Integration of Thermal Energy Recovery into Solid Waste Management

Pat Howes and Kathryn Warren, IEA Bioenergy Task 36

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Introduction

Energy from waste (EfW) – the thermal conversion of waste to energy – is regarded as one of the most significant commercially available bioenergy technologies. Its application is growing worldwide and many countries now integrate EfW into their waste management strategies, contributing to their country's heat and power supply. Loenicker (2012) estimates that some 250 EfW plants will be built worldwide between 2012 and 2016. This will result in an estimated total global capacity in 2016 of around 300 million tonnes (Mt). UNEP (2011) estimated the market for EfW to be US $19.9 billion in 2008 and forecast that it would grow by 30% by 2013. They expected more than a third of investments in EfW to be in Asia, with Latin America representing 20% of the investment market and Europe 16%. This increase will be driven by new waste strategies and policies, increasing concerns about landfill and open dumps, rapid urbanisation in emerging economies and rising GDP accompanied by increased waste arisings in some countries.

This paper examines the current global situation for EfW, the drivers that will result in the expansions predicted and where the technology may go in the future.

Box 1 describes the difference between incineration and EfW and Box 2 discusses the waste streams examined in this paper.

Box 1 Thermal combustion: incineration or EfW?

Conventional waste thermal combustion processes are often referred to as 'incineration', but this term was originally used to denote the combustion of waste to decrease volume and mass, with no energy recovery. Developers of most modern plants aim to enable recovery of energy and these plants are referred to as *energy from waste* (EfW) plants to differentiate them from incineration that does not include energy recovery. EfW is a commercially proven technology that is well established globally. However, there are countries where the technology has made little or no inroads and these could benefit from the evolving experience of those countries where EfW is used[1].

[1] Thermal combustion is the most well known technology for energy recovery from waste, but there are other options, including biological technologies and what is frequently called 'advanced' thermal conversion (usually gasification and pyrolysis). Further information on these technologies is available from IEA Bioenergy Task 37 (www.iea-biogas.net) and www.ieabioenergy.com.

Box 2 What waste streams are relevant to EfW?

The major waste stream relevant to EfW is Municipal Solid Waste (MSW) (and similar commercial and industrial waste streams).

The term MSW means different things in different countries, but is usually defined by what is included (e.g. whether or not street, market and commercial waste such as restaurant waste is included). Generally it is true to say that it is the waste that comes under the responsibility of local or regional (waste) authorities. In OECD countries local authorities often develop strategies for waste management for up to 20-25 years. The long-term nature of these plans means that it is possible to invest in technology with a long lifetime and to allow for payback over this period. This can present the local authority with the opportunity to integrate local energy demand with energy generation from waste. Countries that invest in EfW often also have a strong legislative framework for municipal waste management and relative certainty in the market place. These factors decrease the risk in plant development so that investment in EfW plants is feasible and can be designed to deliver local benefits. Consequently this paper concentrates on MSW, as it is the most common feedstock for integration of energy into solid waste management. However, there are other waste feedstocks that are of interest for energy recovery and increasingly refuse derived fuels, perhaps mixed with commercial and industrial waste, and solid recovered fuel (SRF), which may also be manufactured from other waste streams, are becoming more significant in some countries (particularly those in Europe).

Drivers and trends for EfW

Global waste trends indicate that the amount of waste being produced is increasing in most countries (UNEP 2011). In 2010 an estimated 1.7-1.9 billion tonnes of MSW was produced worldwide. UNEP (2011) estimated that power generation from waste in 2010 was about 71,600 GWh, with a capacity of 54 GW, mainly from EfW plants. They modelled future growth and concluded that under business as usual this could grow by over 200 GW by 2050 (corresponding to 0.5 billion tonnes of waste going to EfW each year). This compares to World Bank (2012) estimates that arisings are currently 1.3 billion tonnes/year, rising to 2.2 billion tonnes/year by 2025.

Waste arisings and composition are in general influenced by factors such as wealth/income/GDP, population, urbanisation and culture, which vary between countries. Figure 1 shows the substantial differences in waste arisings in selected countries. Box 3 shows the characteristics of waste that influence the amount of energy that can be recovered.

In examining waste arisings some authors have commented on how there are relationships between typical income in a country, the waste generated and its characteristics. The World Bank (2012) divides countries into high, medium and low income and uses this to generalise about the suitability of the waste for EfW. Chalmin and Gaillochet (2011) used these relationships but, in addition, introduced size of country and available space as differentiators for waste management trends, particularly for high income countries. Even so, using GDP, waste arisings or geographical characteristics as a proxy for whether or not EfW is suitable for a country is misleading. What really matters are the local factors and drivers in a country, usually policy drivers such as landfill diversion and geographical constraints such as lack of space near areas of high population and high waste production. Warren and Read (2013) examined drivers for EfW in a number of countries globally. They showed the importance of the Landfill Directive in the EU, which requires diversion of waste from landfill, and how it has driven the increase in recycling and EfW in some EU countries. In Sweden energy generation is a major driver. In other countries (e.g. Japan and Singapore) lack of land for landfill has resulted in a drive towards incineration and EfW. Conversely they showed that the presence of abundant space for and low cost of landfill in the absence of drivers to divert waste from landfill can be an important barrier to the development of EfW in countries such as Australia and the USA. In these countries drivers for EfW are more likely to be energy and resource based rather than focussed on environmental impacts or landfill diversion. Other barriers include emissions (to air and in ash), the level of investment in infrastructure relevant to EfW (such as roads and refuse disposal vehicles) and public perception related in particular to the ability to regulate air emissions.

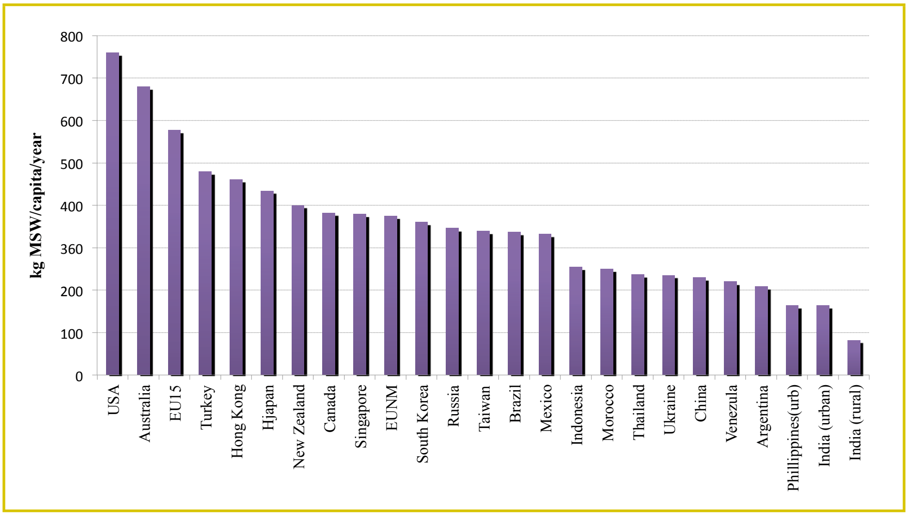


Figure 1 Municipal waste production in selected countries

(Source: based on Chalmin and Gaillochet 2009, which draws from various statistical sources, including OECD, Eurostat, Veolia, UN, UNESCAP and the World Bank)

Box 3 Waste characteristics that influence energy recovery

Calorific value (CV): This is the energy content of the waste. The CV of waste fuels is impacted by moisture content, as with other fuels. Organic waste, which has a high moisture content can make a significant difference to the overall CV of a waste stream. In Europe, Australasia and North America most mixed municipal waste has a calorific value of 7-12 MJ/kg. Residual waste, after recycling (sometimes termed refuse derived fuels) is generally in the higher range, 10-12 MJ/kg (but can be as high as 25 MJ/kg); and the CV of Solid Recovered Fuel (SRF) can range from 3-25 MJ/kg. MSW dominated by organic waste, such as that produced in many low-income countries, has a low calorific value (<4.6 MJ/kg), which is insufficient to support combustion, making the waste unsuitable for EfW unless it is processed further. In urban areas of emerging economies recent figures show an increase in calorific value to around 4-7 MJ/kg (ISWA 2013a,b).

Despite all of these variables there are some important generalisations that can be made about trends in the deployment of EfW and the drivers for EfW:

1. There is no single solution for waste management: the choices made by policy makers and local communities depend on a combination of factors such as costs, quantity of waste produced, composition of waste, space available for disposal (countries with large amounts of space relative to population tend to favour landfilling, regardless of GDP and waste arisings) and the environmental awareness and wealth of the population. EfW tends to be adopted in countries with sophisticated waste management policies and is often driven by a desire to decrease waste to landfill. Other countries investing in EfW are driven by the high cost of land and/or a need for alternative low cost energy.

2. It is common to see policies that aim first to minimise waste production, recover and/or recycle materials from waste and then to recover energy prior to final disposal, with some policies placing a cap on the amount of waste that can be used for energy recovery. This rationalisation of waste management is known as the 'Waste Hierarchy'.

3. A growing theme in OECD countries is the adoption of a target of 'zero waste to landfill'[2]. Countries adopting such policies do so in response to the recognition of the longterm environmental impacts of landfill and set statutory targets for recycling and landfill diversion. These pressures have resulted in significant (and increasing) recycling of waste in many countries, which has in turn impacted the composition of residual waste that cannot be recycled[3]. Most significantly for EfW, reduction and recycling of waste results in changes to the calorific value of the residual waste (usually by decreasing moisture content).

[2] For example, Scotland and Wales have adopted zero waste strategies; as have parts of Asia (e.g. Thailand and Taiwan), Australia and the USA. See, for example: http://www.sfenvironment.org/zero-waste, Natural Waste Scotland (2010), Government of South Australia (2011).

[3] These trends were reviewed by Task 36 in 2009 and the results are presented on the website, See IEA Bioenergy (2009).

4. Increasing urbanisation in low-income countries has important environmental and health issues related to waste disposal. Despite this, waste management is often low on the list of priorities after health care, water sanitation and education (World Bank 2012). As a result there can be low waste management budgets and a lack of support for local authorities to help them invest in improved waste management. Consequently low cost solutions such as landfill and open dumps prevail (Chalmin and Gaillochet 2009).

5. The typically high organic content of waste in low income countries means that opportunities for recovery of energy from these wastes are likely to be related to the organic composition i.e. anaerobic digestion or landfill gas recovery. It is possible to use incineration as a volume/weight reduction or sanitisation process by the addition of fuels to aid combustion. Energy could be recovered in such a process but the efficiency of energy recovery will not be high.

6. Waste recycling in low-income and emerging economies often relies on a network of informal recyclers. It is important to consider the contribution and effectiveness of these recyclers in waste management strategies, particularly if investment in expensive large-scale equipment is being considered (Read 2013). Other strategies with a better fit to local culture, such as anaerobic digestion are also worth considering.

EfW in global regions

Figure 2 presents UN data on percentage of waste incineration (including EfW) on a national basis. This section examines the drivers for EfW and the uptake of EfW in more detail using Europe, North America and Asia as examples.

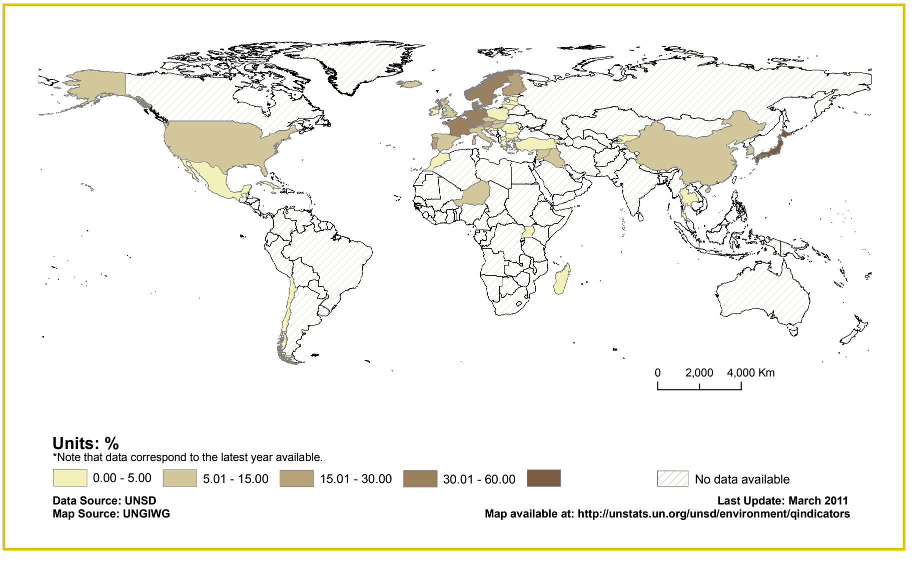


Figure 2 Percentage of municipal waste incinerated

(Source: UN Statistics)

European Union

The European Union is characterised by a high level, sophisticated waste management strategy, including a Waste Framework Directive setting out agreed waste policy, and Directives controlling Landfill and emissions from EfW (the Industrial Emissions Directive). The EU Waste Framework Directive includes an emphasis on the Waste Hierarchy and the inclusion of carbon accounting in decisions concerning waste management. The Landfill Directive sets targets for diversion of biodegradable waste from landfill[4]. EfW is seen as a viable option for residual waste after reuse and recycling. Europe has supported the production of guidance documents to outline Best Available Technology, known as the BREF guides, which provide useful information on what can be achieved[5]. In addition, relatively long, harsh winters result in a significant heat demand in some European countries, so that district heating is cost effective and EfW is seen by municipalities as a useful local source of heat in these areas. All of this means that some of the best data on EfW is available from the EU. European Union policies have resulted in a fall in MSW arisings, a decline in landfill in some countries and a rise in recycling, composting and EfW. Even so, waste arising remain high (in 2010 the figures ranged from <320 kg/person/year in the Czech Republic and Poland to > 650 kg/person/year in Denmark, see Eurostat, 2012).

Figure 3 demonstrates that even in the face of this uniform EU framework of legislation there are diverse national trends. There are countries where 30-45% of waste is treated by incineration[6] and over 30% of waste is recycled; but there are also countries where >90% of waste is landfilled. Overall, incineration has increased over the past decade by 140%[7]: Energy production from MSW reached 15,480 thousand tonnes oil equivalent in 2010 (Eurostat 2011). Figure 4 shows the countries with the most EfW facilities (and that EfW in the EU is dominated by countries such as Germany, Denmark, Sweden and the Netherlands). According to the International Solid Waste Association (ISWA 2012), there are 455 plants across the EU, with an average plant capacity ranging from 9-78 tonnes/hour. The calorific value of the waste going to EfW is 7.0-15 MJ/kg (generally between 8 and 12) (ISWA 2012).

Eurostat observes that in those countries where there are landfill bans in place (such as banning of certain organic components from landfill) there has been a high increase in recycling, composting and incineration. New member countries may be lagging behind in diversion of waste from landfill, but they also produce less waste compared to the countries with higher diversion rates.

[4] The Landfill Directive requires Member States to reduce the amount of biodegradable municipal waste going to landfills to 75% by 16th July 2006, to 50% by 16th July 2009 and to 35% by 16th July 2016.

[5] The current BREF is EC (2006). This is in the process of being updated.

[6] Mainly EfW, but the data is not presented separately.

[7] Eurostat notes that there has been a 56% increase in incineration per capita, 159% increase in recycling and 224% increase in composting, with a 35% decrease in landfilling from 1995-2009.

Spittelau Energy-from-Waste Plant, Vienna, Austria

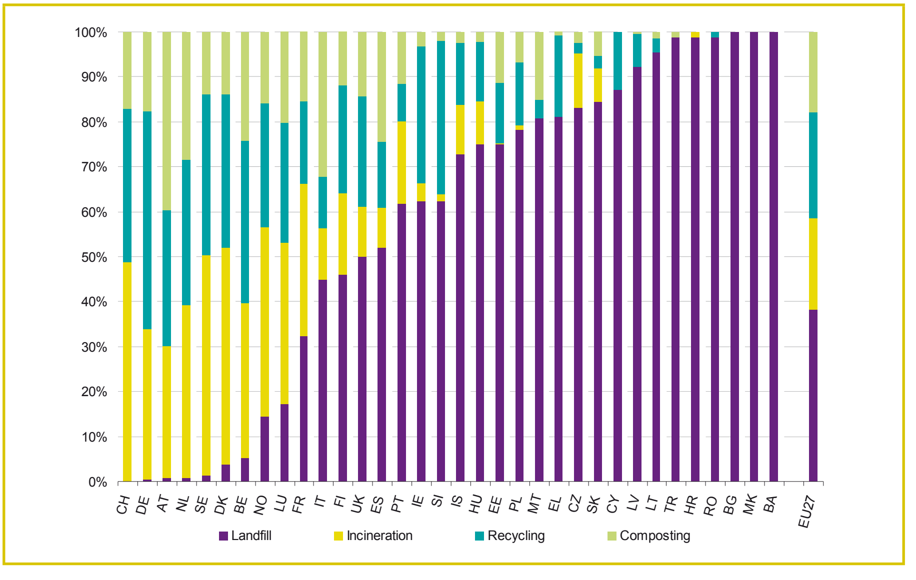


Figure 3 Municipal waste treated in 2009 by country and treatment category, sorted by percentage landfilling (% municipal waste treated)

(Source: Eurostat 2011)

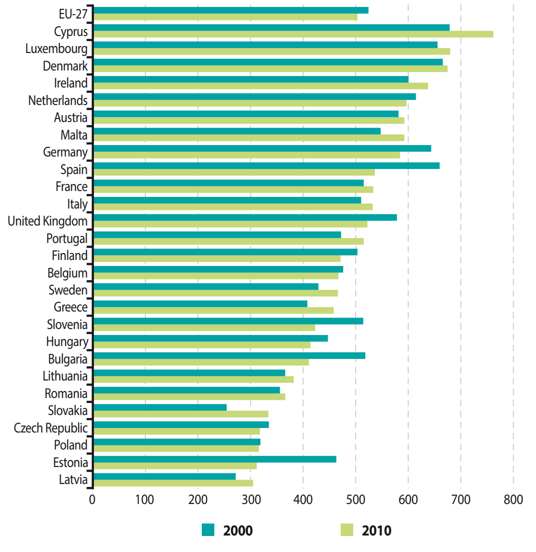


Figure 4 Energy production from MSW incineration (thousand tonnes oil equivalent)

(Source: Eurostat 2012)

North America

Waste disposal in North America is dominated by landfill, which has historically been relatively low cost due to the availability of sites and the low cost of transport. Waste can be transported over considerable distances, across states or even across borders to landfill, although there are examples of waste being prevented from crossing borders to recycling plants[8]. The current increase in the costs for transport and the decreasing landfill void space in some areas is resulting in a re-think, but landfilling remains dominant. The US EPA has adopted the waste hierarchy, which is resulting in overall decreases in waste production and increases in recycling: 250 Mt of MSW was produced in 2011 (around 730 kg/person/year) (EPA 2013); excluding composting, 66.2 Mt of this was recycled (see Figure 5). The organic waste content of US waste is around 52.5% (this includes food waste from commercial premises and restaurants).

8 In general this is to protect the State's own landfill site, i.e. the State will not allow waste to leave its jurisdiction to be recycled.

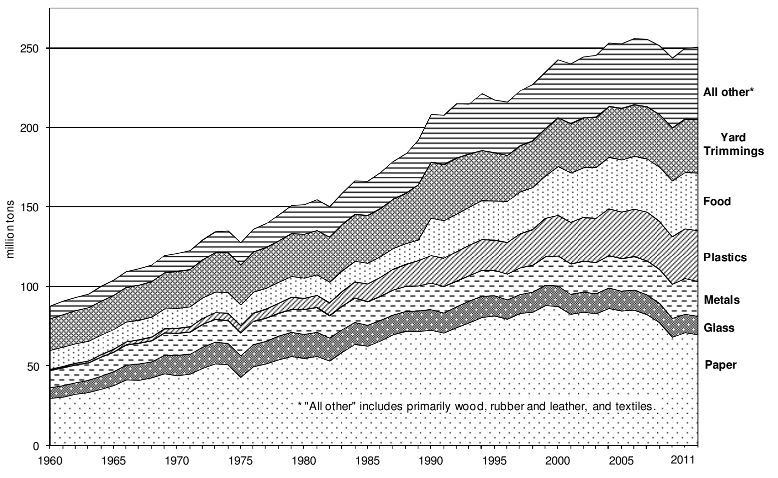


Figure 5 Trends in waste management in USA

(Source: EPA 2011)

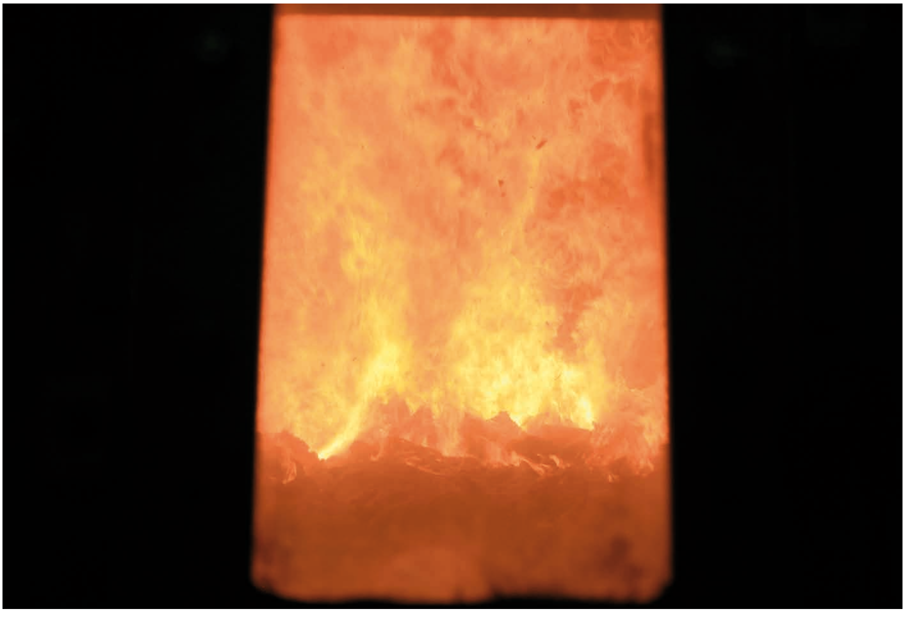
According to data from ISWA (2012) there are 86 EfW plants in operation in the US (in 29 States). Around 29.3 Mt are currently sent to EfW (11.7% of waste arisings)[9], a figure that has not increased since 1990. One of the reasons for this is the relatively high cost; emission limits on these plants can be as strict as in the EU. In addition, due to wide availability of landfill, gate fees remain low. EfW tends to be concentrated in the Northeast USA, near the most densely populated regions.

Canada generated 25 Mt of non-hazardous waste in 2010, of which 9.3 Mt was household waste (Statistics Canada, 2013). Waste arisings were 729 kg/capita in 2010, of which household waste represented 271 kg/capita; and waste recycled was 236 kg/capita. In Canada there are 8 EfW facilities treating 3% of total MSW[10]. However, there is renewed interest in EfW and it is being examined as a part of waste management strategies (e.g. in Vancouver, Ontario[11]). A 100,000 tonnes/year waste gasification facility is being constructed by Enerkem in Edmonton and a 140,000 tonnes/year plant (mass burn) is being constructed by Martin in Durham/York, Ontario.

9 These figures also include EfW for plants that burn rubber tyres in cement kilns, pulp and paper mills, industrial burners and dedicated plants, which amounts to some ~3.3 Mt 2011. Tyres are banned from landfill in many states in the USA.

10 http://www.energyfromwaste.ca/resources/EFW-Worldwide Canadian energy from waste coalition

11 http://www.ec.gc.ca/air/default.asp?lang=En&n=5427E598-1



Energy-from-Waste grate incineration

Asia

According to the World Bank (2012), waste production in Asia is estimated to be around 433 Mt/year (dominated by China with an estimated 190 Mt/year). Data available from the Waste-to-Energy Research and Technology Council (WTERT) and the Confederation of Waste-to-Energy Plants (CEWEP) indicates that 301 EfW facilities treating 70 Mt/year are in operation in Asia. Most of these are in a few countries and predominantly Japan. Outside of Japan the story is very different. In general the waste calorific value (CV) in Asia is low, 4-7 GJ/t (ISWA 2013a), so that the CV of much of the waste produced is too low to support combustion unaided (World Bank, 2011). There are considerable differences across the region. In their 2012 report on South Asia, the Asia Development Bank (ADB) identifies differences between 'low', 'medium' and 'high' income countries:

- Low-income countries are characterised by the lack of a statutory framework and the absence of statistics. Waste is low in calorific value (3.3-4.6 MJ/kg) and less suitable for energy from waste. The ADB (2012) also states that low-income countries tend to spend the bulk of their budget on collection rather than disposal.
- Medium-income countries also have high organic content waste, although the CV is higher (around 4.6-5.4 MJ/kg) and there are often national strategies that provide the framework for waste management. However, these countries are often hampered by a lack of statistics and little application of strategic waste management. Consequently development of EfW can be low, except in highly urbanised areas.
- High-income countries have a mixture of high CV waste and appropriate national frameworks to enable EfW to be applied successfully.

In Asia this provides a useful guide to the adoption of EfW, although the difference between urban and rural areas is important, as densely populated cities may produce waste that is suitable for EfW, whereas rural areas do not. Table 1 shows selected data for Asia.

The population of Asia is expected to grow significantly and this will result in increased urbanisation coupled with an increase in GDP (World Bank 2012). Together these trends are likely to increase future waste arisings. The introduction of more effective waste management strategies could provide a significant opportunity for recycling technologies and for EfW.

A further important point is the regulation of emissions from EfW. Japan has strict emissions limits and residue requirements. This is not the case elsewhere in Asia, a fact that can lead to mistrust of EfW proposals, particularly with regard to their impact on air quality and the disposal of the incinerator ash. If EfW is to be credible for this region, the development of a legislative and regulatory framework for sustainable waste management will be important.

Table 1 Development of EfW in selected Asian countries

Country	EfW status and trends
China	Estimated 140 operational plants; 22 new plants commissioned in 2011. Capacity expected to grow by 40 Mt/year between 2012 and 2016.[a]
Japan	73% of waste incinerated (2005). Strong recycling policy and targets to decrease landfilling[c].
South Korea	Target for energy to be sourced from waste and biomass: 3.17% in 2013 and 4.16% in 2020. All waste facilities planned to be converted to energy recovery by 2020 by building at least 74 RDF and biogas plants, 24 EfW plants and 25 landfill-gas recovery plants. National targets for recycling 61% of waste in 2012.[b] Waste production ~400 kg/person/year (2002)[b].
Singapore	90% waste incinerated (2007)[c].
Sri Lanka	0% waste incinerated (2001), but recent press reports that energy from waste is being considered[c].
India	55 Mt waste produced in 2012. 43 MW EfW (2007).[d] There have been several proposals for EfW in large Indian cities (e.g. Dehli), but the population remains concerned about emissions and ash disposal.
Malaysia	8 MW RDF plant in operation; small scale incineration on tourist islands. The Government has passed a Solid Waste and Public Cleansing management act that proposes phasing out landfill and encourages reuse, reduction and recycling, but it is not clear how EfW would develop[e].

[a] Loenicker 2012 China: 2011; [b] UNEP 2011; [c] World Bank 2011 and http://www.miga.org/projects/index.cfm?pid=1199; [d] National Solid Waste Association of India; [e] Kadir et al (2013).

Technologies for integration of energy into solid waste management

This section examines EfW technologies and their commercial status. There are a number of options for energy recovery from solid waste, as shown in Figure 6:

- Conventional grate combustion plants
- Fluidised bed combustion
- Gasification
- Pyrolysis

There is growing interest in optimising the configuration of EfW in waste management so that waste recycling and recovery options are combined in a variety of configurations to optimise management and use of resources in waste. Further information on these technologies is also available in IEA Bioenergy (2009) and ISWA (2013b).

Table 2 shows the commercial status of the different technical options.

Table 2 Summary of commercial status of EfW technologies

Technology	Commercial status	Size of plant	Efficiency
Grate Combustion	Proven >500 plants in operation globally	3-40 t/h Up to 1.4 Mt/year	Electricity: 21-30% Heat: >70%
	Combustion of untreated waste in air or oxygen enriched atmosphere on a grate. Pre-treatment requirements are minimal. Can take mixed waste or residues from mechanical biological treatment (MBT). Figures 7 and 8 provide flow diagrams of operating plants.		
Fluidised Bed Combustion	Proven. >50 plants in operation globally	3-15 t/h Most plants>50,000 tonnes/year	Electricity: up to 25% Heat: >70%
	Combustion of pre-treated waste in a bed of sand, fluidised by air injection through nozzles in the floor of the furnace. Usually used to treat solid recovered fuel (SRF). Waste particle size normally <200mm. Proportion of waste in the sand is in the region of 2-10%. Performance is dependent on the pre-treatment of the waste to appropriate particle size and the presence of abrasive material in the sand. Figure 9 shows a flow diagram of a fluidised bed EfW plant.		

<table>
<tr><th>Technology</th><th>Commercial status</th><th>Size of plant</th><th>Efficiency</th></tr>
<tr><td rowspan="2">Gasification</td><td><100 installations, mainly in Japan

Demonstrations in EU and USA</td><td>1-11 t/h

Most plants <150,000 tonnes/year (Kymijärvi II takes 250,000 tonnes SRF/year)</td><td>Electricity: claims of 22-33%

ISWA report net efficiencies: 13-19%</td></tr>
<tr><td colspan="3">Involves multi-stage processes with gasification of waste in shaft or fluidised bed furnaces, in gasification chambers, in entrained flow systems or on grates. Combustion takes place under a low oxygen atmosphere. Process results in a synthesis gas, which can be used for chemical synthesis, fed into gas engines, directly burnt or co-combusted in power plants. All processes produce molten solid residues. Plasma gasification includes treatment using a high intensity electron arc, leading to high temperatures. Plasma arcs are used in two ways to break down organic components to their component elements: plasma gasification of waste at >2,000 °C and the use of the plasma arc to clean up the syngas. The former is very energy intensive.

Information on the operating performance of waste gasification plants is limited in the open literature. Nevertheless, interest in gasification has increased recently and a number of plants are in planning or under construction in Europe and North America[12].</td></tr>
<tr><td rowspan="2">Pyrolysis</td><td><25 plants worldwide, most in Japan</td><td>2.5-8.3 t/h</td><td>Not known</td></tr>
<tr><td colspan="3">Thermal breakdown of waste in the absence of air or oxygen, producing char, pyrolysis oil and syngas. Typically pyrolysis of waste is 'slow pyrolysis' in an externally heated rotary drum, with combustion of pyrolysis gas in a high temperature combustion chamber. The pyrolysis coke is separated from inert ash and burnt together with the pyrolysis gas. The residue (char) is a combination of non-combustible materials and carbon (DEFRA 2007). Little information on the costs and operational performance of waste pyrolysis is available in the public domain.</td></tr>
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[12] Proposals listed in Howes (2012) include a 50 MW plasma gasification plant in Tees valley, UK; a gasification plant similar to Lahti Energi in London; a 12 MW plasma gasification plant in France, a proposed plasma gasification plant in Perth, UK; a proposed waste gasification plant in Bilsthorpe in UK; a $40 million gasification contract in Dallas, USA; and a US Air Force plasma gasification contract. Demonstration of three gasification plants is underway in the UK supported by ETI (see: http://www.eti.co.uk/news/article/eti_announces_shortlist_of_companies_in_2.8m_competition_to_design_energy_f).

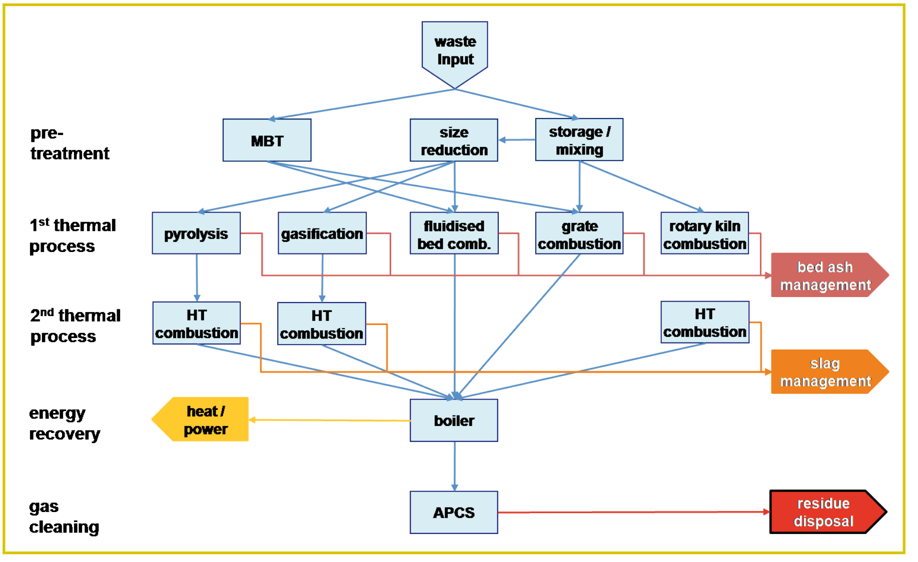

Figure 6 Common configurations for energy from waste plants

HT: high temperature

APCS: air pollution control system.

MBT: mechanical and biological treatment

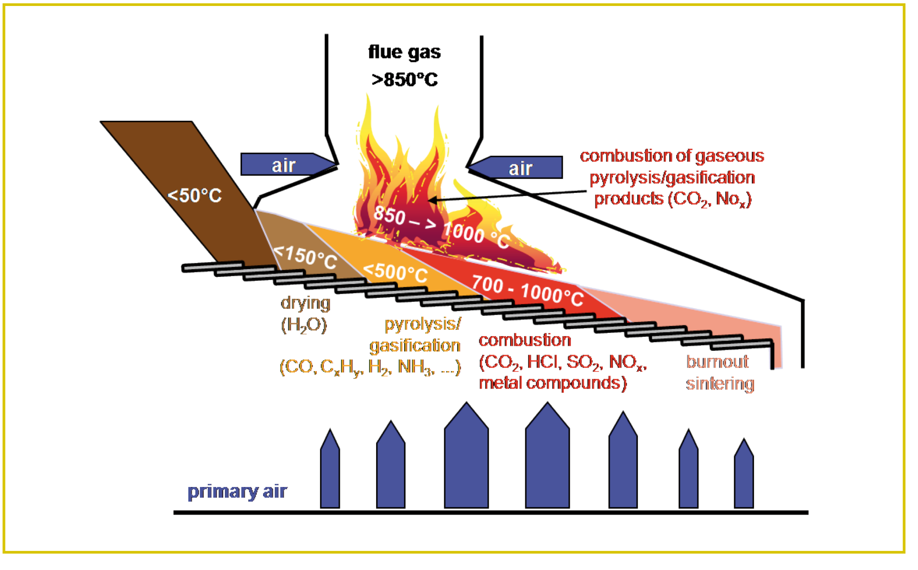

Figure 7 Principles of combustion in a grate furnace

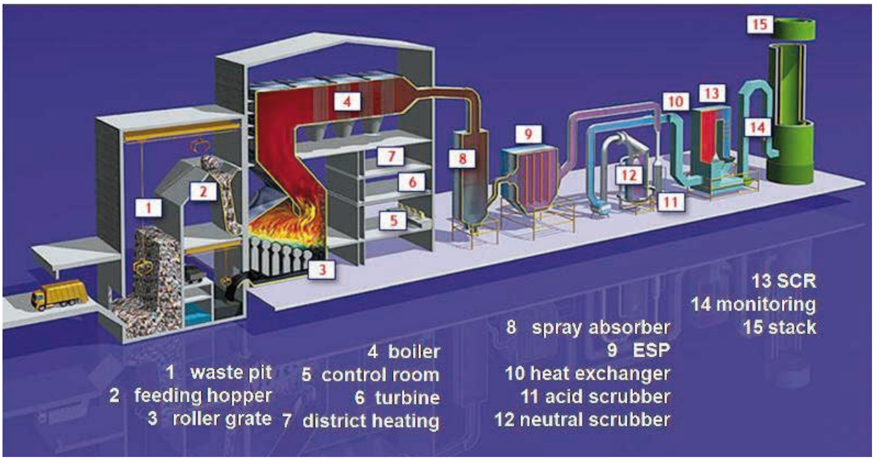

Figure 8 Flow diagram of a MSW grate incinerator equipped with a roller grate, parallel flow combustion chamber, horizontal boiler, wet scrubbing with a spray dryer and SCR for NOx abatement (Offenbach, Germany)

ESP: Electrostatic precipitation (for particulate removal)

SCR: Selective catalytic reduction.

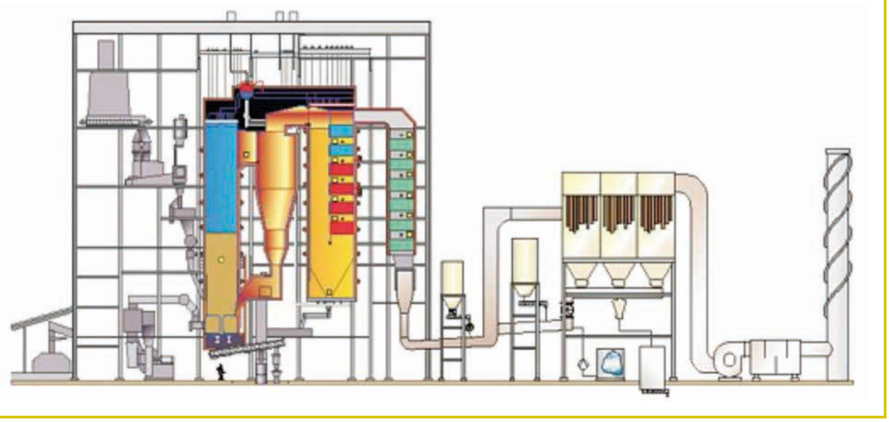

Figure 9 Flow diagram of Norrköping FB incineration waste plant

Other types of EfW plants

It is possible to integrate a number of waste management processes to optimise environmental benefits such as decreased carbon emissions, optimised resource management and energy recovery. The most commonly proposed configuration in Europe is the combination of mechanical and biological treatment (MBT), for example anaerobic digestion with combustion of the residues. Task 36 examined these options in 2012 (Schüssler 2012) and found that energy performance could indeed be improved using such configurations and that use of advanced technologies such as gasification may be advantageous, but that data on gasification is too poor to allow the energy and environmental performance to be realistically assessed.

An alternative option involves the production of biofuels from waste. There are a number of plants in pilot or demonstration stage in North America and the EU. Examples are listed in Box 4. The principle behind many of these processes is "hydro-pulping"[13] of the waste followed by separation of the plastics, glass and other inorganic components, and use of the organic fraction as a feedstock for bioethanol or other biofuel production. The number of proposed fullscale plants is increasing. One attraction is the potential to produce high value chemicals such as solvents, polymer coatings and adhesives in addition to transport fuels. However, as with advanced thermal combustion, more data on energy balance and operational parameters, including environmental performance, is required.

Box 4 Demonstration and proposed biofuels from waste plants

Bluefire (USA): Cellulosic ethanol from the organic fraction of post-sorted MSW. Three plants in planning (2x19 Mgallons/y and one at 3.9 Mgallons/y). Lignin from one plant will be combined with wood to make wood pellets for the EU market[14].

Fiberight (USA): pre-sorting in MBT prior to pulping of the organic residual fraction and fermentation of this fraction to ethanol. Pilot plant in operation. Four full-scale plants proposed. http://Fiberight.com

Enerkem (Canada & USA): production of methanol and ethanol from non-recyclable, non-compostable MSW. Demonstration (100,000 dry tonnes of sorted MSW, expected to be operational in 2013). Developing commercial scale plants for MSW and wood residues to ethanol.

13 The term 'hydro pulping' is commonly used and rarely defined. It generally refers to a process in which organic material is slurried, enabling breakup or pulping of the organic material and separation from the heavy and light non-organic fractions.

14 http://www.biomassmagazine.com/articles/9502/bluefire-renewables-adds-pellet-production-to-miss-facility

Box 4 Demonstration and proposed biofuels from waste plants *continued*

Ineos Bio Waste Vero Beach (USA): gasification of vegetal and municipal waste followed by fermentation to bioethanol. Production started in August, 2013. Expected production: 30 ML cellulosic ethanol and 6 MW electricity.

Dong Energy (EU): Renescience waste refinery (demonstration plant). Liquefies waste, followed by recycling of non-degradable fractions and flexible use of organic fraction (currently for biogas production).

PERSEO project (EU): second generation bioethanol production from municipal waste after pre-treatment using thermochemical treatment of waste, followed by fermentation to bioethanol. Preliminary work undertaken on lignocellulose such as cereals (http://www.biofuelstp.eu/spm2/pdfs/PERSEO_presentation.pdf)

Abengoa (EU): Demonstration of bioethanol from municipal waste. Plant proposed (Seville) to process MSW to 28 ML bioethanol. The process involves production of organic fibre from the municipal solid waste and fermentation and enzymatic hydrolysis for bioethanol production.

Figure 10 Ineos Bio's Vero Beach plant in construction, August 2012

(Courtesy Ineos Bio)

Summary

In this paper we have reviewed the implementation of EfW globally. This is a well established bioenergy technology commonly applied to a wide range of wastes, which delivers valuable renewable energy. It can be used as part of a strategy to enhance the recovery of biodegradable resources in waste, to divert waste from landfill and to reduce greenhouse gas emissions. Analysis shows that deployment is likely to increase over the coming decade, particularly in emerging economies.

Modern EfW is deployed typically within a policy framework aimed at effective and efficient waste management, combining environmental, social and economic drivers. To date major drivers have been improved sanitation, energy generation and diversion of waste from landfill, but new drivers related to carbon management and the management of commodities are becoming important. For EfW to be successful, consideration of local culture, waste arisings, the nature of the waste and local infrastructure are important.

We have reviewed the major relevant technologies and the most common type of plant remains conventional combustion using moving grate technology. Advanced thermal treatment options are of increasing interest because of their potential to deliver flexibility in end products, such as biofuels and high value chemicals, as well as heat and power. However, the information available on performance is limited and commercial viability often remains unproven.

EfW continues to evolve and to face new challenges. These include technological challenges resulting from changes in waste management that affect the feedstock for EfW, overcapacity of existing EfW facilities in Europe (Berthoud 2012) and negative public perception globally.

Future drivers are also evolving. Carbon emissions are becoming increasingly important in the EU (particularly in the use of solid recovered fuels and of heat). There is also increasing interest in the development of high value commodities from waste, including high value chemicals and biofuels. These issues and more are being examined by IEA Bioenergy Task 36. Recent topics examined include methodologies for demonstrating the biogenic content of waste; the management of ash residues from EfW plants; the impact of anaerobic digestion on EfW and the development and use of SRF. For further information refer to www.ieabioenergy.com.

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