WHITE PAPER

ISWA
International Solid Waste Association

Alternative Waste Conversion Technologies

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1 INTRODUCTION

This White Paper is intended as an introduction and overview for decision makers who are considering investments also in alternative thermal waste conversion technologies.

Prospective investors in thermal waste conversion capacity are increasingly and assertively approached by vendors of so-called alternative technologies, claiming high environmental and energetic performance for their technology, combined with cost - benefit rates. The ISWA Working Group Energy Recovery therefore decided to make an inventory of the present status of alternative thermal waste conversion technologies and to develop a guideline for the set of information that would be required to assess the performance and readiness for market introduction of any thermal waste conversion technology being provided to the market.

For a century, the goal of diverting non-recyclable waste from landfill and producing energy from this waste has been fulfilled by predominantly grate-based Energy from Waste combustion technologies in addition to fluidized-bed applications ("waste incineration"). During recent decades, alternative technologies have started to emerge with visions of improved recycling options for the residues remaining after incineration, higher energy efficiencies and even lower emissions. Three classes of alternative thermal waste treatment technology are proposed to the market: pyrolysis, gasification and (as a special group) plasma gasification.

This paper contains a short definition of alternative thermal waste conversion technologies, in relation to conventional Energy from Waste combustion technologies, an overview of the Energy from Waste value chain that must be the basis for any further investment decision, then a guideline of items to be considered when assessing alternative thermal waste conversion technologies, and subsequently an overview of technologies with pro's and con's from an investor's perspective as well as the most important attention points for decision makers.

2 DEFINITIONS AND INTERRELATIONS

2.1 Definitions

There are a large number of technologies on the market at the moment and the use of many terms and definitions, with often different meaning. This reduces the possibility of comparing the different options. This chapter lists the most important concepts used in this field alphabetically.

Energy from Waste (EfW)
is the process of creating energy in the form of electricity or heat from the thermal breakdown of waste through any thermal conversion technology or combination of conversion technologies. Any technology discussed in this paper is an EfW technology. With conventional EfW we mean grate fired or fluidized bed combustion of waste.

Combustion/incineration
is the thermal breakdown of waste supplying an excess of air, producing a flue gas (CO_2, O_2, N_2, water vapor) and heat.

Gasification

is the thermal breakdown of waste under oxygen starved conditions (oxygen content in the conversion gas stream is lower than needed for combustion), thus creating a syngas (e.g. the conversion of coal into city gas).

Plasma gasification

is the treatment of waste through a very high intensity electron arc, leading to temperatures of > 2,000°C. Within such a plasma, gasifying conditions break the waste down into a vitrified slag and syngas.

Pyrolysis

is the thermal breakdown of waste in the absence of air, to produce char, pyrolysis oil and syngas (e.g. the conversion of wood into charcoal).

2.2 Interrelations between waste treatment system steps

To make a proper evaluation of a technology for thermal treatment of waste, the complete system of waste pretreatment, energy and material input, technology and energy and material output should be assessed and quantified. In that way a proper material and energy balance can be made (see figure 1, next page). This total system evaluation will prevent any inconsistent comparisons.

Often neglected steps within the complete waste treatment system are for instance mechanical pretreatment that is necessary for a number of thermal treatment systems or energy input for oxygen production and effects of final combustion.

The alternative technologies pyrolysis, gasification and plasma gasification each create intermediate products, which need to be further combusted to generate energy. In that way the final - integrated - conversion process based on alternative technologies is comparable to that of conventional EfW combustion. The important difference is that within conventional EfW processes the complete process happens in a single furnace / boiler. In that respect alternative thermal technologies yielding a gas or liquid fuel instead of heat or steam must be considered a "thermal pretreatment" step.

A possible added value of alternative thermal treatment technologies is that the intermediate products can be refined and converted with combustion processes of higher efficiency (gas engine, gas turbine). However, this has up to now not been demonstrated on a large scale. Combustion of intermediate products under comparable conditions as in conventional - single stage - EfW combustion plants will always lead to loss in thermal and electrical efficiency.

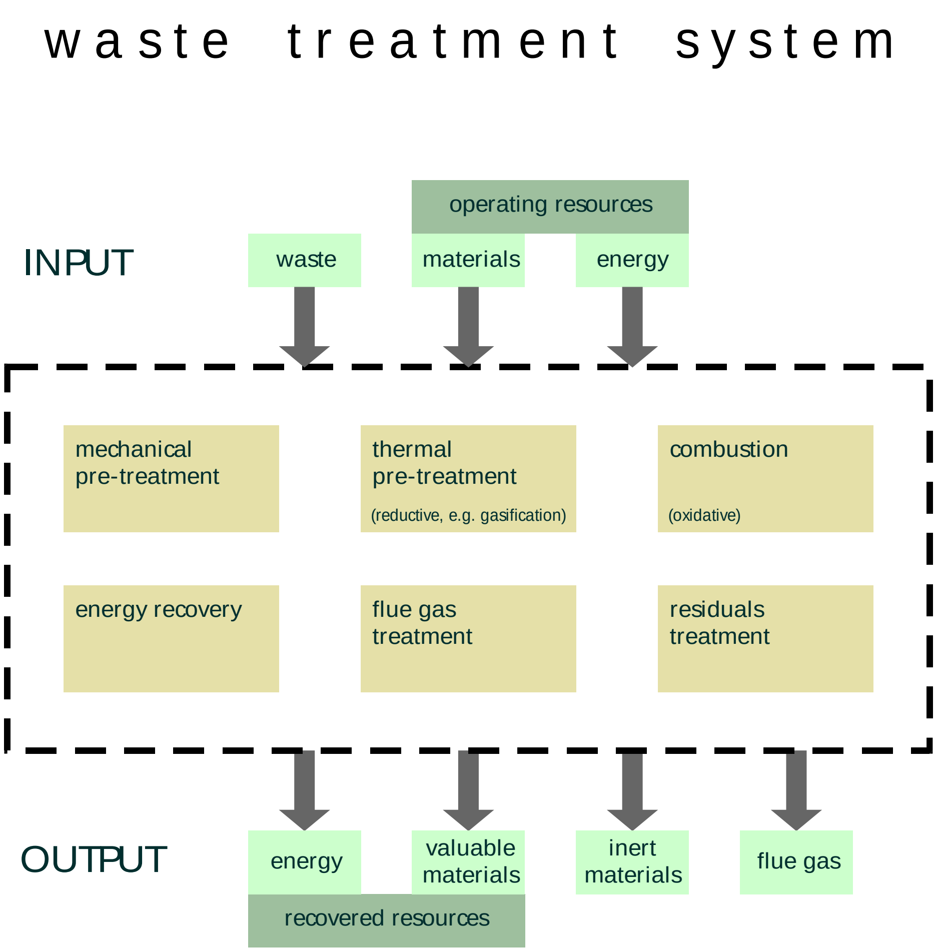

Figure 1 Overview of the waste treatment system

3 THE ENERGY FROM WASTE PROJECT VALUE CHAIN

Provided that the legislative requirements for a thermal waste conversion technology are met (both for alternative and conventional waste conversion technologies), the total value chain for a thermal waste conversion technology is shown in figures 2 and 3. In case a developer puts extra value in innovation or in improved environmental performance, he can choose to calculate higher gate fees, which has to be discussed and agreed in the contractual arrangements. For some countries additional feed-in tariffs or subsidies are available in case of alternative thermal waste conversion technologies.

Figure 2 shows that to create a feasible project, the operational result of the thermal waste conversion project must be positive and meet the financial requirements; the result being dependent from the balance between income (gate fee and energy revenue) and cost (utility cost and residue cost).

Gate fee and energy revenue are variable income dependent on the quantity of waste being treated and the quantity of energy being generated.

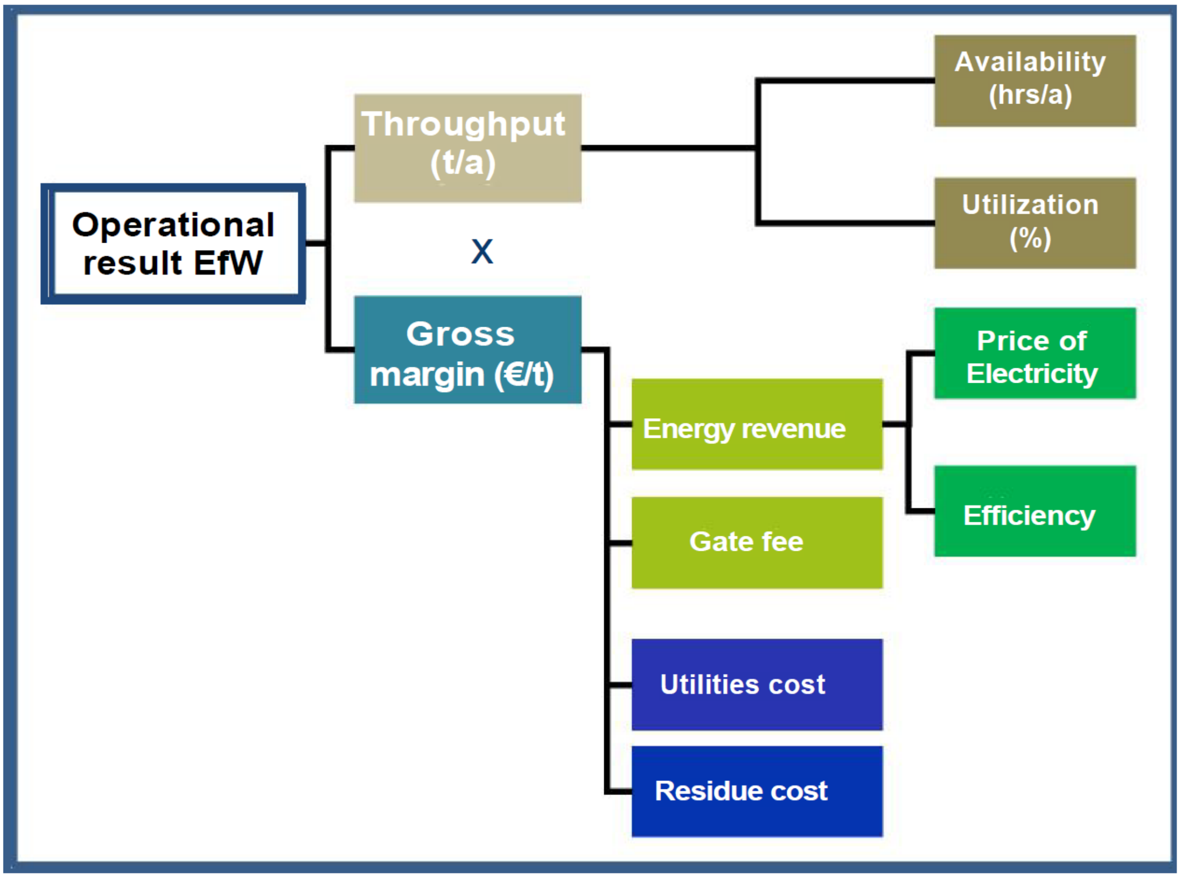

Figure 2 Overview of the value chain for a thermal waste conversion installation

From figure 3 it becomes clear that variable cost includes personnel, maintenance, utilities and materials. For proven technologies with a long experience base, it is possible to do a good and accurate prediction of the variable cost items and of the full investment cost, whereas that is less the case for alternative technologies. The main risks when choosing an alternative technology are therefore associated with the difficult predictability of the cost over the projected total lifetime of the project (typically > 20 years).

In case of poor/wrong prediction, the income will in many cases be substantially lower than expected (often because the installation runs less of the time and cannot generate the expected throughput and energy output) and the costs will be higher (for instance for maintenance, repair and additional material / personnel to solve problems, replace components / systems).

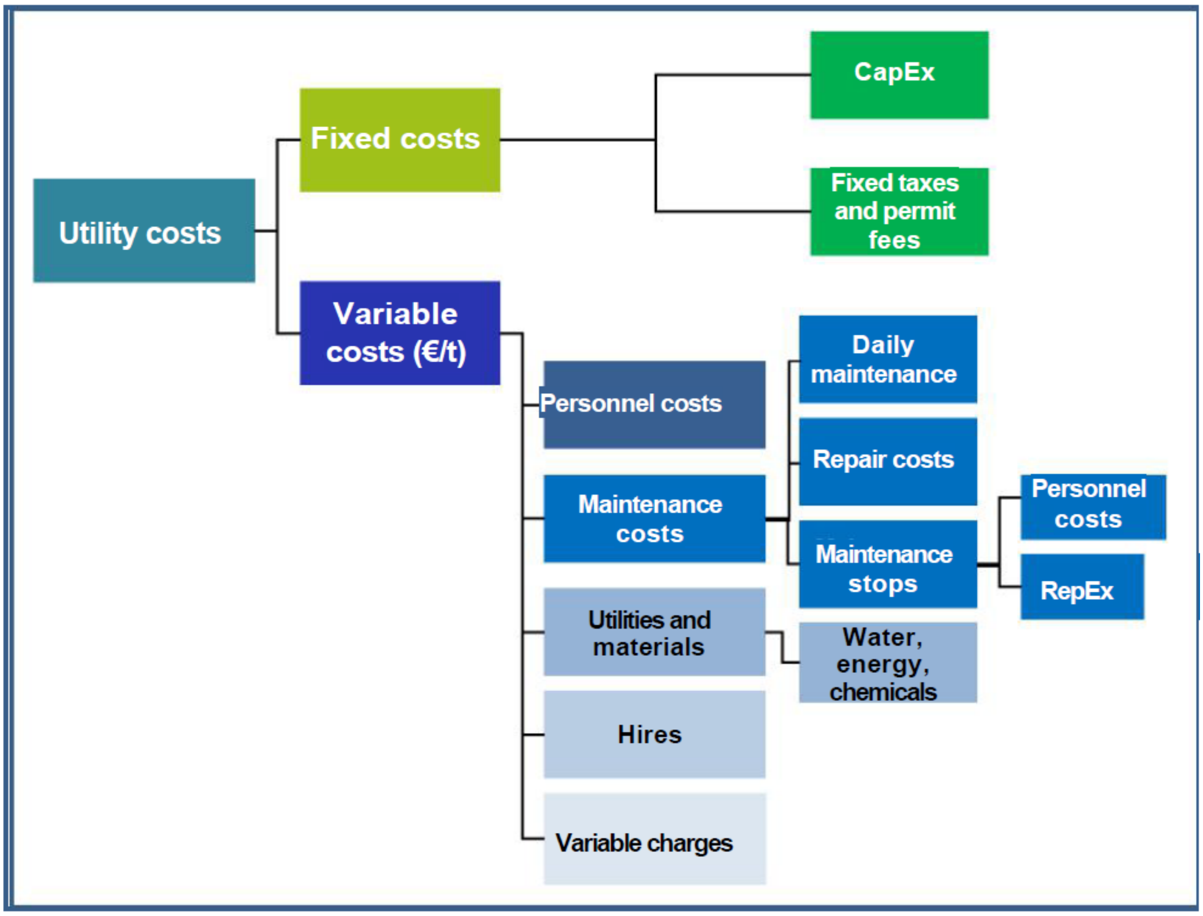

Figure 3 Overview of utility cost items within a thermal waste conversion installation

4 GENERAL ENERGY FROM WASTE TECHNOLOGY ASSESSMENT GUIDELINE

To assess and compare the technologies that may be considered for thermal waste conversion, an overview of the important aspects is given that may influence the total project value tree: operational experience at required scale of operation, availability, reliability, fuel flexibility, complete mass and energy balance, environmental performance (all technical aspects), costs / economics (economical aspects) and scale aspects. This paragraph will provide an overview of these aspects to assist in making a well-founded decision and limit the risks during the procurement process.

4.1 Technical aspects

Operational experience at required scale of operation

Any external financer considering investment in assets for EfW will require that a proven technology is used. Proven technology is a technology that has been shown to meet its requirements during a number of years of operation with one or more installations at a comparable scale, with comparable feedstock and with a comparable output. In view of comparability of cost and operational performance requirements we propose to require operations in Western Europe or America. Japanese installations are state-of-the-art when it comes to technology and operation, but have completely different cost / benefit levels and also a different legislative framework compared to so-called western countries. Only investors used to take a certain risk or developers with own funds will allow less proven technology - to support innovation. In that case the risks have to be understood and priced and contingency cost has to be included.

Availability and Reliability

Proven reliability of a plant will form a strong indication for an investor that he will be able to earn back his investments in a predictable way. The best measure of reliability of a thermal treatment technology is operational experience under similar conditions. Not only the number of reference plants, but also the size and used feedstock matter. For many alternative technologies this is a problem as there is little experience at a commercial scale and results of demonstration plants cannot be used as proof of a reliable process for a facility of five or more times that size. Past experiences show that the innovative part of the process, such as the pyrolysis drum or the gasification reactor, by itself often performs as designed. Problems occur with failures in the fuel pretreatment lines or syngas cleaning equipment. The availability will never be very high when a long string of waste pretreatment and syngas cleaning steps is required and a failure in any of these steps results in a shutdown of the process. Simple and robust process control helps with reducing outages, but reliability increases investment cost for redundancy.

Fuel flexibility

The tolerance of an installation for variations in fuel composition, size distribution and heating value is even more important if there is no clarity on long term fuel input. If an installation has a very low flexibility for changes in fuel properties, then it means that either a long term contract for a specified fuel is necessary or significant pretreatment of the fuel is necessary. A large number of alternative thermal technologies (including fluidized bed combustion / gasification options) require fuel properties (size distribution, chemical composition, changes in feed of mass and heating value) within a very narrow range. The investment and operational costs for a pretreatment installation / or the costs for acquisition of a pretreated waste stream, have to be taken into account when evaluating feasibility of specific options. A plant with a low fuel flexibility has an increased risk of outages, lowering the payback expectations.

Mass and energy balance

The total mass and energy balance of the plant will give an overview of all costs and revenues as a result of gate fees, tipping fees, possible emission tradings, chemicals costs and energy revenues.

To get an overview of the total inputs and outputs of the process, a complete mass and energy balance has to be made available. The mass and energy balance has to include any waste pretreatment and also the waste streams. Typical aspects to be covered in a mass and energy balance:

- waste quantity (quantities) in - start at the pretreatment (tonnes/h)
- unit operations and mass quantities for each flow
- air flows in (for the thermal treatment (m^3/h) / flue gas flows out (m^3/h)
- water flows in and out (m^3/h)
- supplementary materials and chemicals in (kg/h)
- waste quantities out, for each flow (tonnes/h)
- thermal energy in (through the waste)
- electrical energy out
- thermal energy out for supply to district heating or industrial heating

Environmental performance

One of the main reasons to consider alternative thermal treatment technologies are the claims of lower emissions from the stack, waste water or solids disposal. The environmental regulations for alternative thermal treatment technologies are the same as for waste incineration plants and both alternative and state-of-the-art conventional EfW plants have emissions far below these regulatory requirements. The advantage of the alternative thermal treatment technologies is that the combustions process is better controlled by separating the drying / pyrolysis / gasification phase from the final combustion phase. This would in theory result in fewer peaks in the emissions, but this advantage is relatively small. Table 4 in Appendix II gives an overview of the emissions of a number of alternative thermal treatment technologies and the currently Best Available Technology (BAT) for conventional waste incineration plants.

Energy production

The goal of EfW plants has shifted from waste treatment to energy production. The selected thermal treatment technology should therefore have a high net efficiency to maximize the amount of fossil fuels replaced by the EfW plant. A high electrical efficiency also increases the revenues from electricity sales. When reviewing the efficiency, the entire conversion process starting at the waste tipping floor to the electrical power delivered by the generator, should be considered. Especially parasitic loads from shredders for waste pretreatment or fans can differ significantly between different technologies. Conventional mass burn incinerators have both an efficiency advantage due to their size and their low pretreatment requirements. Common net efficiencies for these installations are 18 - 27% for normal EfW installations running up to 32% for high efficiency installations. A small scale, multi stage process operating at similar temperatures and pressures can at best match that efficiency. In practice the efficiency of alternative thermal treatment technologies is considerably lower than from normal state of the art EfW; Table 5 in Appendix III shows the (claimed) efficiencies of a few of these technologies. These electrical efficiencies are not bad considering the small size of these installations, especially when syngas is used in gas engines, but they are significantly lower than large scale mass burn incineration plants. The alternative thermal treatment technologies can be more efficient when combined heat and power (CHP) production is possible due to the small size of the installation and location near heat users. However CHP is also being utilized with great success by conventional EfW combustion. Any efficiency advantage of alternative technologies over conventional EfW will disappear in case of CHP.

4.2 Economical aspects

To compare the cost and income streams for several thermal treatment options, the value chain and the costs of a proposed technology need to be understood (see figure 2 and 3):

Total investment costs

It must be clearly understood what is in the investment costs within the supplier package:

- Equipment costs
  - Thermal treatment equipment investments
  - Necessary pretreatment investments
  - Air pollution control and ash treatment investments
- Civil engineering costs

Furthermore it must be clear what the height of the following cost items is:

- Owners engineer costs
- Costs of working capital
- Other financing and insurance costs
- Contingency fund

In that way the investor will get an overview of his capital cost base, which will be part of his fixed costs.

Operational / exploitation costs

In operation, the cost to run the EfW plant consists of:

- Costs of additives/chemicals
- Costs of auxiliary fuels (including pretreated waste fuels if contracted outside)
- Internal energy costs
- Personnel costs
- Maintenance costs
- Costs of by products and residues
- Variable charges

Revenues

Basically the revenues come from gate fees for the waste delivered and energy revenues, both for electricity supply or (if relevant) heat supply. Special energy feed-in tariffs for alternative thermal waste treatment technologies may increase revenues but the investor should be aware that feed-in tariffs may not be consistent during the entire life time of the installation.

5 THERMAL CONVERSION OF WASTE

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. Figure 4 presents a principal 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.

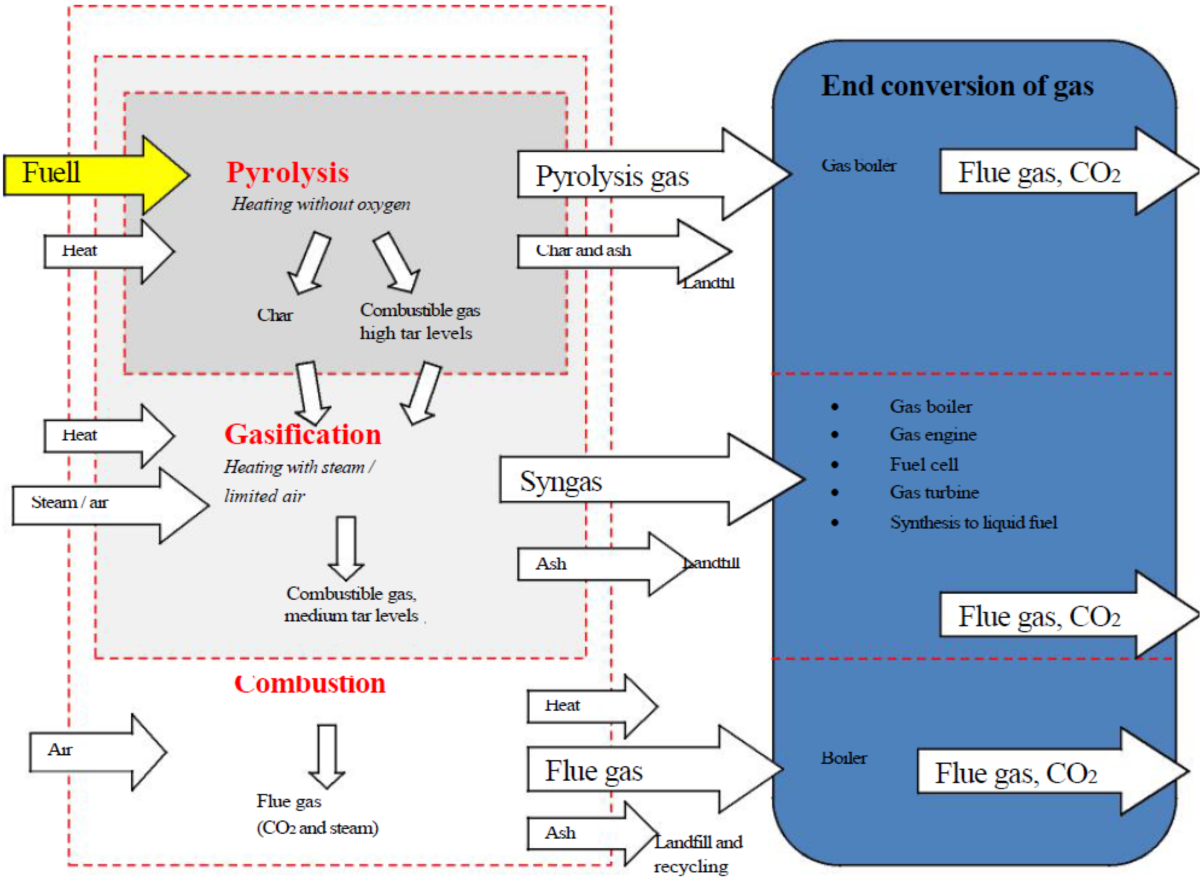

Figure 4 Overview of conversion steps within total thermal waste conversion processes and end uses of intermediate product

6 ALTERNATIVE ENERGY CONVERSION SYSTEMS

6.1 Pyrolysis

Definition

Pyrolysis is the thermal breakdown of waste in the absence of air. Waste is heated to high temperatures (> 300°C) by an external energy source, without adding steam or oxygen.

The intermediate products that will be created are char, pyrolysis oil and syngas. An example of pyrolysis is the conversion of wood into charcoal.

Technical aspects

Typically two types of pyrolysis processes are used, namely ‘slow pyrolysis’ in a drum or stationary kiln, generating syngas and char and so called ‘flash pyrolysis’, generating primarily pyrolysis oils through condensation of gases into liquids. A main point of attention for pyrolysis oils is their acid nature. Flash pyrolysis is typically used on biomass streams.

Slow pyrolysis of waste (often in a drum) is followed by incineration of the gases and chars with subsequent electricity generation in a boiler and a steam turbine; flue gas cleaning is carried out via conventional processes.

Claims for pyrolysis

The claims by providers are the following:
Pyrolysis oil and syngas can be utilized as high value fuels in more efficient conversion cycles (such as gas turbines or gas motors); from the char, metals and carbon black streams can be easily recycled with a high product value. Through the pyrolysis route, lower emissions will be generated.

Energy balances

For pyrolysis external energy has to be added (gas/oil). In a number of pyrolysis concepts the chars are incinerated at high temperatures. This will decrease operational efficiencies. If syngases cannot be incinerated in a gas turbine or a gas engine, electrical efficiencies will be substantially lower than for conventional EfW combustion.

Experiences

Within Europe Siemens had developed a pyrolysis system, “the Siemens Schwelbrenn process”, which was demonstrated in the 90’s in Germany (Fürth). The plant was constructed in a technical scale and never achieved a continuous operation of more than a couple of weeks. This was abandoned after a long period of numerous trials of optimization In the UK Ethos Energy has taken over Compact power. After construction of a small scale pilot in Bristol still no new projects have been generated. In the USA a pilot facility by IES in Romoland has operated between 2004 and 2009, but never met the air emission limits and was decommissioned. IES is preparing larger scale investments.
In Japan Mitsui Engineering and Shipbuilding (MES) - prior Mitsui Babcock - has taken over the Siemens Schwelbrenn process and has brought into operation a number of installations based on this technology. There is no insight into the cost available, which may be very high. MES is no

longer actively marketing the technology. All in all around 25 installations are in operation worldwide, with an installed capacity of less than 1 million per year tonnes, of which the vast majority is in Japan. A tentative supplier overview is given in table 1.

Available information

In literature the information about operational performance of existing pyrolysis plants is very limited. There is a small number of papers about the Mitsui Babcock process, however without indications / reports on energy efficiency. No public information is available on costs and long term performance.

Overview of risks

The main risks with pyrolysis are associated with the quality of the intermediate products:

- High requirement for pretreatment for the waste input, leading to extra costs
- Claims of high quality carbon black production (the char) cannot be met in many cases, lowering income streams
- Pyrolysis gases contain high amounts of tars, that lead to malfunction of the power generation cycle behind the pyrolysis installation, reducing income
- Maintenance requirements and cost of the systems is high

Table 1 Overview of alternative thermal treatment technologies using pyrolysis

Process name	Suppliers	Process description
Advanced pyrolysis system	IES / Wastetopower	Pyrolysis (continuous), combustion
Compact Power	Ethos Energy	Pyrolysis, gasification, combustion
D4 Energy Devolatization System	D4 Energy Group	Pyrolysis, gas engine
Mitsui Recycling 21	Mitsui	Pyrolysis, gasification, combustion, ash melting
P.I.T. Pyroflam	SERPAC, TPF-Basse Sambre	Pyrolysis, combustion
PKA	Gipec (former Gibros), PKA Umwelttechnik, Toshiba	Pyrolysis, gasification, gas engine, ash melting
Pyropleq	WasteGen (Technip/TechTrade)	Pyrolysis, gasification, combustion
RCP (Recycled Clean Products)	Hitachi Zosen Co.	Pyrolysis, combustion, ash melting

6.2 Gasification

Definition

Gasification is the thermal breakdown of waste under a controlled (lower than necessary for combustion) oxygen atmosphere, thus creating as an intermediate product syngas instead of direct combustion of the waste (e.g. the conversion of coal into city gas). The waste (having passed pyrolysis) is allowed to react chemically with steam or limited amounts of air at high temperatures exceeding ~750°C. This consumes the carbon in the waste and produces combustible gases. The tar levels from the syngases are lower than in pyrolysis gas. The resulting amount of tar in the syngas differs however between gasification technologies.

The purpose claimed by gasification technologies is to create higher efficiency and a lower carbon footprint in view of advanced conversion of the gases compared to combustion technologies that always have to make use of a steam boiler combined with a steam turbine or of a hot water boiler when only providing energy for a district heating circuit. Cleaned syngases should be supplied to a gas turbine or a gas motor or alternatively converted into a liquid fuel.

Gasification, subsequent syngas cleaning and supply of the syngas to a higher efficiency thermal process (such as coal combustion) to be able to upgrade the energy efficiency of the subsequent steam cycle (compared to regular energy from waste) is also considered “true” gasification.

A number of successful suppliers of gasification use so called staged gasification / combustion. The waste is gasified in the first stage of the installation, but further on - after gas quality and quantity has been established - the gas is combusted in a steam boiler coupled to the same installation. Basically this approach can also be called staged combustion. The differences with regular combustion are:

- At a specified point in the installation the quality and quantity of syngases can be measured: based on that, compliance with regulatory demands for gasifiers can be determined
- Staged combustion takes more time and space and therefore is essentially less efficient than direct combustion
- In view of controlled gasification temperatures, NO_x emissions without any $DeNO_x$ measures can possibly be lower
- Companies categorize staged combustion as gasification in view of the consideration that gases can be fed into a cleaning stage - as soon as a syngas cleaning technology has been developed; afterwards these cleaned gases can then be converted into energy in a gas engine of gas turbine; for the moment effective cleaning of tars is still not possible, therefore the gases have to be fed into a conventional combustion / steam boiler system; the total process of gasification and combustion is less effective than once through regular energy from waste combustion.

  In view of the significant differences, staged gasification / combustion is discussed separately from other gasification. Staged gasification / combustion does formally comply with regulatory demands for gasification plants, but is in reality not different - even worse in efficiency - from regular combustion.

Technical aspects

The total energy performance (specifically the conversion into electrical energy) of a gasification / further conversion cycle is dependent from two aspects:

1. What is the energy output within the gas after the gasification cycle (the so called “cold gas efficiency”)? The “cold gas efficiency” is influenced by the temperature of gasification and by the oxygen content during gasification.
2. What is the conversion efficiency in the final energy conversion step?

These two put together will give electrical efficiency for the total conversion cycle. Often lower temperature gasification has a high cold gas efficiency but also a high tar content. Because of the tar content, further conversion in a gas motor or gas turbine is not advisable, leading to an efficiency that is all in all still comparable or lower than from a conventional EfW combustion installation. Higher temperature gasification (> 1,000°C) has a clean syngas but lower cold gas efficiency, also leading to an overall efficiency that may not exceed conventional combustion.

Cleaning of syngases from tar is technically and commercially still not feasible and it is expected that it will last at least 10 - 15 y before appropriate technologies are available.

Claims for gasification

The claims by providers are the following:

"True" gasification

Syngas can be utilized as a high value fuel in more energy efficient conversion cycles (such as gas turbines or gas motors). Through the gasification route, lower emissions will be generated. A number of gasification technologies provide high temperature (> 1,500°C) vitrification of the ashes, thus improving the recycling of the ashes (however also significantly reducing energy efficiency).

Staged gasification / combustion

For staged gasification / combustion, the main claimed advantages are: potential for special feed-in tariffs in view of gasification character (only certain countries) and apart from that, a potentially smaller installation scale for the same waste quantities and lower NO_x emissions. Efficiencies are lower than for conventional combustion systems. Actual net electrical efficiency claims for a number of staged gasification technologies are in the order of 12 - 18%, which is significantly lower than for modern conventional energy from waste (18 - 27%).

One of the potential advantages may be the small scale (down to 1 tonne / hr) at which some of the systems are supplied. This can make them fit for use in smaller municipalities. In general conventional waste to energy combustion systems are supplied at scales of 6 tonnes or more, although small installations are technically possible. On the other hand, substantially higher treatment cost must be taken into account.

Experiences

Within Europe and America the main operational experiences with gasification are based on two stage gasification, which is basically comparable with combustion (Energos, EPI, KIV, cBOS). Recently Metso has installed a 50 MWe fluid bed gasification installation in Lahti (consisting of 2 x 25 MWe lines), where gas cleaning takes place and afterwards combustion of cleaned gas under high P/T circumstances in a gas boiler. Not all two stage gasification developments have however been successful yet. A number of other developments in Europe (such as Thermoselect or TPS in Greve) have failed in view of high and persistent operational problems. All in all less than 100 installations have been in operation worldwide, at a total throughput of around 2.5 million tons / yr; the majority being in Japan.

Available information

In literature the information about operational performance of existing gasification installations is very limited. There are no papers that report on energy efficiency of commercially operating installations (except from the Energos installations) and there is limited information about emissions. No public information is available on costs and long term performance.

Overview of risks

The main risks within gasification are associated with the quantity and quality of the intermediate product syngas:

- High requirement for pretreatment of the waste input, leading to extra costs
- Syngases contain high amounts of tars, that lead to malfunction of the power generation cycle behind the gasification installation, reducing income
- Calorific value and quantity of produced gases may be lower than designed, thus lowering income streams
- For two stage gasification / combustion processes the efficiency of the process is in all cases lower than for "once through" processes
- Equipment suppliers are not always financially sound and bid at too low prices, reducing project success chances in view of inferior interfaces
- Maintenance requirements and cost of the systems is high

Within table 2 and 3 and overview is given of the suppliers of so-called "true gasification technologies" and "staged gasification / combustion technologies"

Table 2 Overview of "true" gasification technologies

Process name	**Suppliers/developers**	**Process description**
ETAG	ETAG Production, vdPas Waste & Energy, WTE Advantage	Gasification, gas engine, ash melting
HTCW	KBI HTCW Technology, WES Waste & Energy Solutions	Gasification, gas engine, ash melting
Metso Fluidized bed gasification	Metso	Gasification, cleaning, combustion at high T/P circumstances
Novera/Enerkem	Biossence, Enerkem	Gasification, gas cleaning, combustion
Refgas CHP	Refgas	Gasification, gas engine
Thermoselect	Interstate Waste Technologies, JFE Engineering, Thermoselect	Gasification, gas engine, ash melting

Table 3 Overview of staged gasification / combustion technologies

Process name	Suppliers/developers	Process description
cBOSTM technology	EnerWaste, Waste2Energy	Gasification, combustion
Energos	ENER-G	Gasification, combustion
EnTech Waste to Gas	EnTech Renewable Energy Technologies, Eucocorp, IET Energy, REM	Gasification, combustion
Fluidized bed gasification and melting plant	Hitachi Zosen	Fluidized bed gasification, combustion, ash melting
High T gasifying and direct melting system	JFE	Gasification, combustion, ash melting
Kawasaki	Kawasaki Heavy Industries	Gasification, combustion, ash melting
KIV	KIV	Gasification, combustion
Kobelco	Kobelco Eco-solutions Co.	Gasification, combustion, ash melting
Nippon Steel	Nippon Steel Corporation	Gasification, combustion, ash melting
TwinRec process	Alstom, Ebara	Gasification, combustion, ash melting optional

6.3 Plasma gasification

Description

A plasma Gasification Process is a waste treatment technology that uses electrical energy and the high temperatures (> 2,000°C) created by an electric arc gasifier. This arc breaks down the organic parts of the waste primarily into elemental gas. A plasma is used most efficiently either in a pyrolysis mode or a pure oxygen gasification mode. The plasma arc has a very high electrical energy consumption. If oxygen is used for the plasma gasification, also the oxygen use for the gasification will contribute towards internal energy use.

A clear advantage of plasma is that the plasma will effectively clean the syngases from any remaining tar, so that a clean syngas is created, which can be f. If no oxygen is used for gasification, however “cold gas efficiency” may be low so that it remains the question what will be the ultimate total efficiency.

The use of a plasma as the single conversion step for waste is extremely energy intensive. Therefore a number of plasma suppliers have opted to use the plasma only for gas cleaning after a conventional low temperature gasifier. In that way energy use is far less and still syngases are created that meet with the requirements for highest quality use (in a gas motor or gas turbine); differences between plasma treatment suppliers are mainly in the pregasification unit and the plasma configuration.

Claims for plasma gasification

The claims by providers are the following:

After plasma treatment syngas can be utilized as high value fuels in more energy efficient conversion cycles (such as gas turbines or gas motors). Through the plasma route, zero emissions will be generated. Plasma can be considered as a carbon saving technology.

Experiences

A number of plasma gasification systems are installed and in operation in Japan. Information about these installations is scarce.

Within Europe and America the main successful experience with plasma gasification of waste is with the conversion of asbestos, in Bordeaux in France. Europlasma is commissioning an installation in Morcenx, France, under the name of CHO Power (construction finalized July 2012). A number of other developments are in advanced stages (Tallahassee US, Ottawa, Can, Tees Valley UK), however none yet under construction. A long standing permit for an installation in St Lucie FL US has recently been abandoned in view of insufficient progress. Both Westinghouse (AlterNRG), Plasco and APP claim to have won one or more projects, but none of these has yet reached final financial close as it seems. All in all around 15 installations are now operating worldwide, of which the majority in Japan. The total throughput is around 300 ktonnes / year. These 15 installations are including a number of pilot installations in Europe and America.

Available information

In literature the information about operational performance of existing plasma gasification installations is almost non-existent. There are no papers that report on energy efficiency of commercially operating installations and certainly not on internal energy use; there is limited information about emissions in operational installations, also because only in Japan a number of installations are in operational use. No public information is available on costs and long term performance.

Overview of risks

The main risks within plasma technology/systems are associated with the total energy use and with the safety risks of working within an ultrahigh temperature environment. High requirement for pretreatment of the input waste, leads to extra costs.

A number of risks that are relevant for gasification basically also count for plasma gasification:

- High requirement for pretreatment of the waste input, leading to extra costs
- Gross electrical output of the plasma through a gas motor or gas engine
- Energy requirement within the plasma cycle and the cleaning cycle is unclear and may be higher than considered (for instance in view of the production of oxygen that is needed for the process)
- Calorific value, quality and quantity of produced gases may be lower than designed, thus lowering income streams
- Equipment suppliers are not always financially sound and bid at too low prices, reducing project success chances in view of inferior interfaces
- Maintenance requirements and cost of the systems is high

Table 4 Overview of advanced thermal treatment technologies using plasma gasification

Process name	**Suppliers**	**Process description**
Alter NRG/Westinghouse Plasma gasification	Alter NRG, Westinghouse Plasma Corporation (WPC) - Geoplasma - Green power	Plasma gasification, combustion or gas engine, ash vitrification
CHO Power	Euro plasma	Gasification, plasma converter, gas engine, ash vitrification
Gasplasma	Advanced Plasma Power	Gasification, plasma converter, gas engine, ash melting
Plasco	Plasco Energy Group	Pyrolysis, plasma gasification, plasma converter, gas engine, ash
Plasma Enhanced Melter, PEMTM	Integrated Environmental Technologies, InEnTec Chemical, S4 Energy Solutions	Gasification, plasma converter, gas engine, ash vitrification
PyroArc	ScanArc Plasma Technologies	Gasification, plasma converter, gas engine, ash vitrification
Solena PGV/GlidArc reactor	ECP GlidArc Technologies, Florida Syngas LLC, Solena Group	Plasma gasification, CC gas turbine, ash vitrification

7 CONVENTIONAL ENERGY FROM WASTE (REFERENCE)

Description

Conventional Energy from Waste (EfW) provides direct incineration of combustible non-hazardous waste, thus combining in one stage, pyrolysis, gasification and combustion. The combustion gases typically are treated in either a dry, semi-dry or wet flue gas treatment system to abate emission levels of HCl, NO_x, SO_x, dioxins and furans, heavy metals, in order to meet the prescribed emission levels. Depending on heat supply possibilities, the energy that is generated in a conventional EfW installation is either primarily converted into heat (which specifically happens in North European Countries that have a high heat demand), into heat and electrical power (CHP) or electricity only if there is no demand for the heat.

Conventional EfW meets with the requirements of the Industrial Emissions Directive on emissions and on the temperature levels within the furnace (flue gases have to show a temperature > 850^{o}C during > 2 seconds).

Conventional EfW is provided in 2 main types of processes:

- Grate (stoker) combustion
- Fluidized bed combustion

Furthermore the so-called oscillating kiln technology is supplied.

<u>Grate combustion</u> (also called: stoker combustion) consists of waste being introduced onto a moving grate, where it is burned. The unburned material - bottom ash - is typically collected and removed in a wet discharger. Flue gases pass through the steam boiler where steam with typical parameters of around 400°C and 40 bar (there are installations that use considerably higher steam parameters, up to 490°C and up to 135 bar) is generated and converted into electricity and heat through a steam turbine. Flue gases are subsequently cleaned from fly ashes and pollutants through ash collection and dry or wet flue gas treatment. Typically waste does not have to be pretreated except for very pieces that have to pass through a simple crusher. In comparison with the other two conventional technologies, grate-based incineration is the more flexible technology. Moving grates form the vast majority of installations that are built and operated worldwide.

<u>Fluidized bed combustion technology</u> consists of particle size reduced waste being introduced in an air stream with a floating sand bed. In view of efficient heat transfer fluidized bed combustion may work at lower combustion temperatures. Flue gases loaded with ash pass the steam boiler section and a dry ash collection / ash cleaning section. Typically waste must be pretreated by particle size reduction and a stable waste quality (limited variation in heating value) is required. Fluidized bed combustion technology is very suitable for homogeneous waste streams and biomass streams.

Claims for conventional EfW technologies

Conventional EfW installations claim that waste with a heating value between roughly 7.5 and 15 MJ / kg (depending on the chosen technology) can be efficiently converted into heat and electrical power. Waste with lower and higher heating value can also be treated, with the design of the plant adapted to these conditions. Complete burnout of the waste and flue gases occurs, at net electricity output of 18 - 27% (depending on chosen technology). If heat is supplied for district heating or industrial heating, this will replace part of the electricity output.

Installations prove an operational life time of > 20 years and a high average availability of (8,000 h for grate-based installations, 7,500 h for fluidized bed). Installations fully comply with regulatory emission standards.

Experiences

Worldwide around 2,000 conventional EfW plants have been built, with a present throughput of more than 100 million tonnes of MSWI per year. Grate-based combustion plants form the vast majority. These installations have a proven average availability of 7,500 - 8,000 h and net electrical efficiencies of 18 - 27% (efficiencies < 20% for older installations). Grate-based installations indeed have a high fuel flexibility but also need proper steering of the waste load to prevent large variations in burnout. All installations in operation today are equipped with suitable flue gas cleaning equipment and improved combustion control and thus easily comply with the strictest emission demands .Worldwide a few tens of fluidized bed combustion installations for municipal solid waste have been built. Experiences are that these installations function well, provided the waste particle size distribution and waste calorific values are carefully managed. This very often means that waste needs to be pretreated (comminuted / broken) before being fed into an FBC installation. If waste quality is not constant enough, problems may arise. Only very few oscillating kilns have been constructed; compared to grate-based installations and fluidized beds they must be considered as less proven.

Available information

Information about the operational performance of conventional EfW installations is broadly available.

Overview of risks

In view of the fact that conventional EfW technologies are widely proven technologies, risks that occur are limited and manageable. Main risks are for failure of installation parts and subsequent non availability of the installation. The risks for such types of failure are however low.

Total investment costs for conventional EfW may be high compared to a number of alternative technologies. However it is not clear whether the cost calculation basis for a number of alternative technologies is comparable with that for conventional technologies (are all cost items taken into consideration - like: civil engineering costs, risk mitigation funds, insurance, project financing costs, pretreatment costs etc.).

Table 5 Overview of conventional thermal Energy from Waste technologies

Process name	Suppliers	Process description
Fluidized bed Energy from waste	Doosan Lentjes	Fluid bed incineration, dedusting incl. dry ash cleaning, either supply of heat, electricity production through a steam boiler or combined heat and power
	EPI	
	IHI / IKE	
	Metso	
	Wheelabrator	
Grate fired energy from waste	Babcock Wilcox - Völund	Grate fired incineration, dedusting, dry or wet gas cleaning, either supply of heat, electricity production through a steam boiler or combined heat and power
	Detroit Stoker	
	Doosan Lentjes	
	Fisia Babcock	
	Hitachi Zosen Inova	
	JFE	
	Kawasaki Heavy Industries	
	Keppel Seghers	
	Martin GmbH	
	Takuma	
	Termomeccanica	
	Vinci Environnement	
Oscillating kiln	Cyclerval	Combustion of waste in a rotary kiln ash cleaning and either supply of heat, electricity production through a steam boiler or combined heat and power
	IHI / IKE	

8 ENERGY FROM WASTE OVER THE WORLD

Energy from Waste technologies are mainly implemented in four regions in the world:

1. Europe - mainly Germany, Scandinavian Countries (Norway, Sweden, Denmark), France, Netherlands, Italy, United Kingdom (around 500 installations over Europe)
2. United States (around 75 installations over the US)
3. Japan (more than 1,000 installations)
4. China and South Korea (around 120 installations, growing fast)

The boundary conditions for EfW are quite different in these regions, therefore what is successful and feasible in one region may not be feasible in another region.

To give an indication about the differences, some of the boundary conditions are given per region.

Europe:

- Comply with strict emission limits as defined in the Industrial Emissions Directive
- Waste caloric value 8 - 12 MJ/kg
- Installation sizes up to 1.5 million tonnes / yr (Amsterdam Netherlands), average line capacity around 150,000 tonnes / yr
- Optimization of availability to > 7,500 hrs / year
- Maximization of heat - and electricity supply to external off-takers
- More and more use of higher caloric value SRF material (12 - 17 MJ/kg) in dedicated installations
- No requirements regarding ash treatment
- Gate fee for waste conversion between EUR 25 (Scandinavia, maximized heat off-take) and 100 (Belgium, protected market)
- Investment amounts for EfW EUR 400 - EUR 1,000 / yearly tonne of throughput

United States:

- Emission limits comparable to or somewhat less strict than in Europe
- Waste caloric value 7 - 10 MJ/kg
- Installation sizes up to 1 million tonnes / yr (several installations); average line capacity 150,000 tonnes / yr
- Maximization of electricity supply to the grid if possible, dependent on local possibilities
- No requirements regarding ash treatment
- Gate fees for waste conversion must be competitive to landfilling therefore low (USD 20 - 40)
- Investment amounts for EfW USD 300 - USD 900 / yearly tonne of throughput

Japan:

- Emission limits strict and comparable to Europe
- Heat and Electricity Supply up till yet less important
- Availability (in view of local requirements) of 6,500 - 7,500 hrs / year
- Installation sizes often significantly smaller than 100,000 tonnes / yr in view of local focus
- Strict requirements regarding ash treatment; often ashes need to be vitrified to be made environmentally harmless

- Gate fees for waste conversion may run up till EUR 300 / tonne
- Investment amounts for EfW unclear, but probably higher than in Europe or United States due to lower scale and focus on ash treatment

China and South Korea:

- Pragmatic emission limits
- Waste caloric value 4 - 7 MJ/kg
- Installation sizes varying
- No requirements regarding ash treatment
- Gate fees for waste conversion low
- Investment amounts for EfW EUR 80 - EUR 200 / yearly tonne of throughput

A number of alternative thermal conversion technologies have been implemented successfully in Japan and Japanese equipment manufacturers can competently supply these technologies, as was shown in the overview lists in Chapter 6, which contained a number of Japanese suppliers. Therefore they can be considered technologically proven. However, the list above suggests that in Japan these alternative thermal technologies are operated under significantly different economic and operational boundary conditions. Some important aspects are listed below:

- a major driver for the use of alternative conversion technologies in Japan is that the ashes are vitrified `
- energy efficiency has played a minor role in the choice of these technologies; in practice the energy efficiency appears lower than for conventional EfW technologies
- the treatment price in Japan seems significantly higher than elsewhere

These aspects strongly affect both the technical and the economical business case for operation of these technologies.

To determine whether a technology is appropriate and suitable for his specific situation, a prospective investor therefore needs to review the total mass and energy balance of this technology and review whether the experience that has been built up with an installation is valid and suitable in his region and for his specific situation.

9 DISCUSSION, CONCLUDING REMARKS

The main purposes of this White Paper are to provide an overview of the following:

- The way Conventional Energy from Waste combustion systems and alternative thermal conversion technologies interrelate
- System boundaries that should be taken into account to compare proposals for different thermal treatment installation for municipal solid waste
- Information that a prospective buyer should have to make an objective comparison of several technologies
- Residual risks within the technologies regarding non availability and their possible effects on income streams
- Operational experiences with installations based on alternative thermal technologies
- Differences in operational boundary

The technology overview as presented in paragraphs 6 and 7 does not pretend to be complete. We have undoubtedly not mentioned a large number of processes. We have furthermore chosen not to provide price or project information as this may either be incomparable, or may be classified information or might provide only costs for part of the total investment.

It is clear that alternative thermal technologies provide interesting statements as to operational performance compared to conventional EfW installations.

However it is equally clear that the quantity of readily available objective information about the performance of alternative thermal waste treatment technologies is lower than for conventional EfW installations, if only because there is less operational experience to dwell upon.

This lack of information makes it difficult to compare value propositions for the investment in several types of thermal treatment installations for waste. A lot of information is either not available or not comparable with the information provided by others.

To overcome this aspect as far as possible, the Workgroup on Energy Recovery has prepared a checklist on information that a prospective buyer should anyhow demand, to make it possible to rank the propositions of several suppliers. This checklist is given in Appendix II
In Appendix III and IV we have presented the results of a literature study of the emissions and energy efficiency from several types of alternative treatment. Both the emission results and the energy efficiency for these treatment installations are ***comparable with or less environmentally desirable*** than for the present generation of EfW installations. It must be stressed that these results may even be influenced by the fact that they are provided by the suppliers, who may or may not have shown the complete system boundaries. The data as presented may therefore present an overly optimistic view of actual emissions and efficiencies. We have in other situations seen indications of electrical efficiencies that in practice were significantly lower than presented in these Appendices. This all goes to show that potential buyers need to make sure that they will be provided with actual and comparable information for specific technologies. The information in Appendix II is therefore essential for each technology proposal.

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APPENDIX I. OTHER DEFINITIONS

Efficiency (gross) is the produced electricity divided by the energy content of the waste and possible auxiliary fuels. The formula for the gross efficiency is:

$$\frac{Produced\ electricity}{Energy\ content\ (LHV)\ of\ waste\ and\ auxiliary\ fuel\ input}$$

Efficiency (net) is the total efficiency of the conversion of waste to electrical energy. The formula for the net efficiency used in this chapter is:

$$\frac{Produced\ electricity\ - Internal\ use\ of\ electricity}{Energy\ content\ (LHV)\ of\ waste\ and\ auxiliary\ fuel\ input}$$

The net efficiency is meant when the term efficiency is used in this chapter

Lower Heating Value (LHV) is a measure for the chemical energy content of a fuel, also called the calorific value. This is the energy that is released when combusting this fuel. In the United States the term Higher Heating Value (HHV) is often used. The difference is that the HHV assumes that the water present in the flue gas is liquid instead of vapour, resulting in a higher heating value. The unit for the heating value is MJ/kg or MJ/Nm^3.

Mechanical Biological Treatment (MBT) is the treatment of waste streams by a combination of a sorting facility with a form of biological treatment such as composting or anaerobic digestion. MBT plants are designed to process mixed household waste as well as commercial and industrial waste.

Normal cubic meter (Nm3) is a volumetric unit used to compare gases at different temperatures or pressures by converting values to a cubic meter at standard conditions: room temperature (20°C) and atmospheric pressure (1 bar).

Efficiency (cold gas) is the efficiency of the conversion of waste to gas, not considering the combustion step and production of electricity. This definition is used when comparing processes that produce a syngas for use as a chemical feedstock instead of electricity. The formula for the cold gas efficiency is:

$$\frac{Energy\ content\ (LHV)\ of\ the\ produced\ syngas - auxiliary\ fuel\ input}{Energy\ content\ (LHV)\ of\ waste\ input}$$

Syngas is a mixture of CO and . The gas is diluted with N_2 when air (instead of pure oxygen) is used to gasify the waste. CO_2, H_2O and CH_{44} are also present, their concentrations depending on the process used to produce the gas. The heating value depends on the composition of the syngas, ranging from 4 to 20 MJ/Nm^3. Syngas can be used to create diesel (Fischer-Tropsch process), synthetic natural gas (SNG), hydrogen, ammonia and base chemicals like methanol or dimethyl ether (DME) besides direct combustion for power generation.

APPENDIX II. LIST OF QUESTIONS TO BE ANSWERED FOR EVALUATION OF A TECHNOLOGY OFFER

Basic points of attention when assessing technologies

Fitness for purpose

- Feedstock requirements compared to expected feedstock quality
- Mass and energy balance (complete, including internal use), including
  - Emissions compared to Permitting requirements
- Scale of operation per unit

Operational expectations

- Reliability of operation assessment (expected availability)
- Maintenance requirements

Reference installations

- How many reference installations exist and can they be visited?
- Operational track record reference installations
- Scale of operation reference installations

Economics

- Expected capital costs
- Expected operating costs
- Expected maintenance costs
- Tonnage throughput per year
- Expected income:
  - energy income
  - recycling income (metal streams) o required gate fees

Suppliers track record and financial capacity

- Description of the company or consortium
- EPC projects successfully carried out - Balance sheet
- Capacity to carry EPC risks

Fitness for purpose

A lot of alternative thermal treatment installations are both offered for thermal treatment of biomass and for thermal treatment of waste. In view of the fact that this White Paper concentrates on municipal solid waste, a number of aspects need to be clarified beforehand, to make sure that thermal treatment technologies are compared "like with like".

Feedstock requirements need to be clarified, such as:

- Particle size requirements:

  Depending on the method of thermal treatment (fixed bed or grate transport bed, fluidized bed or entrained
  flow), there are specific requirements towards particle sizes (minimum and maximum). As a rule, batch reactors (residence time 12 - 24 hrs), fixed bed and grate transport bed reactors (residence times 30 minutes

- several hrs) have only limited particle size requirements (maximum sizes > 1,000 mm are allowable if limited) and are versatile for variations; these installations can handle untreated municipal solid wasted. Fluidized bed reactors (residence time minutes) require maximum particle sizes of around 150 - 200 mm. If

  particle size get larger than that, collapsing of the bed may occur, leading to a forced outage. This means that Fluidized Bed reactors require pretreatment (shreddering < required grain size boundary) of the waste to bring it up to specification.

  Entrained flow reactors (residence time seconds) work basically with grain sizes < 1 mm; for municipal solid waste these are unsuited.

- Pre-separation requirements

  For some of the technologies, preseparation of metal streams is a necessity (some fluidized bed reactors require substantial iron and aluminum removal since aluminum droplet and metal parts may lead to excessive fouling and obstruction of air nozzles in the bottom plates.

- Homogeneity requirements

  Any fluid bed or entrained bed reactor requires an extent of homogeneity over time of the grain size distribution in view of gas speeds that need to be maintained.

- Calorific Value requirements

  An overview needs to be given on the operational window for the installation (minimum and maximum calorific value.

Mass and energy balance - during typical operation - is required to get a complete overview of the technology. This includes:

Massflow, input

- Feedstock, 1 metric ton:
  - Composition (is it pre or post sorting potential pretreatment)
  - Calorific value
  - Particle size indication
- Additional solid materials input (fluidized bed materials, flue gas treatment and water treatment chemicals
- Air / oxygen input
- Water input / water use in the process

Massflow, output

- Solid residues
  - Bottom ashes / coarse ashes
  - Fine ashes, APC residues
  - Water treatment sludges
- Water streams
- Flue gas / exhaust gas output

Energy flows: input

- Energy input through the waste GJTh / ton of waste
- Imported energy input (or internal use) MWhel/ ton of waste

- Additional energy input for oxygen production (if system is operating on oxygen instead of air) - Energy used for potential pre-treatment
- Imported thermal energy input (for instance for system start and for SCR operation)

Energy flows: output

- Gross and net energy output MWhel /ton of waste
- Additional other energy output GJTh/ton of waste (gas or liquid fuel output)
- Additional heat output GJTh/ton of waste

When comparing energy efficiencies of different plants, be aware that higher heating values normally increases the energy efficiency potential for a given technology. Technologies emphasising high energy efficiencies are often specified to be fed with pure plastics or other waste streams with extra high heating values.

Scale of operation

Obviously an overview is necessary of the minimum and maximum installation size to verify whether the installation footprint will fit with the requirements of a local waste provider, considering to invest in thermal treatment of waste

Will the installation work satisfactorily

- The operational performance is dependent on the mass- and energy balance and on the number of hours that an installation can work yearly. For alternative thermal treatment installations, often this is information is scarcely available and must be derived from only a small number of reference installations. To gather whether the installation will perform, information must be provided on the following aspects:

Reliability of operation assessment (expected availability)

Often new installations suffer from various start-up problems regarding fouling, corrosion, air leakages, other blockages. It is not known yet for each thermal technology whether the same operational availability can be reached that is normal for a conventional grate fired combustion plant. Therefore a reliable assessment is necessary of the expected availability, based on real time experiences or based on a conservative assessment of operation over a period of at least 5 yrs. Yearly availability to be defined as: number of actual operational hrs / 8,760. In some years availability will be lower due to major maintenance repair work.

Maintenance requirements

Maintenance requirements and major critical maintenance points to be described

Reference installations

A good indication on the performance of the installations can be derived from experience of running installations on one hand. If alternative treatment installations are new, often running installations do not yet exist. An indication on the trust by clients can then be derived from the number of installations in planning or under construction. Obviously co-operation by owners of existing installations (or developers / constructors of new installations) is crucial to get the required information.

Important aspects of the installations to get reliable information are in that case:

How many reference installations exist and can they be visited

The number and scale of reference installations gives an indication on operational experience. Preparedness of owners of installations to provide access to the installation and to provide operational information may contribute towards confidence in a new installation

How many installations are in construction and can the construction sites be visited

Number of contracts closed for an alternative treatment installation and progress in the construction process gives an indication on the following aspects:

- Attractiveness and persuasiveness of technical / economical presentation towards the developer - Any challenges during construction
- Years towards first commercial operation

Furthermore information is required on:

Operational track record reference installations

- Yearly availability
- Critical components for maintenance Major outage reasons
- Emission levels and license breaches

Scale of operation reference installations

APPENDIX III. OVERVIEW OF AIR EMISSIONS

Overview of emissions from several alternative thermal treatment technologies and the currently Best Available Technology (BAT) for conventional waste incineration plants (GENON, 2010)

Company		Flue gas [Nm^3/t]	mg/Nm^3								PCDD/PCDF [$\mu g/Nm^3$]
			Dust	HCl	HF	SO_2	NO_2	CO	Hg	Cd+Tl	
AlterNRG	PL	1.400-2.400	<3	22-39		<1-2	62-82	<29			0,00059-0,00067
Compact Power	P+G		1,4	0,96	0,12	0,74	21	3,9		0,006	<0,003
Ebara	G	2.952	<1	2		<2,8	29,3		<0,005		0,000051
Energos	G	7.894 LCV 10.8MJ/kg	0,2	3,6	0,02	19,8	42 (without deNOx)	2	0,00327	0,00002	0,001
Enerwaste	G			0-6,5		16,6-25,4	58,7-199,2 (without deNOx)	30,9-40,5			
Mitsui	P+C		<1	9		8	150	5	0,01	<0,001	0,016
Nippon Steel	G	5.760 LCV 8,4MJ/kg	6	3		0,5	16	5,2			0,023
TechTrade	P	6.495 LCV 8,5MJ/kg	0,3-1,8	5,5-6,4		5,42	179,5	5,65	0,0066-0,0117	0,0006	0,0013
Thermoselect	P+G		0,2	<5			14				0,0072
Tpf Basse Sambre	P+G	5.600 LCV 12,5MJ/kg	2,8	9,3	0,12	11,1	327 (now 200 without DeNOx)	7,4	0,00013	0,0011	0,06
D. Lgs. 133/2005			10	10	1	50	200	50	0,05	0.05	0,1
BAT			1-5	1-8	<1	1-40	40-100	5-30	<0,05	0.005-0.5	0,01-0,1
Reported values to dry gaseous effluent to O°C, 1 atm, 11% O_2 G = gasification P = pyrolysis; Plasma = plasma gasification											

Note:
Data on emissions for specific technologies are based on best knowledge and may be based on data as provided by the technology suppliers. For some suppliers data are based on actual air emission measurements during several years.

APPENDIX IV. OVERVIEW ELECTRICAL EFFICIENCIES

Overview of the net electrical efficiencies of several alternative thermal treatment technologies (GENON, 2010)

Company		Reference plant	Electricity produced [MWh/t]	Electricity to National Grid [MWh/t]	Heat produced [MWh/t]	Heat to external users [MWh/t]	Net efficiency (1) [%]
AlterNRG (Canada)	PL	Utashinai, Japan	0,934	0,508			18,6%
Ebara (Japan)	G	Project for New York	0,547	0,383			13%-15%
Energos (Norway)	G	Project data 30.000 t/y; LCV=12MJ/kg	0,750	0,625			18,5%
Enerwaste (USA)	G	Project data	0,55				
Entech (Australia)	G	Project data	0,573				17%
Nippon Steel (Japan)	G	Shin Moji, Japan 194.000 t/y; LCV=11MJ/kg	0,784	0,536			15,7%
TechTrade (2) (Germany)	P	Burgau, Germany 26.807 t/y; LCV= 8,5MJ/kg)	0,214	0,059		0,056	2,9%
		Project data 50.000 t/y; LCV= 14,6MJ/kg	- Steam cycle: efficiency pre internal energy demands = 24,6% - IGCC (in need of experimental tests): efficiency pre internal energy demands = 33,6% - Gas engines (in need of experimental tests): efficiency pre internal energy demands = 38,3%				
Thermoselect (Switzerland)	P+G	Theoretical value LCV=12 MJ/kg	1,03	0,705	1,39		19%
Tpf Basse Sambre (3) (Belgium)	P+G	Keflavik, Iceland 12.000 t/y; LCV=12,5MJ/kg	0,200	0,140	-	-	4%
		Project data 30.000 t/y; LCV= 12,5MJ/kg	0,700	0,620	-	-	18%
C = combustion ; G = gasification ; P = pyrolysis; PL = plasma gasification							
(1) Ratio of the energy extracted from the waste as electricity after internal energy demands, divided by the energy content of the waste feedstock.							
(2) Data in the table refer to Burgau plant, started in 1987. A new plant of 50.000 t/y and LCV=14,6 MJ/kg, according to the Supplier, would achieve electric conversion efficiencies pre internal energy demands of 24,6% through the use of a steam cycle.							
(3) Keflavik plant was designed to produce hot water and then modified to produce electricity. A new plant of 30.000 t /y and LCV=12,5 MJ/kg, would allow to produce totally 0,7 MW/h/t with internal parasitic energy demands of 0,08 MWh/t.							

Note:

Data on electrical efficiencies for specific technologies are based on best knowledge and may be based on data as provided by the technology suppliers and therefore heavily influenced in a positive way (Thermoselect, Nippon Steel). It is significant that for the two situations with project estimations and real time data, the differences between the project estimations and the real time data are large, implying that project estimations of technology suppliers are not realistic. Only for some suppliers data are based on actual efficiency measurements during several years (Energos).

Even then, electrical efficiencies of the alternative technologies are all inferior to that of conventional energy from waste technologies that may reach net electrical efficiency of 18 - 27%