result if the plant was damaged by an earthquake?
- ☐ What is the elevation of the site, and what environmental and health impacts would result if the site was affected by rising sea levels?

Alternatives

- ☐ Are there alternative WtE technologies that better suit the local conditions?
- ☐ Is thermal Wte, including biogenic Co, emissions,a good option in the local context according to the life cycle assessment?
- ☐ Is there a way to improve rates of recycling and composting?
- ☐ Are there waste prevention policies in place?

All necessary information needed to develop a new plant can easily be made available for Advanced Moving Grate Combustion during the feasibility study of a new project if necessary with contractors’ preliminary proposals, but this is hardly possible for the other technologies, due to their lack of references and also lack of contractors.


Oxford (UK)EfW Credit: Julien Goldstein - Viridor

8.2 Technology selection

For all reasons explained in detail in the paper, advanced moving grate combustion is the most appropriate technology for residual MSW treatment with specific features to cater for local waste characteristics such as moisture / LCV, seasonal variations ...

This is confirmed for example by the case studies such as Baku, Addis Ababa, Istanbul and Belgrade mentioned in §6.7.

8.3 Conclusions

The **ISWA** Working Group consider that Energy-from-Waste **(EfW) (considered as a resource recovery treatment) is the preferred option to deal with all the remaining Municipal Solid Waste which cannot be reused, recycled or composted in particular for large cities where land availability, health, environment impacts, and climate change are major concerns and huge tonnages have to be treated**.

Sanitary Landfill will remain necessary for waste for which materials and / or energy cannot be recovered.

In line with this WG conclusion, let’s quote the executive summary of the UNEP document *“Waste-to Energy – Considerations for Informed Decision-making”*

> All materials have an end-life and eventually become waste, and in these cases thermal WtE (Waste-to-Energy) is the preferred way of treatment compared to landfilling and open burning.

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