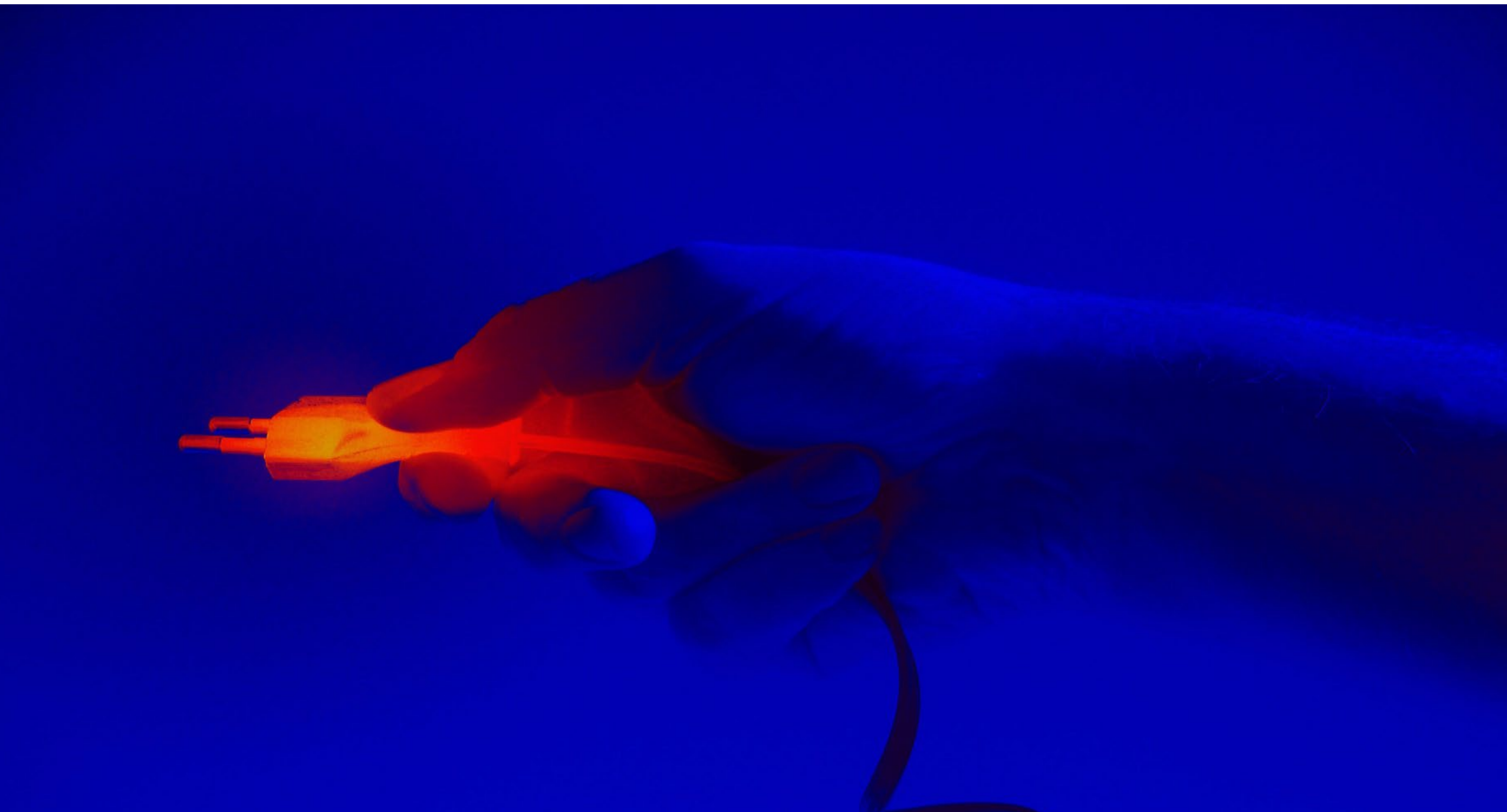
Jaspers
Joint Assistance to Support Projects in European Regions

# Key Considerations in Planning
# Waste–to–Energy Facilities

August 2013



JASPERS Knowledge Economy and Energy Division

# Staff Working Papers

## Key Considerations in Planning Waste–to–Energy Facilities

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JASPERS Staff Working Papers are prepared by JASPERS experts with the aim of facilitating the discussions with counterparts in the context of their different assignments, mostly in terms of project scoping and applicable criteria and methodology. These papers normally originate as part of the assessment of a specific project, in which case the version published here is edited to be made non-project and non-country specific and therefore easily applicable to other projects in the sector. Most of the issues discussed in this note rose from the discussions during JASPERS supported projects in Poland (six Waste-to-energy facilities and two Mechanical-Biological Treatment Plants).

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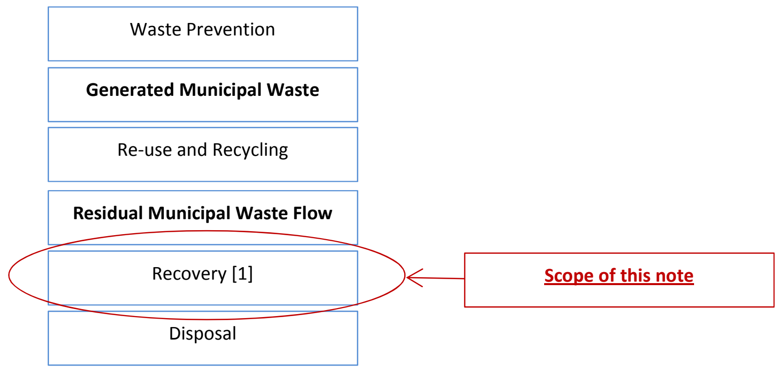
## Contents

# 1 INTRODUCTION

EU waste policy aims to reduce negative environmental and health impacts and to create an energy and resource-efficient economy. The Waste Framework Directive (2008/98/EC) introduces a five-step waste hierarchy where prevention is the best option, followed by re-use, recycling, and other forms of recovery, with disposal operation as the last resort.

The application of the waste hierarchy implies that once the possibilities of waste prevention, re-use and recycling has been exhausted, the residual municipal waste flow should be managed in a way that options for recovery (i.e. energy recovery) are preferred against the final disposal.

The scope of this note is limited only to the residual municipal waste flow management and assumes that options for waste prevention, re-use and recycling has been already exhausted upstream in the process.




[1] Mostly through W-t-E facilities, but also possible through well-functioning MBTs depending on their configuration.

In the period of 2007-2013 most of the new EU member states launched an extensive reorganization of the waste management sector that resulted in updated policies and the initiation of the new investment heavy infrastructure aimed at tackling the residual municipal waste flow. Various technologies are being applied for the residual municipal waste flow treatment that in broad terms may be split into Mechanical Biological Treatment (MBT) and Waste-to-Energy (W-t-E) technologies. Both technologies are used in many European Countries and under certain conditions may work in complementing each other.

The objective of this working paper is to provide information that could be used at the feasibility study stage of the project preparation for a residual municipal waste management project. This Working Paper aims at contributing to a constructive dialogue between interested parties in defining most advantageous way of residual municipal waste flow treatment for a specific project. If a soundly performed option analysis results in W-t-E technology as most advantageous, the paper will facilitate further discussions required for determining techniques to be used in the technological process.

The technologies discussed in this note cannot be considered as primary measures for reaching challenging re-use and recycling targets and should be designed in a way not to jeopardize initiatives aimed at the selective collection, re-use and recycling. In fact, the consideration of options for the treatment of residual waste should always take place once the prevention and recycling has been taken care of.

While efforts have been made to provide accurate and objective data, this paper cannot replace detailed evaluations of project proposals for a specific country that must be based on accurate data, local context and latest technology developments.

# 2 POLICY BACKGROUND

The 7$^{th}$ European Union Environment Action Programme (EAP) to 2020 is being widely consulted with public shareholders[1] and places focus on turning the Union into a resource-efficient, green and competitive low-carbon economy. It acknowledges that the use of natural resources is still largely unsustainable and inefficient, and waste is not yet properly managed.

[1] http://ec.europa.eu/environment/newprg/7eap.htm

Under the Priority Objective 2 EAP states:

- There is a considerable potential for improving waste management in the EU to make better use of resources, open up new markets, create new jobs and reduce dependence on imports of raw materials, while having lower impacts on the environment.
- Turning waste into a resource, as called for in the Resource Efficiency Roadmap, requires the full implementation of EU waste legislation across the EU, based on strict application of the waste hierarchy and covering different types of waste.

The proposed programme draws on a number of recent strategic initiatives of the EU in the field of environment, including the Resource Efficiency Roadmap[2] which among others provides that by 2020, waste is managed as a resource and energy recovery is ensured from the non-recyclable waste.

The Waste Framework Directive (2008/98/EC) establishes a waste hierarchy, introduces requirement for the increase of re-use and recycling of waste materials such as at least paper, metal, plastic and glass from households to a minimum of overall 50% by weight by the year 2020.

The Directive on the Landfill of Waste (1999/31/EC) introduces requirement to reduce the amount of biodegradable municipal waste landfilled to 35% of 1995 generation levels by 2016 (for some countries by 2020). The same directive states that only waste that has been subject to treatment is landfilled.

Therefore, as a first step, there is a strong focus on prevention and recycling. Then as a second step there is a need to reduce the amount of biodegradable waste finally going to the landfill, which puts additional pressure on the treatment of residual waste, including the need for energy recovery when feasible, this way ensuring higher step on waste hierarchy than disposal.

# 3 OPTION ANALYSIS

## 3.1 TECHNOLOGICAL COMPARISON

Before any comparison of available technological options is being performed, it is absolutely necessary that the general requirements for the system are established (acceptable landfill limits, biodegradability, separation of recyclables, energy production, basic environmental requirements, required result for the reduction of GHG, etc.).

For any municipal waste treatment system, <u>sound waste generation and demand analysis is essential</u>: current and future waste generation, waste composition (including seasonal variations); waste properties (moisture, composition, calorific value); required amounts to be separated to conform with re-use and recycling targets; required amounts of municipal waste to be diverted from landfilling to comply with target for reduction of disposal of biodegradable waste; possibilities and conditions for the off-take of heat and electricity production; possibilities and conditions for the off-take or further use of MBT outputs (CLO, SRF, RDF[3]). The latter factor is important to consider when assessing the applicability of MBT options in a particular context.

In conducting a project option analysis it is necessary to pay attention to the fact that residual waste treatment technologies (W-t-E or MBT) can only support recyclable waste separation from the municipal waste flow but cannot be relied on to ensure achieving targets set for re-use and recycling of materials (papers, plastics, metals, glass). Therefore particular attention should be paid to the establishment of realistic mass flow balances under proposed options.

W-t-E facilities in most cases provide a final treatment solution with residuals ready for recycling (i.e. metals), use or disposal (ashes and flue gas treatment residues). At the same time MBT facilities can be viewed as an intermediate step of treatment as it produces outputs like RDF, SRF, and CLO that require further handling.

MBTs are usually found more appropriate for the smaller cities / agglomerations and where the off-take of produced outputs can be guaranteed at reasonable cost. In case it is not possible to guarantee the off-take

[2] Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions Roadmap to a Resource Efficient Europe (COM/2011/0571 final)

[3] Compost-like Output, Solid Recovered Fuel, and Refuse-Derived Fuel, respectively

of produced outputs, there is an uncertainty in O&M costs and a risk that outputs have to be disposed on landfill. For this reason, in absence of appropriate off-take agreements may MBTs end up carrying a function to simply prepare waste for final disposal and therefore they will rank lower than actual recovery facilities in the waste management hierarchy. In fact a recent report from the European Court of Auditors[4] notes a very low performance of MBTs in terms of recovered materials and waste diversion from landfills. It should be noted that poor MBT performance with regard to the stabilization of biodegradable fraction leads to difficulties in implementing requirement of Directive on the Landfill of Waste on reduction of disposal of municipal biodegradable waste.

Particular attention should be paid to the outputs of the bio-drying technologies that result in SRF product. In case off-takers for the SRF cannot be found and the SRF has to be landfilled in most cases it would be considered bio-degradable in relation to the Landfill Directive.

In large cities/agglomerations W-t-E facilities are often considered as most suitable option for residual municipal waste flow treatment, as SRF/RDF off-take markets at large quantities cannot be guaranteed for prolonged time periods. Technically, W-t-E facilities are more sensitive to variations in the designed waste flow, and can usually operate in +10%/-20% range from design mass and thermal load. MBT plants are more flexible to variations in throughput. Both MBT and W-t-E have their advantages and depending on circumstances, both technologies could be considered and could also complement each other and are able to provide desired results separately or in combination.

To come up with most suitable project implementation scenario, the option analysis exercise shall ensure fair comparison of technologies considered fully considering enabling and inhibiting factors in the local context. To ensure same grounds of comparison, any option considered shall take into account the full waste treatment cycle (i.e. final utilization of refuse derived fuels, slag, fly ashes, stabilized organic fraction, etc.). In the option analysis for MBTs it is important to take a realistic view with regard to long term options for utilization of produced outputs, e.g. RDF/SRF in cement kilns or other plants, or with regards to the use of compost like outputs for e.g. dumpsite/landfill cover or contaminated site rehabilitation. Similarly, for W-t-E plants it important to ensure that as high degree of the energy as possible, in particular the heat, is recovered. Furthermore a realistic view should be taken on the degree of slag reuse in construction industry.

In options where MBT technologies are preferred and no reliable refuse derived fuel off-taker is available in reasonable distance, introduction of a dedicated refuse derived fuel utilization plant with energy recovery could be considered. This would however significantly increase the overall costs. Likewise, options that consider Waste-to-Energy facilities but indicate difficulties to reach recycling targets in the short term through selective collection of recyclable waste may consider introducing mechanical sorting part of the MBT plant to as complement to upstream selective collection. This should however not be seen as an alternative but a complement to selective collection. It should also be taken into account that MBT plants that are designed exclusively for stabilization of the biodegradable waste fraction with disposal of the overall stabilized output to landfills, or W-t-E facilities not reaching the Waste Framework Directive R1 energy efficiency criteria, are considered as disposal activities and are at the lowest step of waste management hierarchy.

## 3.2 FINANCIAL AND ECONOMIC COMPARISON

The comparison of technological options will ideally provide clear answer as to what options are technologically most suitable for the achievement of the project targets. At the same time the overall impact of considered technological options may be significantly different and therefore difficult to compare. For this reason ranking of options should also be based on their net present values in financial and economic terms.

Economic analysis among other factors should take into account greenhouse gas (GHG) emissions because, when comparing MBT and W-t-E facility technologies, the expected impact on climate change of each option is significantly different.

GHG relevant to waste management include carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$). The overall impact on the climate will depend on net balance of GHGs, accounting both direct and indirect emissions and savings. Upstream (indirect) emissions relate to GHG emissions from production of energy and materials used in the facility and infrastructure/equipment. Direct emission comes from the treatment process. GHG emissions in MBT facilities are mainly released from the fuel consumed in waste treatment

[4] Special Report 20/1012: Is structural measures funding for municipal waste management infrastructure projects effective in helping Member States achieve EU Waste policy objectives? (http://eca.europa.eu/portal/pls/portal/docs/1/20156748.PDF)

facility, biogenic $CO_2$, $CH_4$, and $N_2O$ from anaerobic and aerobic composting processes. Further GHG may occur downstream, depending on the application of compost product – $CO_2$, will be gradually released as the compost further degrades and becomes integrated with soil-plant system. In W-t-E facility the direct source of GHG emission is combustion of waste.

The level of GHS is influenced by many factors. For example, the overall impact on climate of a particular MBT technology will depend on a number of factors:

- The efficiency of front-end sorting processes, as recovered materials (high quality) contribute to potentially significant downstream GHG savings;
- Energy consumption of the system, as more automated, sophisticated systems have a higher energy demand and higher upstream GHG emissions;
- Energy generation, as in the case of anaerobic digestion (AD) type MBT facilities, energy produced from biogas – either heat or electricity – will account for a GHG saving;
- Control of emissions during the maturation phase, as best-practice for MBT involves the use of air pollution control systems, such as scrubbers and bio-filters, to prevent emissions of nitrous oxide and methane;
- Biodegradability of final output, as the biodegradability of the final composted output will decrease with increased maturation time, and the lower the biodegradability, the less potential for the material to generate methane (if landfilled) and therefore higher contribution to GHG.

Also, the climate impact of a particular W-t-E technology will depend on:

- Whether electricity, heat or combined heat and power (CHP) is to be produced, as the more heat and power is produced the higher contribution of the facility to GHG savings;
- The type of energy displaced by energy generated through the process, for example if coal is assumed to be replaced, as the GHG emissions savings are double than if natural gas is assumed to be replaced;
- The content of fossil carbon in the input of waste, as the lower fossil carbon content, the lower impact on GHG emissions.

W-t-E facilities also contribute to avoidance of GHG emissions due to reduction of landfill of waste, possible reuse of bottom ash and recovery of metals.

The summary of GHG emissions from waste management actives can be found in the UNEP document on "Waste and Climate Change - Global Trends and Strategy Framework" (2010). More information on calculation of GHG emissions in waste and waste to energy projects could be found under JASPERS staff working paper released on March 2013[5].

The analysis should take into account all investment, operating and maintenance costs (land property costs, design and construction costs for the different facilities, costs of equipment with the corresponding replacements when its economic life is lower than the reference period, operating and maintenance costs, etc.). Also, the analysis should take into account revenues obtained from the sale of sub-products generated during the operation of the facilities like compost and recyclables, and any revenues (or cost savings in case of internal consumption) from the sale of heat and/or electricity. Finally, the analysis should also take into account the residual value of the different facilities at the end of the reference period.

The financial and economic options analysis may result in similar FNPV and ENPV for MBT and W-t-E technologies. In such cases the analysis can be complemented by a sensitivity or risk analysis to select the optimum solution. In this case, the selected option should be the one that is capable to reach the project objectives with the least risks for its implementation/operation.

## 3.3 PROS AND CONS

Each option analysis is heavily dependent on the local context and related enabling and inhibiting factors. Therefore it is not possible to provide generalised conditions under which MBT or W-t-E technologies would be preferred. The following aspects might be considered in comparisons of MBT and W-t-E options for treatment of residual waste:

[5] http://www.jaspersnetwork.org/jaspersnetwork/download/attachments/4948011/13-03-11+JASPERS+WP_Methodology+for+GHG+Emission+Calculation_Waste+Calculation_FINAL.pdf?version=1&modificationDate=1366389231000

| W-t-E | MBT |
|---|---|
| Subject to an adequate scale in terms of capacity, once sufficiently high and reliable demand for the produced energy off-take is ensured, W-t-E facility would be preferred option. | If sufficient capacity for off-take of the MBT products is readily available at a reasonable distance and at acceptable costs, the mechanical biological treatment facility could be regarded as applicable. |
| | If MBT product off-take opportunities are readily available and there is no need to construct dedicated treatment facility (for RDF/SRF), MBTs result in lower capital cost than W-t-E. |
| Ensures more reliable performance for biodegradable waste diversion from landfill targets. | MBT facilities are able to ensure meeting biodegradable waste diversion targets assuming that there are markets for outputs produced. If that is not the case and biodegradable outputs needs to be landfilled there is limited reduction of biodegradable waste landfilled. |
| W-t-E facilities usually result in lower residual flow that needs to be landfilled if overall waste treatment cycle is taken into account. | |
| Due to economy of scale W-t-E facilities often prove to be more appropriate and cost effective residual waste treatment option for large agglomerations. | MBT facilities usually show more flexibility in adapting to varying waste flow and composition, although benefits can only be fully achieved if there are markets for produced outputs (CLO, RDF/SRF). |
| | MBT facilities provide possibility for separation of wider range of recyclable materials (while W-t-E are basically limited to ferrous and in some cases non-ferrous metals separation), however the quality will be lower than for recyclables from selective collection. |
| W-t-E technologies usually result in positive contribution to reduction of GHG if also the heat can be recovered and utilised. | MBT systems may have varied carbon footprints, possibly resulting in negative impact on the GHG reduction balance due to the often high energy consumption and limited energy recovery. |
| W-t-E facilities are more energy efficient if compared to MBT with energy production module. | |

# 4 WASTE-TO-ENERGY FACILITIES

If the option analysis results in the choice of W-t-E technology, the information provided in this section could be considered while defining the basic configuration of the W-t-E plant.

## 4.1 CONFIGURATION / CAPACITY / TECHNIQUES

The most common techniques used in waste-to-energy facilities are described under the Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration. The Industrial Emissions Directive (2010/75/EU) states that permit conditions to operate W-t-E facilities shall use Best Available Techniques (BAT) as a reference.

Apart from generic measures, the BAT for waste incineration provides specific BAT for the municipal waste incineration and specific BAT for the pretreated or selected (including municipal refuse derived fuel) municipal waste incineration. BAT shall be consulted throughout once different types of W-t-E components are being considered (type of grate, flue gas treatment, slag and ash management, etc).

The sections below do not intend to provide extensive description of techniques given in the above documents, but rather aims at facilitating the discussion and underlining topics that may emerge during the projects preparation process.

### *4.1.1 Capacity and availability*

One common issue is the overestimation of the capacity of currently available and planned W-t-E facilities. To ensure that the capacity of the foreseen facility is not over-dimensioned a proper demand analysis should be performed. The demand analysis shall take into account at least the following: existing and predicted future waste flows; existing and foreseen future waste characteristics; requirements and targets for re-use and recycling of materials such as glass, paper, metals, plastics and for biodegradable waste diversion from landfills. The waste flow balance in the overall waste management system shall demonstrate that, with the proposed capacity of the W-t-E facility, the achievement of the remaining municipal waste management targets (mainly recycling) is possible.

The capacity of the facility and the number of thermal treatment lines is determined based on the overall demand for treatment, required flexibility, and energy market in the project area.

The number of treatment lines to be constructed depends on the overall waste inflow and the capacity limit for one line which is considered to be app. 300,000 t/year. However also for facilities with lower capacity a two line configuration can be considered, since it will increase the reliability of the plant, and enable continued operation during maintenance periods. However, these advantages come at a cost, since a two line configuration has higher investment costs than a one line configuration.

The guaranteed availability of the W-t-E facility is expected to be ca. 8,000 hours annually. In some cases conservative availability of 7,800 hours is being indicated. The number of the guaranteed operating hours is one of the factors influencing designed capacity of the plant and has impact on the final capital and operating costs of the facility.

### *4.1.2 Waste storage*

W-t-E facilities foresee bunkers for temporary waste storage and mixing sufficient for up to 5 days capacity. For longer shut-down periods, the facilities should foresee temporary storage for the incoming waste flow. Often, bailing and temporary storage of bales on the site or off the site is being proposed. Larger bunkers or other arrangements are required to accommodate the maintenance periods for one-line facilities.

### *4.1.3 The thermal treatment stage*

For the thermal treatment stage the grate incinerators and fluidized bed technologies are being observed as dominant technologies. Grate incinerators are most common technology applied for treatment of the residual mixed municipal waste flow (to avoid high pre-treatment cost), while fluidized beds are being considered for RDF/SRF treatment.

Fluidized bed facilities often consider treatment of RDF/SRF in combination with some other non-hazardous industrial waste e.g. sludge.

#### *4.1.4 The energy recovery stage*

The energy recovery stage of a W-t-E facility is designed to ensure that the energy contained in the waste can be recovered to the extent local conditions for the off-take of produced electrical and thermal energy allows. It is noted that the highest energy efficiency of W-t-E plants is achieved when not only electricity but also heat can be utilized (i.e. district heating networks or nearby industries able to utilize steam for technological purposes). If the heat cannot be utilized an important revenue stream is foregone, and the carbon footprint of the plant increases.

The type of turbine is determined depending on the possibilities to supply the heat and electricity to customers. In cases where the heat or steam off-take varies significantly throughout the year, the extraction condensing turbines are preferred. If a significant and constant amount of heat can be supplied to customers, the back pressure turbines are preferred. Condensing turbines are preferred if there is no possibility for heat off-take and recovered energy is to be converted to electricity.

If the W-t-E facility is foreseen to be qualified as energy recovery operation following the provisions of the Waste Framework Directive, it shall be designed in a way to comply with minimum energy efficiency requirement ($R1 \geq 0.65$). Plants working in co-generation mode demonstrate highest energy efficiency levels and usually qualify as performing recovery operations.

#### *4.1.5 Flue gas treatment*

Flue gas treatment technologies are employed to meet the strict Emission Limit Values in the Industrial Emissions Directive. Flue gas treatment technologies aim for reduction of e.g. dust emissions, acid gas emissions, reduction of oxides of nitrogen, PCDD/F emissions, mercury emissions. It is important to notice that flue gas treatment should be considered as an integrated system where the application of available techniques for different emissions is interdependent.

For the reduction of dust emissions the following systems are being used: cyclones and multi-cyclones, electrostatic precipitators, bag filters.

For the reduction of acid gases (e.g. HCl, HF and SOx emissions) dry, semi-dry or wet flue gas treatment technologies can be applied. It is often found that wet flue gas treatment technologies may achieve lower emission limits and result in less residual than dry or semi-dry flue gas treatment technologies. However the use of wet flues gas treatment technologies maybe limited in the areas where exhaust of visible fumes from the facility is not allowed. At the same time wet flue gas treatment technologies usually result in higher capital cost, but allow lower operational costs than dry or semi-dry flue gas treatment systems. Semi-dry systems result in higher amounts of solid residuals (mainly due to the bigger amounts of reagents used) but do not result in the need for wastewater treatment as from the wet flue gas treatment.

If properly designed and operated wet, semi-dry and dry flue gas treatment technologies should all allow achieving emission limits well within those specified in the Industrial Emissions Directive and therefore in general should be regarded as suitable technologies.

Besides primary measures to achieve required levels of NOx emissions, the following secondary techniques for $NO_X$ reduction are being used: Selective Non-Catalytic Reduction Process (SNCR) and Selective Catalytic Reduction process (SCR). Once SCR system is applied, lower NOx emission levels can be achieved with smaller relative consumption of reagent (ammonia or urea). On the other hand larger investments are required and energy efficiency of the plant is reduced marginally because of lower electricity generation and consumption of electricity for process equipment. The decision on which system is to be applied also depends if $NO_X$ emissions are taxed.

Reduction of organic carbon compounds (PCDD/F) emissions are usually achieved by using adsorption on activated carbon reagents in an entrained flow system (by injecting activated carbon into the gas flow, specific design of SCR system, catalytic filter bags, other methods).

Reduction of mercury emissions is being achieved by one of the following methods: low pH wet scrubbing and additive addition, activated carbon injection, use of condensing scrubbers and other methods.

### *4.1.6 Solid residue treatment*

The solid residues in W-t-E facilities are: bottom ash, boiler ash (treated together with fly ash) and fly ash. Requirements for slag and bottom ashes from W-t-E facilities are detailed in the Industrial Emissions Directive and proven W-t-E technologies are able to comply with it.

Fly ash, boiler ash and flue gas treatment residues are regarded as hazardous waste and require specific treatment. In most observed cases, such residues are either being subject to solidification and chemical stabilization prior landfilling or to disposal in e.g. salt mines. Due to the comparably low quantities of fly ash and flue gas treatment residues generated as well as required capital costs for fly ash stabilization in W-t-E facilities, it could be advised to look at possibilities to outsource this activity to the dedicated service providers.

In most of the facilities where extensive metal separation on the waste flow before entering the facility is not applied, bottom ash is the subject for separation of metals. While almost all initial amount of ferrous metals can be recovered from the bottom ash (at app 1.0% of incoming waste flow), the recovered amounts of non-ferrous are lower due to losses during the thermal treatment process (dripping).

Most of the facilities apply bottom ash treatment using ageing before its planned use as a construction material or if that is not possible before landfilling. Some projects foresee high and often over optimistic level of planned use of bottom ash as construction material. Over optimistic expectations on bottom ash usage as construction materials may result in higher than expected bottom ash management costs.

The above technological steps of waste thermal waste treatment technology represent only a general overview of the process. For more information on possible configurations and applied processes it is advised to consult Reference Document on the Best Available Techniques for Waste Incineration[6].

## 4.2 W-T-E EMISSIONS AND CONSUMPTIONS

Emissions and material/energy consumptions at W-t-E facilities are mainly influenced by: waste composition and content, furnace technical measures, design and operation of flue-gas cleaning equipment.

### *4.2.1 Emission to air*

Emissions of HCl, HF, $SO_2$, $NO_X$, and heavy metals depend mainly on the structure of the waste and the flue-gas cleaning quality, but also the operational regime. CO and VOC emissions are determined primarily by furnace technical parameters and the degree of waste heterogeneity when it reaches the combustion stage. The furnace design and operation to a large extent also affect $NO_X$. Dust emissions are very dependent upon flue-gas treatment performance. PCDD/PCDF emissions to air depend on waste structure, furnace (temperature and residence times), plant operating conditions and flue-gas cleaning performance.

Municipal waste incineration plants generally produce flue-gas volumes (at 11 % oxygen) of between 4,500 and 6,000 $m^3$ per ton of waste.

It is to be noted that generation of $NO_X$ that results from combining prepared or selected wastes with fluidized bed technology may be lower than in grate furnace based incinerators, and therefore this can potentially lead to similar or lower emission levels using simpler flue gas treatment than inherently high $NO_X$ combustion systems. Due to relatively lower temperature of the fluidized bed combustion, the contents of heavy metals in the raw flue-gas (and hence FGT residues) may be lower than from mixed waste grate combustion.

Air emission limit values for waste incineration plants are determined by Annex VI of the Industrial Emissions Directive.

### *4.2.2 Emissions to water*

Depending on the type of flue-gas cleaning applied, emissions into the medium water may also occur. Wet flue-gas cleaning is the main source of effluents in case of W-t-E facilities observed by JASPERS.

[6] Reference Document on the Best Available Techniques for Waste Incineration, August 2006, http://eippcb.jrc.es/reference/BREF/wi_bref_0806.pdf

Waste water generation from the wet flue gas treatment and its discharge are among the factors considered while determining which flue gas treatment technology would be applied. BREF indicates typical quantities (from the W-t-E facilities of 250,000 t/year with two stages of flues gas cleaning) of scrubbing water arising from the flue-gas cleaning:

- app. 0.15 $m^3$/t of waste if milk of lime is used, or
- app. 0.3 $m^3$/t of waste if sodium hydroxide is used.

### *4.2.3 Solid residues*

BREF provides some typical data on residues from municipal waste incineration plants:

| Type of residue | Specific amount (dry) (kg/t of waste) |
|---|---|
| Slag/ash | 200-350 |
| Dust from boiler and de-dusting | 20-40 |
| Flue Gas Cleaning residues, reaction products only:<br>Wet sorption<br>Semi-wet sorption<br>Dry sorption | <br>8-15<br>15-35<br>7-45 |
| Reaction products, and filter dust, from:<br>Wet sorption<br>Semi-wet sorption<br>Dry sorption | <br>30-50<br>40-65<br>32-80 |
| Loaded activated carbon | 0.5-1 |
| Note: wet sorption has a specific dryness (e.g. 40 – 50 % d.s.) | |

The Industrial Emissions Directive specifies that waste incineration plants shall be operated in such a way as to achieve a level of incineration that the total organic carbon content of slag and bottom ashes is less than 3 % or their loss on ignition is less than 5 % of the dry weight of the material.

Commission Decision (2000/532/EC)[7] establishing list of wastes from incineration or pyrolysis of waste lists the following types of waste:

| Code | Type of waste |
|---|---|
| 19 01 02 | ferrous materials removed from bottom ash |
| 19 01 05* | filter cake from gas treatment |
| 19 01 06* | aqueous liquid wastes from gas treatment and other aqueous liquid wastes |
| 19 01 07* | solid wastes from gas treatment |
| 19 01 10* | spent activated carbon from flue-gas treatment |
| 19 01 11* | bottom ash and slag containing dangerous substances |
| 19 01 12 | bottom ash and slag other than those mentioned in 19 01 11 |
| 19 01 13* | fly ash containing dangerous substances |
| 19 01 14 | fly ash other than those mentioned in 19 01 13 |
| 19 01 15* | boiler dust containing dangerous substances |
| 19 01 16 | boiler dust other than those mentioned in 19 01 15 |
| 19 01 17* | pyrolysis wastes containing dangerous substances |
| 19 01 18 | pyrolysis wastes other than those mentioned in 19 01 17 |
| 19 01 19 | sands from fluidized beds |
| 19 01 99 | wastes not otherwise specified |

* - Hazardous waste

Council Decision (2003/33/EC) establishing criteria and procedures for acceptance of waste at landfills provides leaching limit values for each type of waste landfill (inert, non-hazardous, hazardous). Therefore before the decision for final residue disposal is taken, leaching tests will need to be performed.

In fluidized bed incinerators, because of the difference in the process, the waste properties and the combustion temperatures, the quality of ashes is very different to the ashes of grate incinerators. When recovered fuel is produced for fluidized bed boilers, the ash content is usually 1 – 10 %.

The majority of solid residue from fluidized bed incineration is fly ash, which, according to conditions and applied fluidized bed technology, can form up to 90 % of the total ash residue. The bottom ash is also mixed with fluidized bed material (e.g. sand, additives for desulphurization etc.). When waste or RDF is burnt in a rotating fluidized bed, the ratio of bottom ash to fly ash is about 50:50. In fluidized bed incinerators, a greater proportion of volatile heavy metals remain in the bottom ash.

[7] Commission Decision of 3 May 2000 (2000/532/EC:) replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste, OJ L 226, 6.9.2000.

### *4.2.4 Energy output and input*

The energy recovery system design for the W-t-E facility is often heavily influenced by the energy off-take opportunities. Relative and absolute prices of heat, steam and electricity have an influence on the final design and hence the energy recovery and efficiency levels achieved.

The energy efficiency is limited by high temperature corrosion that may occur in the heat conversion areas due to the contents of certain materials in the waste (in particular chlorine). The corrosion is more pronounced in temperatures above 450 $^{o}$C.

Typical superheated steam conditions applied in W-t-E are 40 bar and 400 $^{o}$C. For higher steam parameters (and hence electrical efficiency) special measures are required to limit corrosion. In order to attain the Waste Framework Directive R1 recovery status, a W-t-E plant with only electricity production would generally have to apply enhanced steam parameters and related corrosion control measures.

Where only heat or steam is produced, operators tend to use lower boiler pressures and temperatures to avoid the need for the additional investment and maintenance and the more complex operation conditions associated with the higher parameters. In the case where heat supply is prioritized, high pressure and temperature of steam is not justified. Typically for heat supply, the steam will be generated at lower values e.g. around 25 to 30 bar and 250 to 350 °C.

Approximately 20-25% of the energy recovered in the steam generator can be recovered as electricity. However, if there is a possibility to connect the steam cycle of W-t-E facility to the steam cycle of an adjacent power plant, the overall electrical efficiency can be as high as 35%.

Besides economic factors, the Waste Framework Directive implies W-t-E facility aiming to obtain recovery operation shall meet certain energy efficiency levels. Energy efficiency is to be calculated based on R1 formula provided in the Directive and should not be less than 0.65. As already indicated in this note highest efficiency is achieved if combined heat and power (CHP) production is being achieved. It is noted, that the energy efficiency formula requires that only off-taken heat amount to be used for the efficiency calculation. Details concerning the calculation of R1 formula are provided in the guidelines on the interpretation of the R1 energy efficiency formula for incineration facilities dedicated to the processing of Municipal Solid Waste according to Annex II of the Waste Framework Directive 2008/98/EC available at the EC website[8].

The BAT for municipal waste incineration indicates an overall total energy production level of 1.9 MWh/tonne of municipal solid waste (MSW), based on average net calorific value of 2.9 MWh/tonne. In situations where less than 1.9 MWh/tonne of MSW can be produced, the following shall be ensured:

- the generation of an annual average of 0.4 – 0.65 MWh electricity/tonne of MSW (based on an average NCV of 2.9 MWh/tonne processed, with additional heat/steam supply as far as practicable in the local circumstances, or
- the generation of at least the same amount of electricity from the waste as the annual average electricity demand of the entire installation, including (where used) on-site waste pretreatment and on-site residue treatment operations.

The BAT also requires that the average electricity consumption of the facility (excluding pretreatment or residue treatment) would be generally below 0.15 MWh/tonne of MSW processed based on an average NCV of 2.9 MWh/tonne of MSW.

The BAT separately specifies minimum required energy efficiency for pretreated or selected waste incineration.

## 4.3 CAPITAL COSTS

Capital costs for W-t-E facilities varies depending on: geographical location, configuration chosen, properties of waste to be treated, requirements for emissions, available site area and connections (road, heat, electricity networks), architectural designs and quality of materials used, energy efficiency solutions, local requirements (fire safety, landscape, labor costs), level of market competition amongst suppliers, interest of suppliers in the project, and existence of similar projects in the portfolio of suppliers in terms of requirements. Development and financing costs may also have a very large impact on the total project cost.

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[8] http://ec.europa.eu/environment/waste/framework/pdf/guidance.pdf

It could be observed that, at the project preparation stage, the project developers tend to underestimate the capital investments required.

Factors that may increase W-t-E (for mixed municipal waste) capital costs are as follows:

- several smaller treatment lines instead of one large;
- wet-flue gas treatment instead of semi-dry flue gas treatment;
- Selective Catalytic Reduction (SCR) instead of SNCR (Selective Non-Catalytic Reduction);
- Enhanced steam parameters;
- Use of extraction turbine versus backpressure turbine;
- Variations in planned civil works (additional requirements for civil engineering and architect services, additional facilities);
- Introduction of fly-ash and/or bottom ash treatment/stabilization facilities on the site.

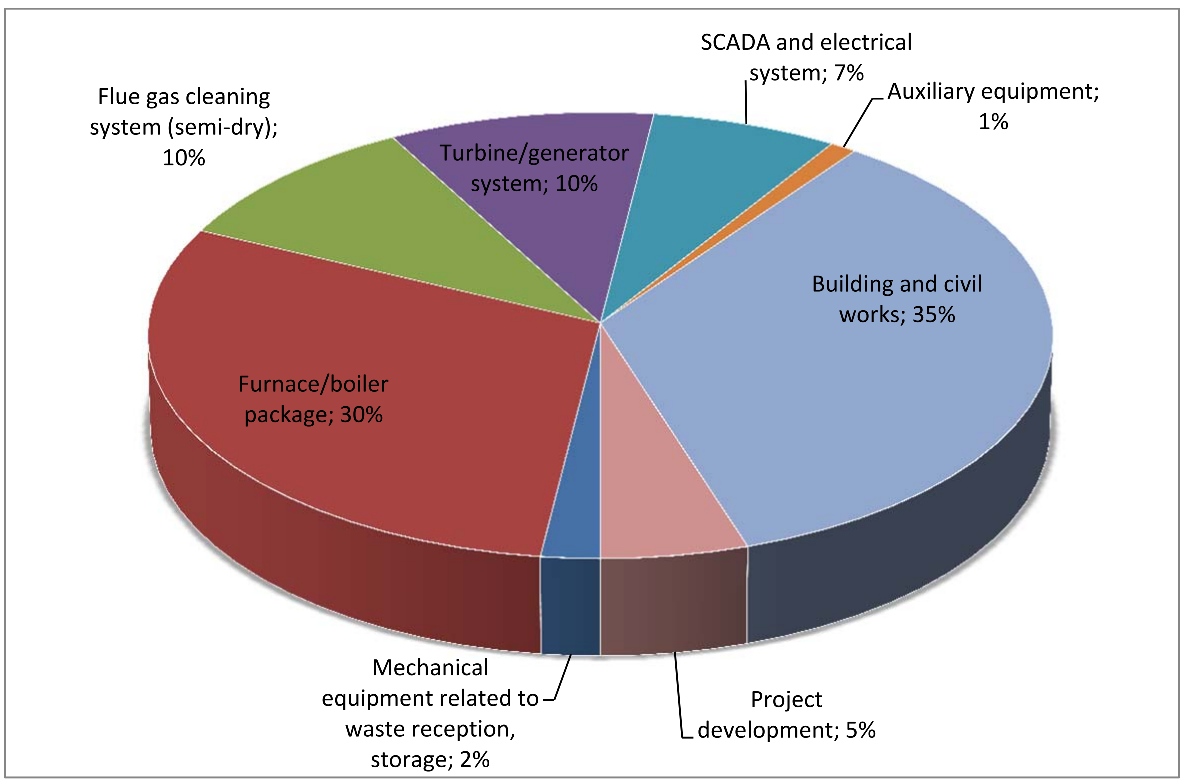
It is estimated that the capital cost difference between a basic configuration of the plant on the one hand (one line, semi-dry with SNCR flue gas treatment, backpressure turbine, basic architectural solution, no ash management on-site, and conservative steam parameters), and a more elaborated one on the other may be up to 20%.

Further, it is estimated that local conditions (site preparation, permitting process, cost of manpower for construction works, lack of economical and personal security) may result in up to 20% increase in the project capital costs.

The economy of scale is observed with increase throughput capacity of the plant. Viability of plants with less than 100,000 t/year capacity should be carefully assessed.

Having in mind the above price influencing factors the configuration and location of the plant should be carefully chosen with regard to energy off-take opportunities and justified based on the actual factors already mentioned in this note.

For a rough evaluation purposes it is often assumed that capital unit costs for the W-t-E facility varies from approximately 500 to 1,100 EUR/tonne/year of mixed municipal waste flow. Public procurement tender results in Poland show that capital unit cost for 6 W-t-E facilities to be constructed up to the end of the year 2015 varies from 680 to 1,083 EUR/tonne of installed capacity. The approximate break down of capital costs could be assumed as follows:



An important factor to be taken into account is the equipment replacement cost during the period considered for the operation of the facilities. It may be assumed that the economic life of a boiler/furnace and a turbine/generator is 12-15 years, whereas flue gas treatment equipment may have a life time of 8-10 years, depending on the operational parameters.

Unit capital costs (EUR/ton) for the dedicated W-t-E facility for RDF/SRF utilization should not be expected to be lower than unit capital costs for the thermal treatment of residual mixed waste flow. At the same time additional capital costs for preparation of residual fuels (i.e. in MBTs) should be taken into account.

## 4.4 OPERATING COSTS

Variations in operating costs are less dependent on the technical solutions applied than the capital costs, but may be heavily influenced by the local conditions especially once it concerns salary level and ash treatment/disposal requirements.

For a rough evaluation purposes, it is assumed that operating costs for the W-t-E facility treating mixed municipal waste flow may vary in the range of 40-80 EUR/tonne.

The biggest share of operational costs of the W-t-E facility is attributed to maintenance of the process equipment (app. 25%). The second biggest operational costs category is salaries (app. 20%), followed by the residual management costs (app. 15%), consumables (app. 10%) and others (30%).

Operating costs of a dedicated RDF/SRF W-t-E facility are expected to be at a similar level as for the W-t-E facility for mixed municipal waste treatment. In case of dedicated RDF/SRF facilities, operation costs for fuel preparation should be taken into account once it is compared with residual mixed waste flow treatment in W-t-E. In case of the dedicated RDF/SRF facility, revenues from the produced heat and electricity may be expected to be higher, because of higher calorific value of material treated.

## 4.5 PROCUREMENT STRATEGY

The procurement strategy largely depends on the level of project preparation and the applicable legislation governing the procurement process. In most observed cases, W-t-E facilities are being procured via open tender or competitive dialogue procedures. The directive on the coordination of procedures for the award of public works, public supply contracts and public service contracts (2004/18/EC) specifies the conditions to be fulfilled if the competitive dialogue procedure is to be applied:

- The procedure could be applied in the case of particularly complex contracts; Member States may provide that where contracting authorities consider that the use of the open or restricted procedure will not allow the award of the contract, the latter may make use of the competitive dialogue procedure.

Therefore due care should be taken that the procedure is duly justified/approved before the start of the process.
It is sometimes argued that the W-t-E facility could be procured based on a designed by the Employer (FIDIC Red Book) and later procured either as one construction contract or via different lots (for furnace, for flue gas treatment, etc). It is noted that such implementation model does not seem to be best placed for implementation of public funded projects as it would contain higher organizational (i.e. coordination between different suppliers) and performance risks (i.e. division of the responsibility between designer and the constructor, responsibility for achieving required performance of the facility). Furthermore, a W-t-E plant is such a complex plant that contractor design of at least the main equipment (FIDIC Yellow Book) appears more appropriate. A combination, with Red Book for civil works and building and Yellow Book for process equipment could be an option.

## 4.6 IMPLEMENTATION MODEL AND SOURCES OF THE PROJECT FINANCING

The next important issue is the selection of the implementation scheme. There are three prevailing models for the implementation of the W-t-E facility project:

- Design and Build (DB) by the contractor, and financing and operation (or tender for operation at later stage) of the facility by the Employer;

- Design, Build and Operate (DBO) by the contractor, financing of the facility by the Employer;
- Design, Build, Finance and Operate (DBFO) by the contractor, partial or none financing of the construction of the facility, monitoring by the Employer.

The selection of the optimal model depends on local conditions, availability of financing sources and competences of the promoter's staff to manage the project in its life cycle.

Most of the EU funded infrastructure in waste management sector was implemented almost exclusively through the DB and DBO contracts. Only recently DBFO type of contracts started to be considered in the sector.

The interest of public bodies in private involvement in large infrastructure projects such as W-t-E facilities is usually driven by two factors:

- using the corporation's skills and competence to improve the quality of public services and reduce their cost,
- budget constraints which push public sector to look for alternative resources for developing the infrastructure, as PPP contracts usually allow for a spread of the cost of new assets over the time they are used, thus avoiding large initial government capital expenditure.

In case of PPP model applied classification of the assets involved in the PPP contract, as public body assets, has an effect on public deficit and debt ratio. When they are classified as the private partner's assets the impact on public deficit is spread over the duration of the contract. However, it should be noted that the assets involved in a PPP can be considered as non-government assets only if there is strong evidence that the partner is bearing most of the risks attached to the asset of the partnership. Therefore the analysis of the allocation of risk between government and the private partner is the core issue[9].

In any case, it would be inappropriate if the only one criterion determining the implementation of the project within PPP scheme would be avoidance to include the project's debt in public body accounts. The objective of PPP arrangement should be to develop the project that provides value for money and lower overall life-cycle costs, and not only provides initial relief for the immediate need of capital.

Public bodies considering the implementation of large infrastructure projects via PPP should also be aware of the backside of such solutions. Based on the experience drawn from past projects, it can be generally said that such projects are characterized by:

- High complexity of procedures and legal documentation;
- Need for highly specialized, experienced and costly experts in legal, technical and financial matters (both on the tenderer's and bidder's sides) during the tender preparation, actual tendering process and throughout all implementation period.

Compared to the classical approach involving public financing and ownership, the implementation of a W-t-E project via DBFO contracts is generally:

- More time consuming, with typical lead times for the conclusion of the DBFO contract under ideal conditions of at least 2 years (construction of the facility not included). However it can be to some extend compensated with the shorter design and construction period, if combined with payments linked to availability of services;
- Less flexibility during the long term operation stage, if such possibilities are not extensively defined and negotiated during the contracting period;
- May result in higher cost if optimal risk sharing and control of performance is not ensured.

Taking into account the above factors, before the start of the project implementation, an in-depth assessment of alternative project implementation models should be carried out. This implies the assessment of risk management structures for potential efficiency gains through alternative structures or modifications, and carrying out value for money and market tests. It should be remembered that the level of risks transferred to the private partner sector determines its expected return, so the aim should be to optimize the risk allocation rather than maximize risk transfer, to ensure that the best value is achieved. Among most important risks factors for W-t-E facilities are supply of waste (certain quantity and quality) and energy off-take (quantity and price) and they should be allocated to the party best able to manage it at least costs.

[9] Eurostat, Manual on Government Deficit and Debt, Implementation of ESA95, 2013 edition, (Chapter VI.5) http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-RA-13-001/EN/KS-RA-13-001-EN.PDF

## 4.7 AFFORDABILITY AND SUPPORT MECHANISMS

The construction of a W-t-E facility involves high investment and operating & maintenance (O&M) costs. The resulting net treatment cost (operating costs minus revenues from the sale of energy and recyclables) per tonne of waste thermally treated is often rather high if compared with waste management techniques attributed to the lowest step of the waste hierarchy (disposal).

The Waste Framework Directive (2008/98/EC) requires the application of the polluter pays principle in waste management sector. In accordance with the Article 14, par. 1 of the Directive the costs of waste management shall be borne by the original waste producer or by the current or previous waste holders. So, in principle the annual net capital and operating costs of the W-t-E plant should be financed through user fees (household, industry, commerce, institutions, etc.).

A W-t-E facility is one of the components of the whole municipal waste system. Fees for thermal waste treatment from households are collected together with charges for collection, transport, and treatment. The implementation of such investment heavy facility may have considerable impact on waste management tariffs. As part of the financial and economic assessment, prior to the decision whether the plant should be constructed, it is recommended to analyse the population's willingness and ability to pay for the foreseen infrastructure. The project will not be sustainable, if users find it unaffordable, seek undesirable alternatives to waste handling or give up paying for services. More details on application of the Polluter Pays Principle could be found in JASPERS Working Paper, *Application of the Polluter Pays Principle (PPP) in Waste Management Projects*[10].

To reduce the burden for the society, public subsidies are introduced in the sector (grant financing, preferential loan for plant construction, direct subsidies for inhabitants).

In some EU regions, the project promoters may request EU financial support for investment heavy infrastructure, including W-t-E facilities through the European Regional Development Fund (ERDF) and the Cohesion Fund (CF). There are also financial instruments on the national level supporting this type of investments, like grants or preferential loans.

It should be noted, that when the project is to be supported by public sector resources, the State aid analysis should be carried out to ensure that the planned co-financing is compliant with EU State aid policy and rules. The guidance for the identification of State aid in projects in the context of Article 107 of Treaty of Functioning of the European Union, as well as the understanding of when the aid can be considered compatible, is available in the JASPERS Working Paper: "State Aid Principles"[11].

In Poland, waste management services are qualified as services of general economic interests and co-financing of projects with grant or any other preferential form of financing is considered as a compensation for services of general economic interest. The example of an application of the Commission Decision 2012/21/EU[12] for W-t-E project is provided in another JASPERS Working Paper: The "Municipal Waste Management Program in Krakow – A Case Study on the exemption of State Aid notification under the EU SGEI Decision"[13].

It should be noted that except direct financing of investments, there are other economic instruments which indirectly support the implementation of W-t-E projects, including:

- Support schemes for energy generated from renewable sources of energy,
- Support schemes for energy generated from high efficient co-generation,
- Landfill tax.

[10] http://www.jaspersnetwork.org/jaspersnetwork/download/attachments/4948007/PPPWaste.pdf?version=1&modificationDate=1366387825000

[11] http://www.jaspersnetwork.org/jaspersnetwork/download/attachments/4947975/State_aid_Guidelines.pdf?version=1&modificationDate=1366384595000

[12] the Commission Decision 2012/21/EU of 20 December 2011 on the application of Article 106(2) of the TFEU to State aid in the form of public service compensation granted to certain undertakings entrusted with the operation of services of general economic interest

[13] http://www.jaspersnetwork.org/jaspersnetwork/download/attachments/4947999/Krakw_State_aid_Waste_Management.pdf?version=1&modificationDate=1366386992000

# 5 SUMMARY AND CONCLUSIONS

The 7$^{th}$ *European Union Environmental Action Programme to 2020* will place focus on turning the Union to resource-efficient economy and one of the sectors where special attention will be directed is waste management sector.

The *Roadmap to a Resource Efficient Europe* underlines the importance of waste avoidance, re-use and recycling activities and suggests that non-recyclable part of the municipal waste flow would be used for energy recovery.

Waste management targets placed under the *Directive on Waste* and *Directive on the Landfill of Waste* establish requirements for significant reduction of biodegradable waste being landfilled, and set targets for the re-use and recycling of such materials as glass, metal, plastic and papers within municipal waste flow.

All the above requirements shape future demand for the waste management infrastructure. The technologies applied in municipal waste management sector shall be those that allow meeting the standards at acceptable cost. In a very simplistic manner, W-t-E facilities are more suited for large agglomerations with low expected variations in the amount and quality of waste to be treated.

On the other hand, MBT plants may be more suited for smaller catchment areas and they usually allow for more flexibility in the adaptation of the process to variations in waste quality and quantity. In both cases, a relevant factor to consider during the feasibility studies is the existence of a reliable off-taker for the products of the treatment (heat and power in the case of W-t-E and compost like output and SR/RDF in the case of MBT).

W-t-E facilities are among few well established technologies offering residual waste treatment option compliant with waste management hierarchy (energy recovery) principles and targets set in the *Directive on the Landfill of Waste*.

W-t-E related projects are technically, institutionally and financially complex. Therefore, they require in-depth analysis before the project implementation stage. Special attention must be paid to establishing reliable data on current and future waste flows and waste properties.

In many countries, thermal treatment plants require long preparation process (in some cases over 10 years) to meet planning approval, financing construction and commissioning. Moreover, these facilities usually last for long periods, often up to 25 years with limited flexibility to adapt to variations in waste flow, which requires very careful planning in the preparation phase.

W-t-E facilities significantly reduce the amount of waste that needs to be landfilled (20-30% from the initial amount if re-use of slag is not possible) and ensure stabilization of its biological components. They also give the possibility of recovering the energy contained in the residual municipal waste flow. Thermal waste treatment reduces both methane gas generation at landfills and replaces fossil fuels, reducing overall green gas emissions.

The final configuration of the W-t-E process largely depends on local conditions and requirements and should be assessed on case by case bases. Determining configuration of the W-t-E facility should be seen as an integrated process to ensure optimal combination of available techniques.

Usually bottom ash resulting from W-t-E facilities designed for the residual municipal waste treatment are not considered as hazardous and can be further used e.g. for road construction, or safely disposed in non-hazardous waste landfills. Fly ashes and flue gas treatment residues that may constitute app 4% of initially treated amount are considered as hazardous waste and usually requires disposal in hazardous waste landfills or other appropriate treatment before final disposal.

A W-t-E facility can be considered as performing a recovery from waste operation if its energy efficiency reaches conditions provided in the Waste Framework Directive (R1 ≥ 0.65).

It could be assumed that lower capital cost for the W-t-E facility could be expected when one process line with conventional grate fired furnace, semi-dry flue gas treatment, and conservative boiler steam data is applied, and when no onsite fly ash treatment is foreseen.

Taking into consideration positive results with achieving environmental targets, produced thermal and electrical energy, and capital and operation costs, W-t-E facilities are often considered as the most technologically and financially advantageous option for the residual municipal waste treatment for larger agglomerations.

The implementation of W-t-E project could be organized either through the traditional implementation schemes or through the relatively novel PPP approach. Risk sharing and financing costs, contract flexibility are among most discussed factors while determining project implementation model. Market and value for money tests are advised to be performed before making final decision on the project implementation scheme.

So far four W-t-E projects in Poland prepared following principles laid down in this note are benefitting support from EU funds. These projects are among first W-t-E projects co-funded by the European Commission in the sector.