IEA Bioenergy

Accomplishments from IEA Bioenergy
Task 36:
Integrating Energy Recovery into Solid Waste Management Systems
(2007-2009)

End of Task Summary Report

Lakeside Energy from Waste Plant, UK

CONTENTS

The CD attached to this Summary Report contains a copy of the complete Task Report including all four chapters in detail and an additional appendix of observations on the operation of waste treatment technologies in Japan at the Task 36 meeting in Fukuoka, Japan, in November 2009.

INTRODUCTION

IEA Bioenergy

IEA Bioenergy is an international collaborative agreement set up in 1978 by the International Energy Agency (IEA) to improve international co-operation and information exchange between national bioenergy RD&D programmes. IEA Bioenergy aims to accelerate the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, to provide increased security of supply and a substantial contribution to future energy demands. The work within IEA Bioenergy is structured in a number of Tasks, which have well-defined objectives, budgets, and time frames. Further information on IEA Bioenergy can be found on www.**ieabioenergy**.com.

IEA Bioenergy Tasks

During the period 2007-2009 there were 12 ongoing Tasks:

Task 29: Socio-economic Drivers in Implementing Bioenergy Projects
Task 30: Short Rotation Crops for Bioenergy Systems
Task 31: Biomass Production for Energy from Sustainable Forestry
Task 32: Biomass Combustion and Co-firing
Task 33: Thermal Gasification of Biomass
Task 34: Pyrolysis of Biomass
Task 36: Integrating Energy Recovery into Solid Waste Management Systems
Task 37: Energy from Biogas
Task 38: Greenhouse Gas Balances of Biomass and Bioenergy Systems
Task 39: Commercialising Liquid Biofuels from Biomass
Task 40: Sustainable International Bioenergy Trade - Securing Supply and Demand
Task 41: Project 3 - joint project with the Advanced Motor Fuels Implementing Agreement
Task 42: Biorefineries: Co-production of Fuels, Chemicals, Power and Materials from Biomass
Task 43: Biomass Feedstocks for Energy Markets

Task 36: Integrating Energy Recovery into Solid Waste Management Systems

Task organisation

In October 2006, the Executive Committee of IEA Bioenergy approved a three-year work programme (for the period 2007 to 2009) on Integrating Energy Recovery into Solid Waste Management Systems - referred to as Task 36. The Task objectives included the maintenance of a network of participating countries as a forum for information exchange and dissemination. The participating countries in this current phase of the Task were: Canada, the EC, France, Germany, Italy, the Netherlands, Norway, Sweden and the United Kingdom.

The National representatives of the Task are noted below and their contact details are listed in Appendix 1.

Canada	Rene-Pierre Allard, NRCanada
EC	David Baxter, JRC the Netherlands
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The Chair of the Task (Task Leader) was Dr Niranjan Patel (Waste Infrastructure Delivery Programme, Defra, UK).

The Operating agent was Kieran Power from the Department of Energy and Climate Change (UK).

The principal contributors to the four chapters that comprise this report were:

Chapter 1	Rene-Pierre Allard, NRCanada; David Baxter, JRC; Elisabeth Poncelet, Ademe; Helmut Seifert and Juergen Vehlow, KIT; Giovanni Ciceri, ERSE; Timo Gerlagh, NL Agency; Michael Becidan, SINTEF; Evalena Blomqvist, SP; Pat Howes and Jim Poll, AEA
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Chapter 3	Judith Bates, AEA
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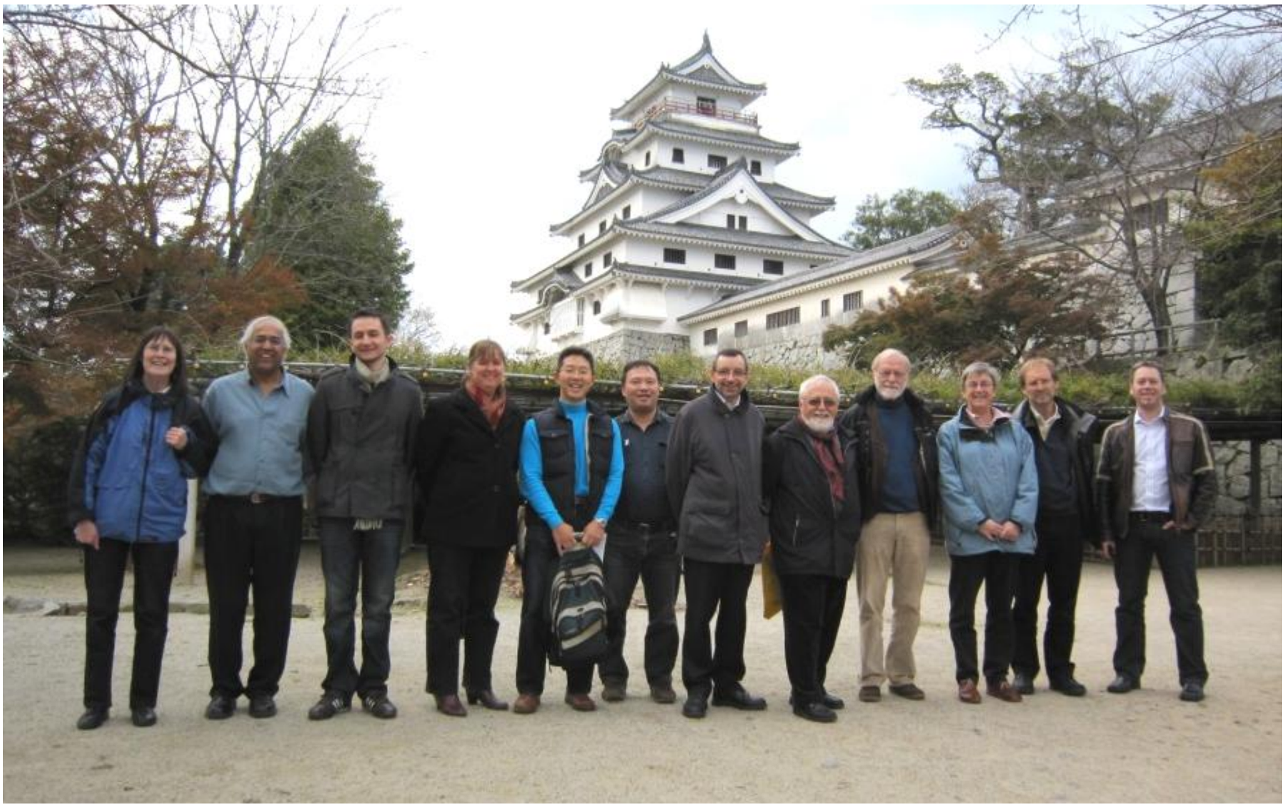


Task 36 Members in Fukuoka, Japan

Aims and objectives of Task 36

The potential for exploiting Municipal Solid Waste (MSW) as an energy resource is at a crossroad. Within the EU, the main driver for diverting waste from landfill is the Landfill Directive. The waste can either be recycled (so recovering its inherent energy value) or energy can be extracted directly from the remaining residual waste. In terms of meeting the Landfill Directive, EU member countries fall into one of two groups: those that already meet the requirements of the Directive - because they have highly developed waste management infrastructure and so consign the minimum to landfill; and those that do not meet the Directive and so provide the greatest opportunity for energy recovery. The former group of countries include Germany, Denmark and the Netherlands. The latter group includes the southern European nations, Scandinavia, the UK and Ireland.

Internationally, developed nations such as Canada, USA and Australia continue to rely on landfill and do not as yet have policy measures such as the EU Landfill Directive. Rather, they rely principally on the economic driver for waste diversion. The potential for energy recovery in these countries is therefore high, though institutional and other non-technical barriers pose considerable challenges.

The last decade has seen considerable efforts in research work on waste management - including policy development, environmental systems analysis, technology development and economic drivers. Whilst this has assisted in the development of waste management systems in many cases, it has also delayed deployment of energy recovery systems in particular due to confused policy making, public awareness (and opposition) and uncertainty over environmental performance and technology performance. Policy makers require guidance and information on all these aspects if waste and resource management systems that are environmentally and economically sustainable are to be developed. It is the aim of this IEA Task to collate some of the most relevant recent research work and to produce a concise report for the benefit of the waste and resource management sector.

The Task has focused on four key areas:

1. The MSW resource
2. Waste and resource management policy
3. Environmental considerations
4. Technology

This report provides a summary of the work undertaken by the Task.

The future

IEA Bioenergy Task 36 will continue to promote information exchange and deployment of environmentally sound energy recovery technologies and to stimulate interaction between RD&D programmes, industry and decision makers.

Further information

For further information on Task 36, contact the Task Leader for the next phase of work (2010 - 2012):

Dr Patricia Howes
e-mail: pat.howes@aeat.co.uk
and visit the Task 36 website at www.ieabioenergytask36.org

For further information on IEA Bioenergy, contact the IEA Bioenergy Secretary:

John Tustin
e-mail: jrtustin@extra.co.nz
and visit the IEA Bioenergy website at www.ieabioenergy.com

EXECUTIVE SUMMARY

Summary of chapter 1: status of solid waste management in task member countries

Introduction

This chapter details the solid waste management practices in the IEA Task 36 member countries in terms of policy, actual practice, and trends for the future (to 2020). The country specific reports include details on:

- national policy/strategy on waste management and the recovery of energy from waste;
- data on the historical arisings and management of solid waste;
- factors affecting waste growth, and estimates the solid waste arisings in the future;
- the potential for increasing the amount of energy which is recovered from solid waste.

The summary below draws on data from a wider source (i.e. from more than just the Task 36 Membership) in order to give a more global perspective where relevant and also focuses on the treatment of the residual waste stream for energy recovery (energy from waste - EfW).

Definition of MSW

The key for designing waste management systems for countries, regions, or municipalities is knowledge of the amount and quality of waste arising. Data are found in various statistics on all levels, collected by local, regional, national, and international organisations like UNEP, OECD, or Eurostat. The problem with these statistics is the inconsistent basis of the data sources, which makes comparison between regions difficult.

Most national and international statistics contain generation and, rarely, composition data for MSW. Unfortunately, there is no common definition of this type of waste and hence, for example, the OECD statistics are characterised by numerous footnotes indicating which waste fractions are included in the actual data. The following illustrates some of the definitions used for MSW:

OECD: ‘In general, municipal waste is waste collected and treated by or for municipalities. It covers waste from households, including bulky waste, similar waste from commerce and trade, office buildings, institutions and small businesses, yard and garden waste, street sweepings, the contents of litter containers, and market cleansing waste. The definition excludes waste from municipal sewage networks and treatment, as well as municipal construction and demolition waste.’

‘Household waste is waste generated by the domestic activity installations of households. It includes garbage, bulky waste and separately collected waste.’ [OECD 2002].

U.S. EPA: ‘EPA includes those materials that historically have been handled in the municipal solid waste stream and sent to municipal landfills. MSW includes wastes such as product packaging, newspapers, office and classroom papers, bottles and cans, boxes, wood pallets, food scraps, grass clippings, clothing, furniture, appliances, automobile tires, consumer electronics, and batteries.’ [U.S. EPA 2004]

‘Household Waste (Domestic Waste): Solid waste, composed of garbage and rubbish, which normally originates in a private home or apartment house. Domestic waste may contain a significant amount of toxic or hazardous waste.’ [U.S. EPA 1997]

‘Residential Waste: Waste generated in single and multi-family homes, including newspapers, clothing, disposable tableware, food packaging, cans, bottles, food scraps, and yard trimmings other than those that are diverted to backyard composting.’ [U.S. EPA 1997]

From the definitions it is obvious that household waste and domestic waste are the same material. Another synonym is often ‘residential waste’, but the EPA definition makes no clear statement in that case.

‘Commercial Waste: All solid waste emanating from business establishments such as stores, markets, office buildings, restaurants, shopping centers, and theaters.’ [U.S. EPA 1997]

IEA: For the IEA, waste is only of interest in view of its energy inventory and - for IEA Bioenergy - also for its biogenic energy fraction. The definition for MSW is: ‘Municipal waste consists of products that are combusted directly to produce heat and/or power and comprises wastes produced by the residential, commercial and public services sectors that are collected by local authorities for disposal in a central location. Hospital waste is included in this category.’ [IEA 2007]. Here again, the last waste type is excluded in most definitions.

EU: The European Commission issued a waste list in 2000 which defines under code 20 ‘Municipal wastes and similar commercial, industrial and institutional wastes including separately collected fractions.’ Code 20 01 ‘Separately collected fractions’ lists paper, wood, textiles, glass, metals, and organic kitchen waste and also hazardous fractions like acids, photo chemicals and others. The latter ones, however, are typically summarised as hazardous household waste in Eurostat or OECD statistics. Code 20 02 ‘Garden and park waste’ comprises compostable waste, soil and stones, and other non-compostable waste. 20 03 ‘Other municipal waste’ covers mixed municipal waste, often called ‘residual waste’, and waste from markets, street cleaning, and septic tanks. [European Commission 2000]

Eurostat, the statistical office of the European Commission, and the national statistical offices of the EU member states compile annual statistics on MSW and household waste, but do not always indicate which waste fractions are separately collected. Commercial waste is only included as long as the material is similar to household waste. Such waste is under the regime of the public waste management system, other waste from commerce, trade, and industry has to be taken care of by the producer himself.

According to the above listed definitions, MSW comprises waste from various sources. Some of these waste streams, like yard and garden waste, are more uniform in composition than others such as waste from commerce and trade or from office buildings. From this perspective, residential waste, the waste generated in private homes, should be the most inhomogeneous and hence, for the purposes of treatment, probably the most difficult type of waste to manage.

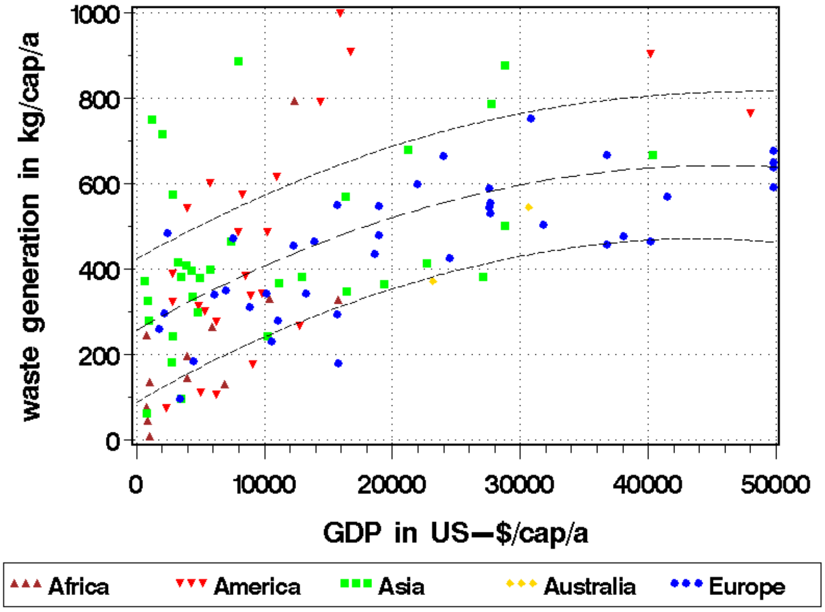
Our focus in this report has been on examining the management of MSW and more specifically on *residual* MSW. MSW is the waste typically collected and managed by local municipalities, i.e. it is predominantly the waste generated by households and collected from households or from areas to which households have access to deposit their waste. It also includes wastes of a similar nature derived from the commercial and industrial waste sector.

Residual MSW is the waste remaining after recyclable materials have been extracted - typically by the householder taking part in source segregated collections.

Generation and composition of MSW

The huge variation of waste data at local level does not mean that regional and national statistics should be regarded as pure guesses. In evaluating the available information, it would appear that the single (MSW) statistics do bear some correlation with other parameters - particularly with the economic situation of a country. On a global level, a good correlation appears to exist between the generation of MSW and the gross domestic product (GDP) of a country. The data plotted in Figure 1 have been collected from several public statistics and scientific publications. European figures date from 2006 or 2007; those from other industrialised countries may go back to 2000 - 2005 and, for some developing countries, data before 2000 are included.

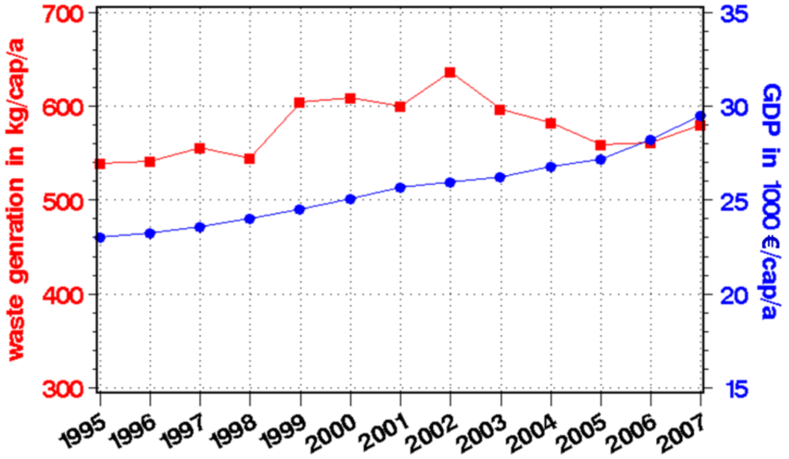
Figure 1: Waste generation versus GDP in 111 countries (fit with 70% confidence limit)



The calculated correlation between the waste generation data and GDP is surprisingly good. This positive correlation leads to the conclusion that economic growth changes consumption patterns and results in higher rates of per capita waste generation.

Decoupling of economic development and waste generation is a major objective in industrialised countries. Policy is driven towards the aims of reducing the amount of waste and diverting reactive waste from landfill. The EU with its many Directives regulating waste disposal is a forerunner towards such goals. Some successes can be noted in terms of reducing landfill, but few countries have been successful at reducing or at least to keeping their waste generation figures constant over the past years. One example where waste reduction has been achieved is Germany (Figure 2).

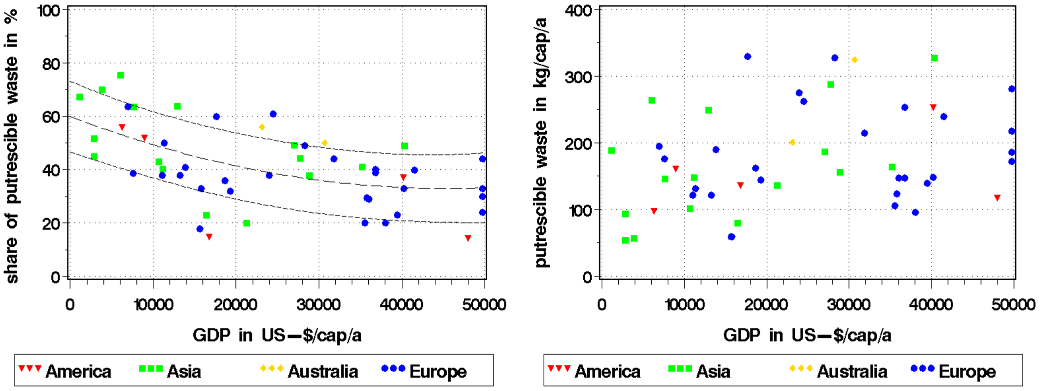
Figure 2: Decoupling of waste generation from economic output in Germany [Umweltbundesamt 2008 - data from Statistisches Bundesamt Deutschland]



A rather good correlation with the GDP is also reflected in the share of food or biodegradable waste in MSW as can be seen in the left hand graph of Figure 3. This correlation is usually explained by reference to the different ways of preparing food: poorer countries live less on prefabricated food and prepare their meals more from fresh food, which causes higher amounts of waste in residential homes. However, keeping in mind that MSW usually also comprises waste from restaurants, small businesses (including food preparing enterprises), canteens, etc. this argument is not necessarily convincing.

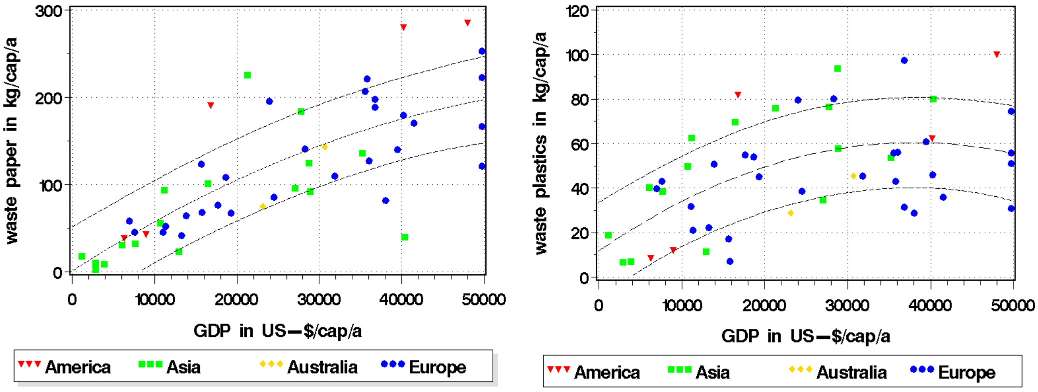
In reality, this explanation does not hold if the absolute amount of this waste is considered. The right hand graph in Figure 3 shows the per capita generation of food and other biodegradable waste plotted against the GDP for 52 countries. The result is a broad scattering of values without any discernable trends. The data for all countries from all continents seem to vary in the same broad range which means that the poor countries do not discard more food waste, but - and this makes much more sense - have not much else to throw away.

Figure 3: Percentage of biodegradable waste fraction versus GDP (left) and per capita generation of biodegradable waste (right) for 52 countries



This fact is underlined by the characteristics of paper and plastic generation data which are depicted again against GDP in Figure 4. The amount of paper correlates rather well with the GDP whereas the correlation for waste plastics is much weaker. The almost uniform distribution of plastics indicates the extent of their use across the globe.

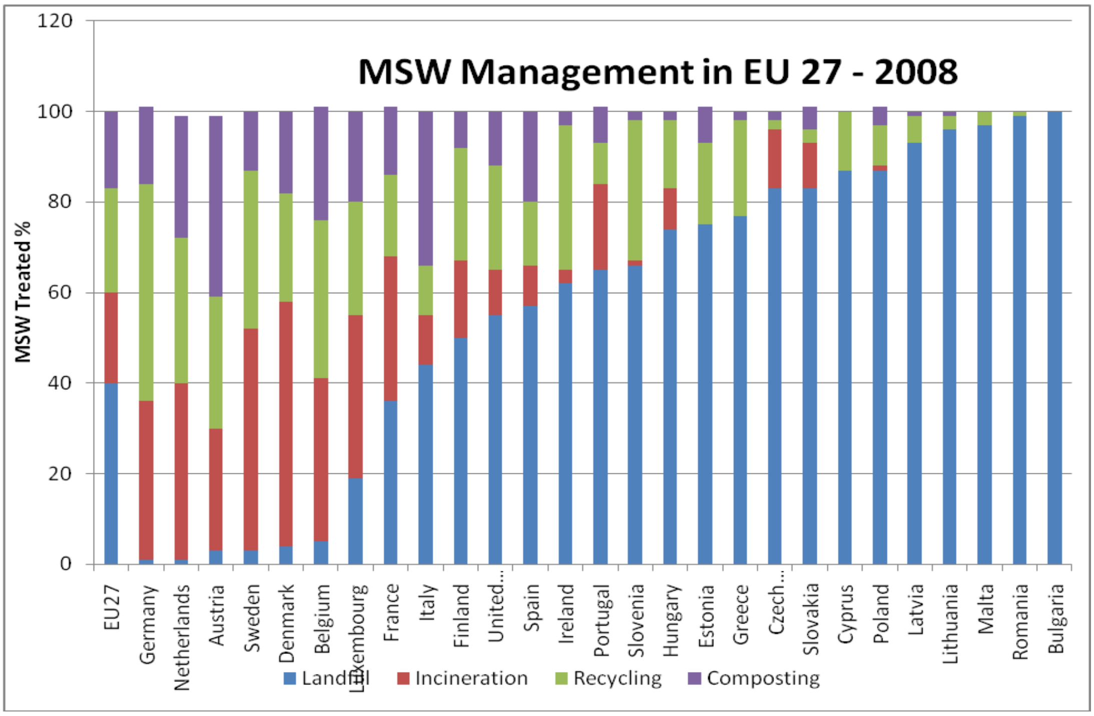
Figure 4: Per capita generation of waste paper (left) and waste plastics (right) versus GDP for 52 countries



Management of MSW

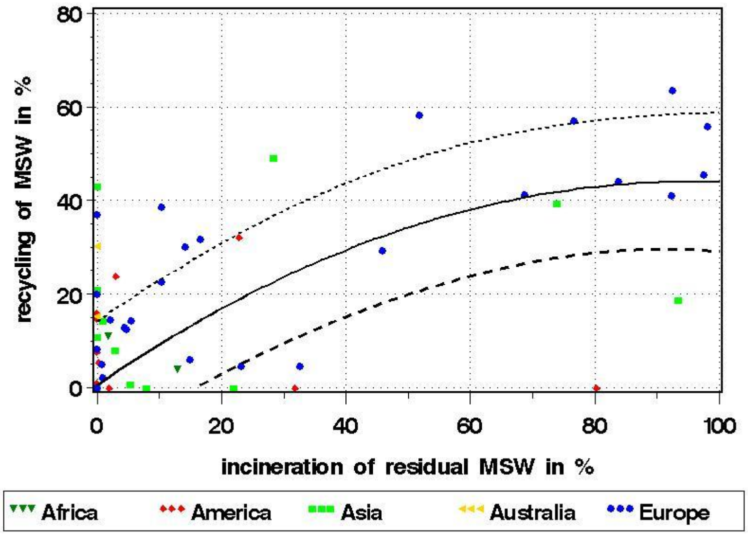
Figure 5 collates (Eurostat) 2008 data for EU27 and shows the destination of MSW to either recycling/composting (or similarly recovered), incineration (energy recovery) and landfill. The EU27 countries are ordered in terms of increasing landfill usage and show Germany at the top with the least tonnage to landfill and Bulgaria at the bottom with virtually all waste consigned to landfill. Norway and Canada are of course not included in these statistics but with landfill levels of approximately 25% and 80% they would appear above France and the Czech Republic respectively.

Figure 5: MSW management in EU27 (2008)



The level of incineration in EU27 was approximately 20% with the highest level recorded by Denmark (50%). Some have argued that waste incineration impedes recycling. However, an evaluation of data in Figure 5 and other wider statistical data does not support such arguments. Figure 6 correlates the incinerated fraction of residual waste - that waste which is left over after all material recovery activities - with the recycled and composted fraction of the total MSW stream. It is evident that most countries with high recycling also tend to have high levels of waste incineration (in almost all cases with energy recovery) for their residual waste prior to its final disposal.

Figure 6: Recycling and incineration of MSW

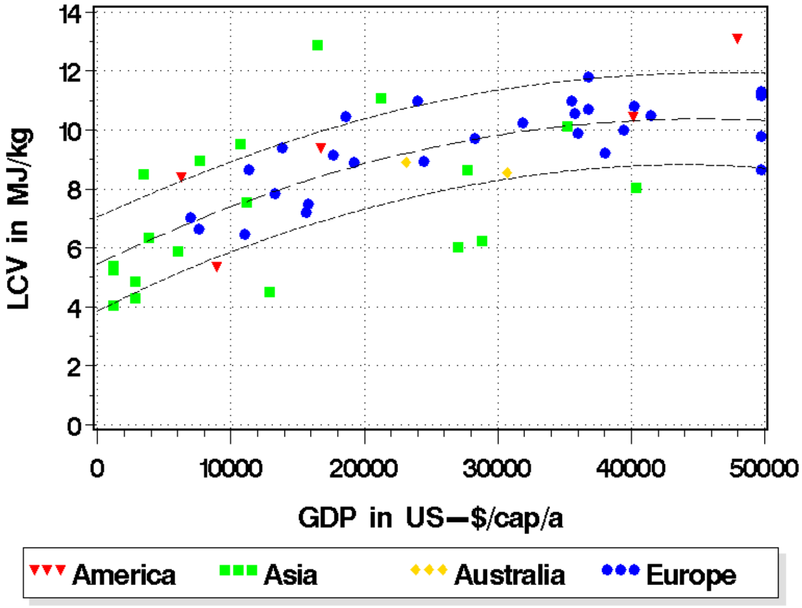


Energy recovery

Feedstock

The feedstock for thermal EfW systems can be the residual MSW as received or a processed product (SRF - Solid Recovered Fuel - meaning waste treated to produce a fuel fraction that can be transported to an off-site user) derived from residual MSW. The energy content of the feedstock is expressed as the lower calorific value (LCV) and covers a wide range. For residual MSW, in developing countries, it is of the order of 2 - 5 MJ/kg and in industrialised countries of the order of 8 - 12 MJ/kg. A good correlation exists between the LCV of MSW and the GDP of a country (Figure 7). A LCV of 6 MJ/kg is needed for the safe operation of thermal EfW systems and this is a level that is reached in many countries.

Figure 7: Correlation between LCV and GDP



SRF is characterised by higher LCV, lower contamination, and better homogeneity. SRF is produced in a number of industrialised countries to substitute fossil fuel in industrial furnaces, or for use in other high efficiency combustion systems. SRF is mainly produced in mechanical biological treatment (MBT) or mechanical treatment (MT) plants: metals are separated for recycling, organics are diverted for composting or anaerobic digestion, the high calorific fraction is separated for SRF, and residual inert materials are consigned to landfill or used in low value recovery processes such as landfill cover.

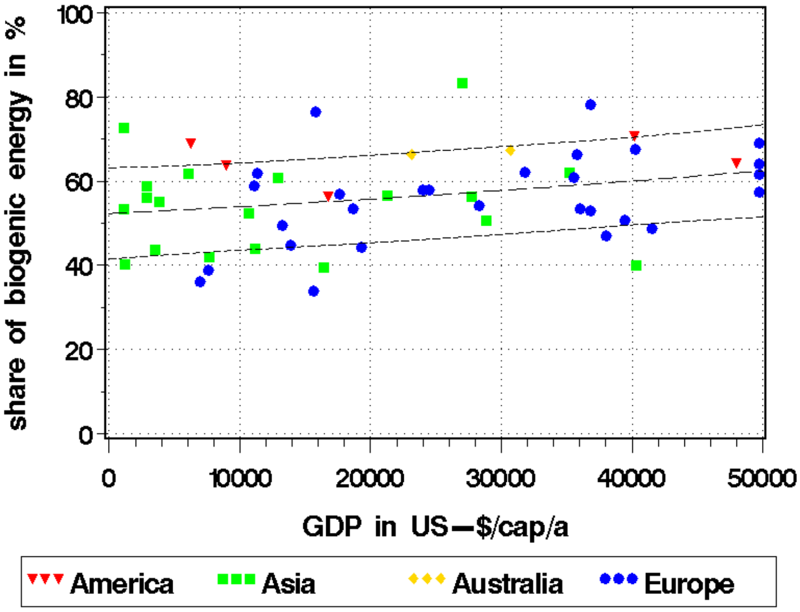
Various types of SRF are on the market to comply with process requirements and applicable legislative requirements. The conversion rate from MSW to SRF is typically 20 - 55% depending on product quality. Some plants produce a high-grade SRF together with a low calorific combustible residue, which is destined for waste incineration. In some countries, quality labels for special SRF types have been established, and on an EU level, EN-standards are under development. The main problem in utilisation of SRF from mixed MSW is the presence of pollutants, especially chlorine and heavy metals. Hence SRF, is mainly produced in countries with well developed MSW source separation and recycling.

The LCV of SRF from MSW is of the order of <15 - 20 MJ/kg. SRF/RDF with LCV >20 MJ/kg is virtually only produced from well-defined residue streams from trade and industry. SRF production and utilisation figures are vague in many countries due to rapid on-going changes in the waste management industries. In the US, approximately 6 Mt out of 30 Mt of incinerated MSW is SRF. Japan operates approximately 50 MBT or SRF plants with a capacity of 4.2 Mt/a. The exported material for incineration is of the order of only 0.4 Mt/a. In the EU, 3 - 4 Mt/a SRF is produced in more than 50 plants with a total capacity of >6 Mt/a.

Biogenic content

A significant fraction of the municipal solid waste stream is of biogenic origin: food and garden waste, wood, paper and to a certain extent, also textiles and diapers. Assessing the waste composition data with the amount of biogenic energy per waste fraction allows an approximate calculation of the share of biogenic energy in the waste. The results of such calculations are depicted in Figure 8. For most EU countries (and all of the Task 36 countries) the biogenic energy content is about 50%.

Figure 8: Share of biogenic energy in waste as a function of GDP (quadratic fit, 70% confidence limit)

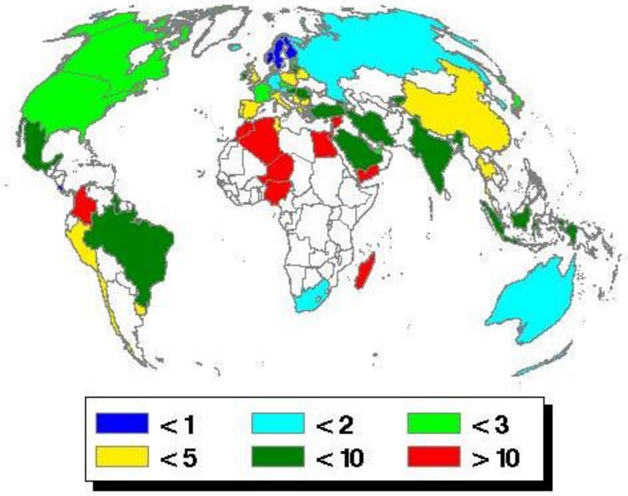


The fact that a certain fraction of the energy in waste is of biogenic origin has been acknowledged by some European countries, such as the Netherlands, Denmark and Finland. In these countries, power generated in waste incineration plants is rewarded by tariffs partly subsidised according to the national renewable energy acts. In other countries (e.g. UK, France, Sweden, Italy, Canada, Norway and Germany) even if the energy generated from waste is not supported by such tariffs, it is acknowledged in the collation of national and EU statistics for renewable energy.

Apart from the revenue support that may flow from the recognition of the biogenic energy inventory in MSW there is also beneficial consequence of the fact that the CO_2 emitted during combustion of this fraction is climate neutral.

The potential for MSW to replace fossil fuel in the power market for selected countries is shown in Figure 9. Even in highly industrialised countries, MSW can supply 1 - 2% of the power demand, a share that should not be underestimated. For the time being, this potential is far from being exhausted in any country. The actual number for Germany is in the order of 0.7% [CEWEP 2008], but it has to be expected that here, and at least in other EU countries, much higher values will be reached in the near future.

Figure 9: Potential of residual MSW to replace fossil fuel in the power market for selected countries, given in % of power supply



Task 36 member country reports

From the individual country reports, a number of common themes can be identified:

1. All countries are guided by a waste hierarchy in their policy - in broad terms, this is waste prevention, reuse, material recovery, material recycling and energy recovery, all of which take priority above final disposal (landfill). The waste hierarchy informs policy development aimed at decreasing waste to landfill and setting out the role of energy recovery (energy from waste).

2. In line with the waste hierarchy, the principal waste management policies are built around the desire to decrease landfill and improve resource recovery - whether materials and/or energy. These policy measures include a combination of fiscal incentives, such as taxes on materials destined for disposal to landfill, and regulatory measures, such as landfill bans on specific waste streams, for example biodegradable (food) and combustible and/or recyclable wastes.

3. At both national and local level, waste policy is frequently targeted at supporting separation, recycling and recovery activities. All of the IEA T36 Member countries have set targets for recycling and all (except Canada) have reported declining levels of waste to landfill and progressively increasing rates of recycling. Some countries (Germany, Netherlands) have clearly managed to break the link between GDP and waste growth.

4. Public perception of incineration (energy from waste) remains a concern in many countries. However, where there is a proactive programme of communications and public participation in decision making, much of the negative perception of EfW (and residual treatment technologies in general) can be mitigated. There has been a strong policy emphasis in response to public concern by, for example, applying more stringent emissions regulations and also to improving energy utilisation, i.e. improving energy efficiency through the generation of electricity and/or heat (combined heat and power).

5. Energy from waste makes a significant contribution to renewable energy in many countries. Increasingly, renewable policy is designed to encourage the recovery of energy from biodegradable wastes that cannot be recycled, composted or digested

and to encourage efficient recovery of this energy. Hence the utilisation of heat should be promoted wherever possible, although negative public perception sometimes results in facilities being sited away from urban areas where there is the demand for heat.

6. There is an increasing trend towards the use of separation technologies for mixed waste followed by composting or anaerobic digestion of the biodegradable fractions - sometimes driven by public opposition to direct combustion of waste. Pre-treatment of residual waste often results in a final fraction of waste that is usually not recyclable/reusable but nevertheless contains residual energy value. Pre-treatment can also produce a paper/plastic combustible fraction sometimes referred to as solid recovered fuel (SRF). Increasingly, waste management systems are required to treat this waste; options include co-incineration in cement kilns, co-firing in power stations (this option depends on the design of the power station) or incineration in a dedicated facility.

7. The European nations are obliged to comply with various EU Directives, e.g. the Waste Framework Directive and the Waste Incineration Directive. These Directives provide a common framework for the EU nations, but when transposed to national policy, there remain wide diversions in the way in which that national policy has developed and in the management of waste in each country. Perhaps, not surprisingly, it is the local conditions, policy priorities and economics that determine the development of the waste management systems and the uptake, in particular, of energy from waste technology.

In terms of future trends, it is possible to conclude that:

- There will be less biodegradable (and combustible?) waste consigned to landfill in the future.
- Most Member countries project that waste production will continue at current or slightly increased levels, indicating that measures to reduce waste arisings are starting to make a gradual impact.
- For those countries that currently rely on landfill, it is likely that the utilisation of energy from waste will expand but that the final deployment rate achieved is uncertain as there are still significant barriers to overcome, e.g. cost effectiveness, public concern, development timescales and planning/facility location issues.
- The utilisation of heat (for heating or cooling purposes) is likely to play a greater role in the future, but this potential will depend on siting issues (developing plants close to heat users) and overcoming other barriers, such as developing infrastructure (heat networks) and cost.
- Anaerobic digestion (AD) is likely to play a greater role in the future as many countries look to segregate this waste stream (food waste) at source.
- Further debate on the biogenic nature of MSW is likely to influence policy making and have practical consequences, for example, in the measurement and monitoring of wastes for this parameter.

Summary of chapter 2: energy recovery from MSW (one step further)

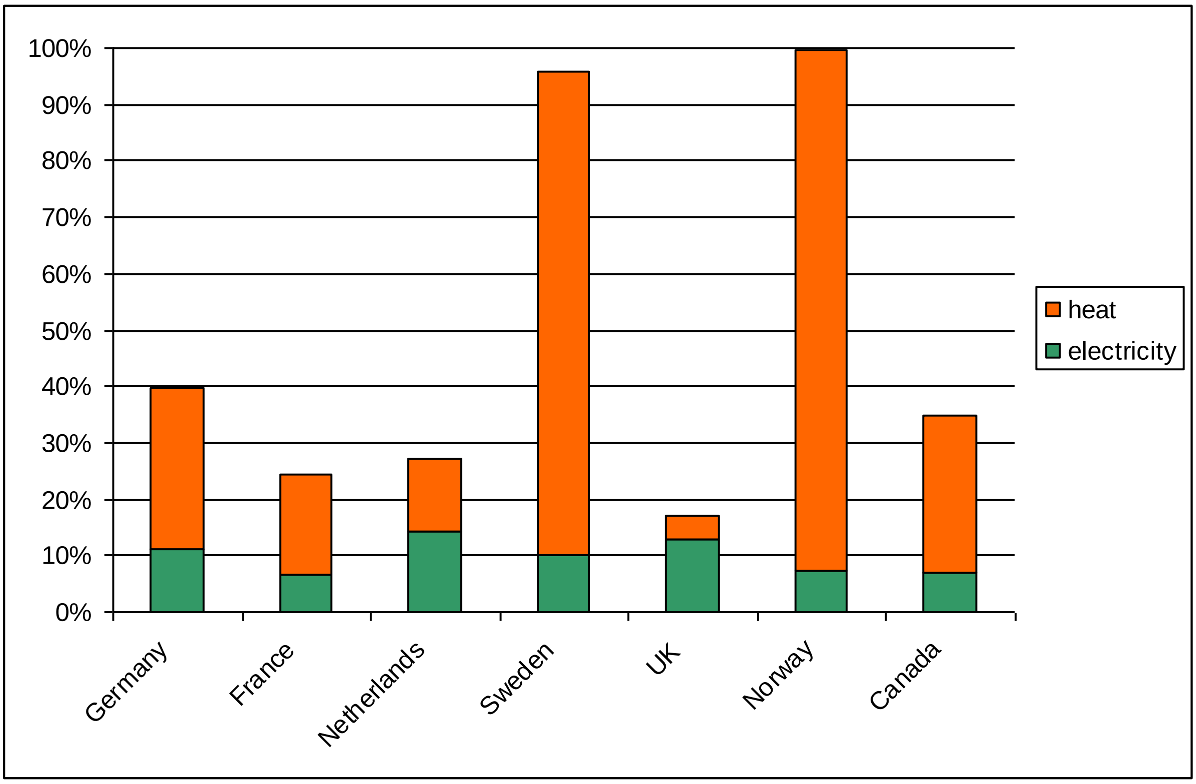
Within the current phase of the IEA Bioenergy Task 36, special attention has been paid to the subject of how to optimise, and thus extend, the application of energy recovery from MSW from the point of view of policy makers. An assessment of drivers and barriers to energy recovery was carried out in each of the countries of Task 36. Based on these assessments, a workshop, organised by Umweltbundesamt, IEA Bioenergy Task 36 and NL Agency (formerly SenterNovem), was held at DECHEMA on April 14 2008 in Frankfurt, Germany.

At the workshop, the experiences in the different countries were shared and recommendations for the promotion of energy recovery from MSW were discussed. Chapter 2 summarises the results of the country assessments and the workshop and recommendations on how to promote energy recovery from MSW in a more effective way are presented. It is not the intention of Chapter 2 to present the outcome of scientific-based research, but more to reflect the results of the workshop presentations and discussions.

The ten most significant lessons learned from the workshop may be summarised as follows:

1. In the countries assessed, the introduction of the EU Directive on the landfill of waste has resulted in a reduction of the amount of waste being sent to landfill and an increase in recycling and EfW.
2. In the waste hierarchy, recycling is given higher priority than EfW - EfW must complement and not displace recycling activities.
3. Drivers for the promotion of EfW (the Landfill Directive and the desire to reduce CO_2 impacts) are the same throughout the countries assessed.
4. Barriers to EfW vary from country to country, as does the rate of EfW utilisation.
5. Policies can change quicker than EfW project development time, thus frustrating projects.
6. Policies need to address the tension in the market between solid recovered fuels (SRF), mechanical-biological treatment (MBT) and EfW.
7. Political will on utilisation of waste heat is often high, but doesn't always lead to subsequent market development; Figure 10 demonstrates the differences in heat utilisation between the Scandinavian countries (high utilisation) and others.
8. Since waste management systems are capital (investment) intensive, long-term (contract) security is crucial.
9. More consideration is required to spatial planning (i.e. making room for EfW) -this is a significantly underestimated policy element.
10. There is a lack of trust between the proponents of EfW and non-governmental organisation (NGOs) and interaction between them is often problematic.

Figure 10: Energy recovery from waste incineration as a percentage of the heat content of the input



Summary of chapter 3: impacts of managing residual municipal solid waste

A wide range of options are available for treating the residual component of MSW, i.e. the waste that remains after source separation of recyclable fractions. These range from combustion based techniques to biological processes, such as anaerobic digestion and composting. There are also systems which combine elements of both, using sorting techniques to recover recyclable materials such as metals, and splitting the waste into an organically based component which can be biologically treated and another fraction - a refuse derived fuel (RDF also sometimes referred to as SRF) - which can be combusted.

A life cycle waste management software tool was used to see whether different types of options for managing residual waste offer particular environmental benefits and whether it is possible to establish a hierarchy of environmentally preferred options. The assessment was carried out using WRATE (Waste and Resources Assessment Tool for the Environment), an integrated waste management life cycle analysis tool developed for the Environment Agency in the UK, which has been peer reviewed and is publicly available.

The following options for the management of residual waste were examined:

- EfW plant.
- Mechanical Biological Treatment (MBT) plant where recyclable materials such as metals are first separated out and the remaining waste is:
    - biodried to produce a refuse derived fuel (RDF) which is burnt in an energy from waste plant (MBT biodrying);
    - sorted into an organic component which is anaerobically digested and a fraction which is burnt in an energy from waste plant (MBT AD);
    - sorted into an organic component which is composted and a fraction which is burnt in an energy from waste plant (MBT IVC).
- Landfill with energy recovery.

The effect of recovering heat at the EfW plant was also evaluated, as were the effects of improving the levels at which energy and materials were recovered, of introducing plastics recovery into the MBT processes and of changing the type of electricity production avoided when energy is recovered.

Four key environmental impacts for which robust evaluation methodologies are available were considered: climate change, resource depletion, acidification and eutrophication. As elements of waste management common to all options (e.g. collection of the waste) were not modelled, the results can only be used to compare treatment options and do not give an absolute indication of the environmental impacts of managing the waste.

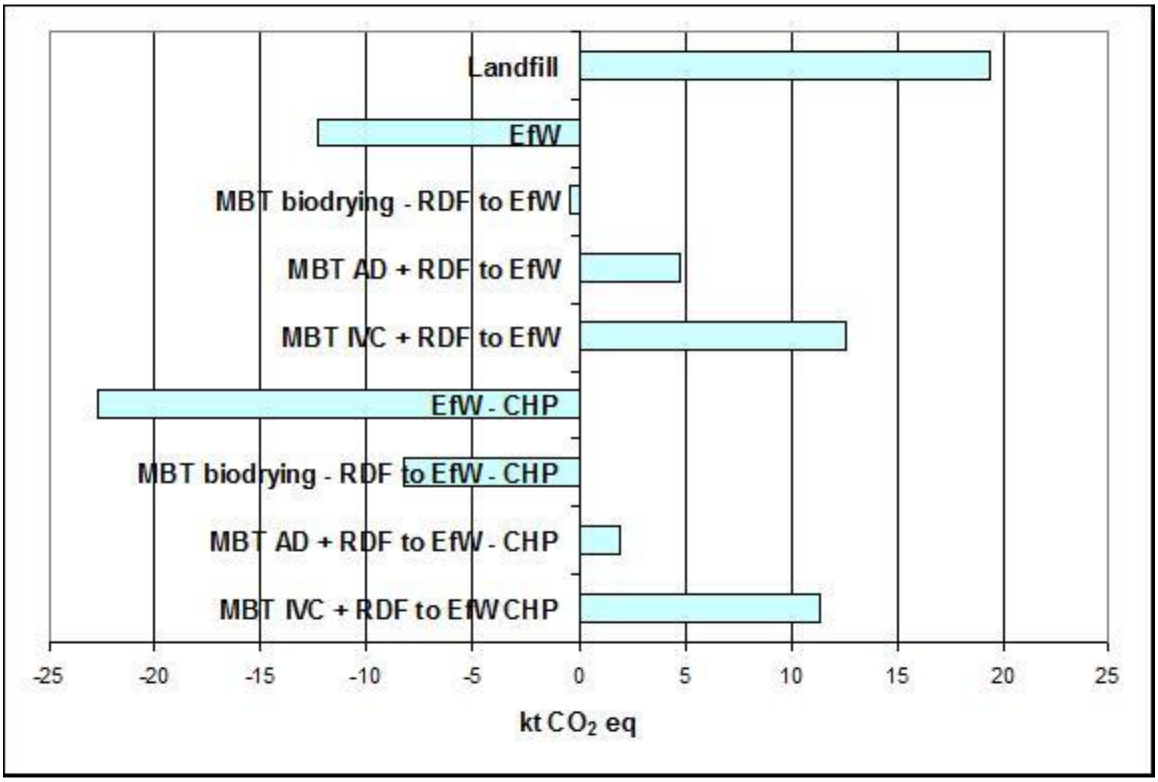
Some general conclusions can be drawn for the work undertaken:

1. All the treatment options considered had, for a typical coal/gas electricity mix, lower environmental impacts than landfill. The ranking of the non-landfill options depends on the environmental impact considered and, for some options, was also affected by the electricity mix that is displaced. While no treatment option performed best under all the cases for all impacts evaluated, overall, the EfW - CHP plant had the best environmental performance. Where there is no opportunity to utilise heat, the EfW plant had the best environmental performance overall.

2. Energy recovery and materials recovery of energy intensive materials such as metals and plastics, have significant benefits for all the environmental impacts evaluated, reducing emissions of pollutants and use of resources. They should be maximised in any waste management option that is implemented. If EfW is part of the option, whether burning MSW directly or RDF, then making the plant a CHP one reduces environmental impacts, in most cases significantly, particularly if heat utilisation is high.

3. Climate change is often a key concern and if this is the case, then an EfW plant (or EfW - CHP plant if heat can be utilised) is likely to be the best choice, whenever the electricity displaced is based on coal or gas or a coal/gas mixture, see Figure 11. However, if the energy recovered is displacing very low carbon electricity (e.g. predominantly from hydro or nuclear), then there is much less differentiation between the waste management options, and the MBT - IVC option performs best, having a slightly lower impact than the EfW plant. An EfW - CHP plant, however, has a lower climate change impact than an MBT - IVC CHP option.

Figure 11: Greenhouse gas impacts



4. In the case of depletion of resources, the EfW and EfW - CHP plant have the lowest impact, although the difference between these and other options is less pronounced for a very low carbon electricity mix. EfW also has the lowest impact when eutrophication is considered, and (together with the MBT biodrying option) has a significantly lower impact than other options even if there is improved material recovery at MBTs, or a low carbon energy mix is evaluated.

5. The environmental impact category where EfW does not perform as well is acidification, where emissions of acidifying pollutants from the process are higher than from the MBT treatment options, and the higher metal recovery rates in the MBT processes deliver substantial savings in emissions of acidifying pollutants. The MBT biodrying process generally has the lowest acidification impact, although if gas or a

low carbon electricity mix is being displaced, then the MBT - IVC process which involves the lowest amount of combustion of waste has the lowest impact.

The results of the modelling suggest that, for locations where electricity generation that is displaced comes from fossil fuels, then a waste management option based on EfW is likely to have the lowest environmental impacts overall. However, for locations where the electricity that is displaced comes mainly from non-fossil fuel sources, then an environmental hierarchy is less clear cut. While an EfW and, in particular, an EfW - CHP option still performs well in some environmental areas, MBT treatments which biologically treat most of the waste (such as MBT - IVC), can offer benefits and a more detailed analysis and decisions on the relative importance of impacts may be necessary to define which option is environmentally preferable.

Summary of chapter 4: overview of technologies used for energy recovery

Chapter 4 provides a brief description of the principal technologies applied for the treatment of residual MSW. It also covers some of the newer technologies, such as pyrolysis and/or gasification, that have been demonstrated at large scale (>100,000 t/y capacity).

In the summary below, a synopsis is provided of the current status of energy recovery technology for managing residual MSW in terms of the processes used and their cost.

Processes

Various processes are in use for energy recovery from MSW, but only the principal EfW processes with actual or future significant potential are described in Chapter 4. The most common and well-established technology (over 130 years operation) is waste incineration on inclined moving grates. Pyrolysis and gasification are practised, but are not as widely used as grate incineration. Various novel processes based on combined pyrolysis/gasification have been developed and implemented, especially in Japan. As well as direct combustion of MSW, it is also possible to co-combust MSW, or more appropriately SRF, with fossil fuel in dedicated plants or in industrial furnaces (e.g. power plants, cement kilns).

Excess air combustion processes: A modern waste incineration plant comprises a furnace, a boiler, the power generation island and an efficient gas cleaning system to meet stringent air emission standards. The most common combustion system with approximately 800 installations worldwide is based on the moving inclined grate furnace that treats MSW in an essentially unsorted state. Grates of various designs (reciprocating, roller, travelling, etc.) and size (typically 5 - 30 t/h) are in use. In some new plants, water cooled grates are used when burning MSW with a high heating value.

The furnace can also be of the fluidised bed type (stationary or bubbling, circulating, revolving systems) -there are over 100 such systems operating on MSW, mainly in Japan. Fluidised beds have special requirements concerning the particle size of the fuel and hence the MSW needs, as a minimum, shredding or some other form of pre-treatment. The throughput of fluidised bed furnaces is typically smaller than that of grate furnaces. Other types of furnaces can also be used - batch type furnaces, rotary or oscillating kilns, combinations of grates and rotary kilns, but these have a minor share of the EfW market.

The boiler efficiency of state-of-the art MSW incineration plants is typically >75% and can reach values around 85%. The boiler steam temperature and pressure (typically 400^{o}C and 40 bar respectively) are lower than in conventional power plants in order to avoid corrosion problems. As a consequence, the efficiency of power generation rarely exceeds 22% (net). European state-of-the-art MSW incineration plants report an average power generation of 0.55 MWh/t of MSW, which equates to an energy recovery efficiency of about 20% (typically 0.4 - 0.65 MWh/t). The electrical consumption for plant operation varies between 0.06 and 0.15 MWh/t with a strong dependence on plant size. Modern European plants export 0.4 - 0.5 MWh electricity per ton MSW. This figure has to be reduced by approximately 0.25 MWh/t if the bottom ashes are melted. If only heat is generated, as is widely done in North European countries, approximately 2 MWh/t MSW can be exported, which equates to 70% energy recovery efficiency. An optimised total efficiency can be accomplished if CHP utilisation is possible. A new and promising heat utilisation route is district cooling.

New boiler designs using nickel base alloys allow increased steam temperature and pressure and allow power generation efficiencies >30%. Such plants have recently been commissioned in Europe and Japan. One option to increase the power efficiency to 30 - 40% involves integration with a combined cycle natural gas turbine. At the moment, approximately 15 such plants are in operation worldwide.

Combustion and co-combustion of SRF: SRF is used as fuel in dedicated combustion plants (grate and fluidised bed furnaces), cement kilns, power plants, district heating plants, blast furnaces, and sometimes also in waste incinerators. SRF gained some interest in Germany in the last few years, especially after the EU Landfill Directive set limits for the direct landfill of combustible waste. Energy recovery from SRF is seen as an alternative to conventional (direct combustion) waste incineration. In most countries, combustion or co-combustion is regulated in the same way as for waste incineration.

Cement kilns are the main consumers of SRF with approximately 2.3 Mt/a in European cement kilns. Cement kilns accept (baled) SRF with a maximum chlorine content <1%. High quality SRF is needed for co-combustion in coal fired power plants. Particle size, halogen concentration, and concentration of abrasive inert materials are critical parameters. In Europe, approximately 0.6 Mt/a of SRF go to the power sector, 90% of this in eight German power plants. Energy recovery in dedicated combustion plants typically configured for CHP with grate or fluidised bed technology and with power efficiencies >30%, is a rapidly expanding sector in some EU countries.

The total SRF production in the EU was according to ERFO, the association of European SRF producers, in 2008 4 - 5 Mt. The market outlook talks about a potential of 24 - 41 Mt, however, the actual discussion about the quality of the production plants as well as of the quality of the SRF does not allow to speculate about the market in future.

Pyrolysis: This is an endothermic process in which organic matter decomposes in the absence of oxygen at temperatures of 450 - 700°C. The products of pyrolysis are a combustible gas, a liquid, and a carbon rich solid residue (pyrolysis coke) that can be utilised for energy recovery.

The preferred pyrolysis reactor is a heated rotary drum. For application to MSW, pyrolysis is currently used as the first stage in a combined process where the pyrolysis coke is separated from inert materials (minerals, metal scrap) and then burnt together with the pyrolysis gas in a high temperature combustion chamber. About 15 of these combined systems with a total capacity of approximately 2,500 t/d are in operation in Japan.

In general, the energy efficiency of pyrolysis systems is lower than that of waste incinerators, especially when the fuel is SRF and the energy used for its production is considered. However, advantages for the operator are easy combustion control, high metal scrap quality and a molten slag. The latter feature is important in Japan. Like waste incinerators, these processes require an efficient gas cleaning system.

Gasification: This is the high temperature reaction of organic matter in an oxidising agent, in most cases air or oxygen, with insufficient oxygen to result in combustion. The gasification product is syngas, a mix of CO and H_2, which is burnt in a connected combustion chamber or fed into another furnace for energy recovery. Alternatively, the syngas can feed a gas engine which would offer a higher conversion efficiency. The syngas from MSW gasification contains waste-born pollutants (particles, HCl, NH_3, H_2S, COS, etc.), which have to be removed, especially if a gas engine is used.

Gasification processes with direct syngas combustion are most commonly found in Japan. The low-ash content Japanese waste seems especially suited for this technology. Reactors are typically shaft furnaces (totally of about 40 plants, 5,500 capacity t/d) and fluidised beds (about 30 plants, 4,700 t/d capacity).

A different design concept starts with a degassing stage in a compacting channel followed by high temperature gasification in a chamber. The syngas is either burnt in a combustion chamber or fed into a gas pipeline. Five plants are in operation in Japan (capacity 1,575 t/d). A plant in Germany with a capacity of 225 t/d was shut down because it could not reach the design throughput. The complex technology employed and energy consumed for gas cleaning and ash melting results in very low energy efficiency.

Economics of waste combustion

A cost assessment for waste combustion systems is difficult since most technologies are primarily implemented for waste treatment/inertisation and energy recovery is a by-product, albeit a mandatory requirement of the legislation in many countries. There is no real competition of waste or SRF with fossil or biomass fuels. A thermal waste treatment plant is financed primarily on the basis of the income from the gate fee for processing MSW - typically 80% of the income is derived from this source. The income from power sales makes up the remaining 20%. MSW and SRF have a negative market price which means the producer has to pay a fee to have it accepted by a processor.

Investment (capital) costs are country specific and depend strongly on the configuration of the plant, particularly with respect to the heat recovery and gas cleaning systems deployed and the capacity or size of the plant. The specific investment cost for a 25 t/h MSW incinerator in the EU is of the order of 700 - 1,100 US-$ per tonne of annual throughput. Similar costs are expected in the US and Japan for waste incinerators without ash melting. Unit costs are typically higher for smaller scale systems, i.e. an economy of scale does apply.

Operating costs are highly variable and again depend on plant configuration and site specific conditions. In European plants they range from 55 US-$/t (at a Swedish heat generating plant) to 460 US-$/t (at a German power generation plant); the average cost range if of the order of 110 - 160 US-$/t. It has to be noted that most published costs are gate fees which may, on one hand, include other costs of the MSW management system, while on the other hand, also be influenced by externally imposed taxes.

Published SRF production costs, usually quoted as gate fees, for MBT plants are in the range 70 - 130 US-$/t for Europe. The figures have to be taken with caution since they are site specific and it is not always clear whether they include the expenses for the energy utilisation (at the lower end almost certainly not). In some EU countries, an extra payment of approximately 25 - 55 US-$/t is required for SRF utilisation in cement kilns. The fee for power plants is in the range 40 - 80 US-$/t, while that for dedicated CHP plants, is up to 130 US-$/t in Germany.

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IEA Bioenergy

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