J Mater Cycles Waste Manag (2007) 9:130–139
DOI 10.1007/s10163-007-0178-9

SPECIAL FEATURE: ORIGINAL ARTICLE

3R Initiatives and Circular Economy

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European Union waste management strategy and the importance of biogenic waste

Received: February 21, 2007 / Accepted: April 28, 2007

Abstract In the European Union (EU), waste management is almost totally regulated by EU directives, which supply a framework for national regulations. The main target in view of sustainability is the prevention of direct disposal of reactive waste in landfills. The tools to comply with these principles are recycling and material recovery as well as waste incineration with energy recovery for final inertization. The adaptation of the principles laid down in EU directives is an ongoing process. A number of countries have already enacted respective national regulations and their realization shows that recycling and incineration are not in competition but are both essential parts of integrated waste management systems. In the EU, the amount of residual waste available for energy recovery can supply approximately 1% of the primary energy demand. About 50% of the energy inventory of municipal solid waste (MSW) in most EU countries is of biogenic origin, and MSW is to the same extent to be looked upon as regenerative fuel. Hence part of the CO_2 released from waste incineration is climate neutral. In the EU, this share could produce savings of the order of 1% of annual CO_2 emissions if energy from MSW replaced that derived from fossil fuel.

Key words EU waste management · Biogenic waste · Recycling · Disposal · Waste to energy · CO_2 emission

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A brief history of waste disposal in Europe

As long as people lived in small settlements and relied mainly on self-hunted game and self-grown food, waste was not a problem for society and definitely was not a problem for the environment. Things changed rapidly as soon as the first urbanlike settlements became established. It is evident that waste disposal started to become more complicated and that it became more and more difficult the higher the population density grew. Europe is a continent where people had started living in villages and towns by about 2000 years ago, especially in the Mediterranean area. Hence it is no surprise that the first public dump site we know about was operated in Greece by the city of Athens around 500 BC.[1]

We have no good records concerning waste management in the Roman Empire other than that the waste water problem was solved in the big cities by the installation of ingenious sewer systems. However, with the decline of the Roman Empire, the advances of civilization and the high quality of urban life could no longer be supported. Most European cities reverted to small villages, and during the Middle Ages people got rid of their waste in the way seen in Fig. 1, which made walking in the streets an unpleasant activity. An advantage in that respect was the uncontrolled dumping outside the city walls, but it is reported that in 1400, garbage piled up so high in front of the Paris city gates that it interfered with the defense of the city.[2] A higher quality of waste disposal can be seen in the practice of distributing the waste on the fields around the settlements and thus using the mainly organic matter as fertilizer.

At about the same time, the first speculations arose that waste might impose a risk to water quality. In 1388 the English Parliament banned the disposal of garbage in public waterways and ditches; however, this regulation remained a singular incident. All over Europe, the careless treatment of waste and the general severe lack of hygiene remained and promoted the spread of germs with the consequence of a series of epidemics such as plague and cholera which

Fig. 1. Waste disposal in a medieval European town

Fig. 3. Handpicking of waste at a Vienna landfill (1900)

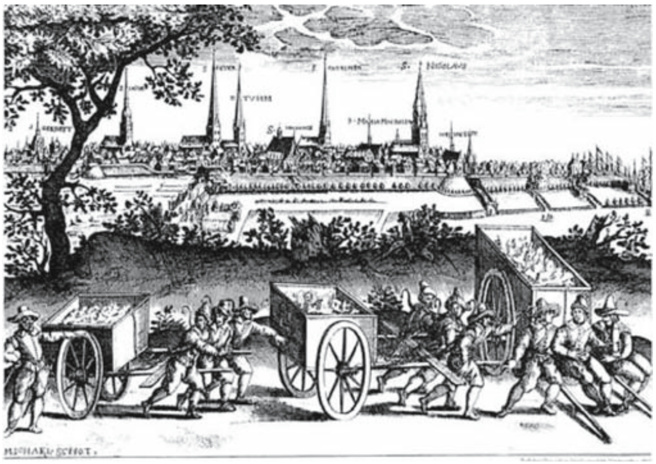

Fig. 2. Prisoners hauling waste out of Hamburg (ca. 1600)

Fig. 4. Sorting plant in Munich-Puchheim (1907)

rolled over Europe in the 16th century, depopulating large areas.

Things started to change in 1507, when plague struck the German city of Hamburg and the medical doctor Johannes Bökel wrote a "Pestilence Order for Hamburg" in which he suggested that the epidemic might have originated from a lack of hygiene; this caused other cities to reorganize their waste disposal – but not so Hamburg. It needed another plague epidemic in 1597 to initiate controlled waste management operated by prisoners who had to haul the waste out of the city to the neighboring villages where it was used as fertilizer (see Fig. 2).[3] This is an early example of intended waste utilization.

In about 1600, many bigger European cities issued street cleaning and waste disposal directives which improved the situation to a great extent, but did not really put an end to the infection risk. A slight shift in the direction of reuse and recycling was the intensified separation of valuables by hand at the landfill site, which was still being practiced in Vienna around 1900 (see Fig. 3).[4] Another utilization strategy at that time was the feeding of pigs at landfills; according to experts, 75 pigs could consume one ton of organic waste per day.[1]

Around the beginning of the 20th century, two different approaches to waste recycling were followed: an organized separate collection of waste fractions and inertization by combustion in dedicated plants. An example for the first strategy is Berlin, where a three-container system was implemented in 1907 in the borough of Charlottenburg. For kitchen waste, recyclables (paper, textiles, glass, metals), and ashes and other garbage, separate bins were provided that were collected in a car with three respective compartments.[4] Sorting plants were built to recover valuables comprising glass, metals, textiles, paper, leather, wood, and bones. The example shown in Fig. 4 is from Munich[4] and looks not so different to sorting plants operating all over Europe today. Whether this is an indicator of the use of advanced technology at that time or of a lack of further development will not be discussed here,

The second waste disposal strategy was initiated in the second half of the 19th century when a campaign started in the UK to support incineration to ensure total destruction of any germs in the waste. In 1870 the first waste incinerator was brought into operation in Paddington, a borough of London, and especially medical doctors strived to convince complaining citizens that the smell from a waste incinerator was far less a danger to their health than the handling and disposal of raw waste.[4]

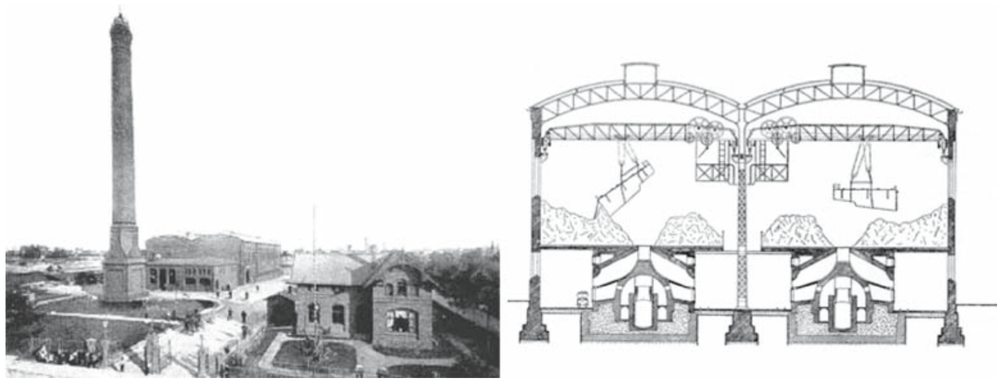

Fig. 5. First continental waste incinerator at Hamburg Bullerdeich (1896): view of the plant (*left*) and schematic of the furnaces (*right*)

On the continent, waste incineration was implemented as a consequence of a cholera epidemic in 1892 – again in Hamburg – and the first incinerator started regular operation in 1896 in that city (see Fig. 5),[5] and very soon, many of the large cities in central Europe had shifted to waste incineration. The Copenhagen incinerator is a good example of the strategy followed at that time. The plant was located in the center of the city; it generated electrical power and delivered heat to a neighboring hospital. Its bottom ashes were used to build bricks for utilization in the building sector. Although such a concept sounds rather modern, the technology applied, the low heating value of the waste (which required in most cases co-combustion of coal), and the emissions and the quality of the residues were far below the standards required and achieved today.

This was the starting point more than 100 years ago. Now, our lifestyle is quite different and is on a higher level due to technological as well as to socio-economic development. However, one major problem to ensure our continued well-being is still the disposal of municipal solid waste (MSW) in a way that endangers neither human health nor the environment, that preserves resources, and that does not require any aftercare.

The European Union (EU) and its member states have developed strategies to establish waste management systems that are in line with the above-listed goals. Furthermore, the opportunities presented by the biogenic fraction in MSW in terms of energy recovery are discussed. The results presented in the following are based to a great extent on the activities of the EU Bioenergy Network of Excellence.

Legislative regulations on waste management

Regulation on disposal

Today the waste management sector in the EU is almost totally regulated by EU Directives that are issued by the European Council and the European Parliament and have to be adopted by all member states. This practice started in the 1970s and resulted in a harmonization of national regulations in terms of management strategies, technological measures, and environmental standards. The Framework Directive 75/442/EEC on Waste Disposal was enacted in 1975. It has been amended a number of times[6] and is currently undergoing fundamental revision. It gives general advice on waste management and disposal, and its objectives are:

- the reduction of waste generation,
- the prohibition of uncontrolled discarding, discharge, and disposal of waste, and
- the promotion of integrated waste management systems following the philosophy of avoidance, recycling, and conversion of wastes with a preference to material and energy recovery.

Under the umbrella of this Framework Directive, a number of directives have been released which regulate the disposal and/or recycling of specific waste streams, e.g., sewage sludge, packaging waste, end-of-life vehicles (ELV), waste from electrical and electronic equipment (WEEE), polychlorinated biphenyls (PCBs) and polychlorinated terphenyls (PCTs), and batteries and accumulators.

Another directive of fundamental importance for the disposal of MSW is Landfill Directive 1999/31/EC.[7] The Landfill Directive is intended to prevent or reduce the adverse effects of direct disposal of untreated waste on human health and on the environment, in particular on surface water, groundwater, soil, and air. It stipulates a system of operating permits for landfill sites. The most important part is Article 5, which requires a reduction of biodegradable waste going to landfills. The reduction targets to be met in comparison to the amount of organic waste disposed of in 1995 are 25% in 2006, 50% in 2009, and 75% in 2016.

Recently admitted countries have transitional periods for full adoption of these EU regulations. Measures to achieve these targets should include, in particular, recycling, composting, biogas production, and material and energy recovery. Consequently, this Directive not only promotes recycling and composting but supports even more waste incineration, which is for the time being the only proven and efficient technology for destroying organic matter. The criteria to be followed for the acceptance of waste at a landfill include basic characterization, compliance testing, and on-site verification. The Landfill Directive specifies only general criteria and principles to be obeyed for the acceptance of a waste or residue at a landfill but it does not

Table 1. Limit values for leaching for acceptance at an inert waste landfill for granular nonhazardous waste accepted in the same cell as stable nonreactive hazardous waste, and for granular waste accepted at landfills for hazardous waste

Component	Inert waste landfill			Granular nonhazardous waste			Hazardous waste landfill		
	L/S = 2 (mg/kg)	*L/S* = 10 (mg/kg)	c_0 (mg/l)	*L/S* = 2 (mg/kg)	*L/S* = 10 (mg/kg)	c_0 (mg/l)	*L/S* = 2 (mg/kg)	*L/S* = 10 (mg/kg)	c_0 (mg/l)
As	0.1	0.5	0.06	0.4	2	0.3	6	25	3
Ba	7	20	4	30	100	20	100	300	60
Cd	0.03	0.04	0.02	0.6	1	0.3	3	5	1.7
Cr_{total}	0.2	0.5	0.1	4	10	2.5	25	70	15
Cu	0.9	2	0.6	25	50	30	50	100	60
Hg	0.003	0.01	0.002	0.05	0.2	0.03	0.5	2	0.3
Mo	0.3	0.5	0.2	5	10	3.5	20	30	10
Ni	0.2	0.4	0.12	5	10	3	20	40	12
Pb	0.2	0.5	0.15	5	10	3	25	50	15
Sb	0.02	0.06	0.1	0.2	0.7	0.15	2	5	1
Se	0.06	0.1	0.04	0.3	0.5	0.2	4	7	3
Zn	2	4	1.2	25	50	15	90	200	60
Chloride	550	800	460	10000	15000	8500	17000	25000	15000
Fluoride	4	10	2.5	60	150	40	200	500	120
Sulfate	560[(1)]	1000[a]	1500	10000	20000	7000	25000	50000	17000
Phenol index	0.5	1	0.3	–	–	–			
DOC[b]	240	500	160	380	800	250	480	1000	320
TDS[c]	2500	4000	–	40000	60000	–	70000	100000	–

L/S, liquid to solid ratio (l/kg dry matter); c_0, concentration in the first eluate of a percolation test at *L/S* = 0.1 l/kg; DOC, dissolved organic carbon; TDS, total dissolved solids

[a] If the waste does not meet this limit value for sulfate, it may still be considered as complying with the acceptance criteria if the leachate does not exceed either of the following values: 1500 mg/l for c_0 at *L/S* = 0.1 l/kg and 6000 mg/kg at *L/S* = 10 l/kg. It will be necessary to use a percolation test to determine the limit value at *L/S* = 0.1 l/kg under initial equilibrium conditions, whereas the value at *L/S* = 10 l/kg may be determined either by a batch leaching test or by a percolation test under conditions approaching local equilibrium

[b] If the waste does not meet this value for DOC at its own pH value, it may alternatively be tested at *L/S* = 10 l/kg and a pH between 7.5 and 8.0. The waste may be considered as complying with the acceptance criteria for DOC if the result of this determination does not exceed 500 mg/kg for inert waste or 800 mg/kg for granular nonhazardous waste

[c] The value for TDS can be used as an alternative to the values for sulfate and chloride

Table 2. Limit values for the total content of organic substances for acceptance at an inert waste landfill

Substance	Limit value (mg/kg)
Total organic carbon	30000[a]
Benzene, toluene, ethylbenzene, and xylenes	6
Polychlorinated biphenyls, seven congeners	1
Mineral oil (C10 to C40)	500
Polycyclic aromatic hydrocarbons (total of 17)	Member states to set limit value

[a] In the case of soils, a higher limit value may be admitted by the competent authority, provided a DOC value of 500 mg/kg is achieved at an *L/S* of 10 l/kg either at the soil's own pH or at a pH value of between 7.5 and 8.0

contain specific parameters and their limit values. These are laid down in Council Decision 2003/33/EC,[7] which prescribes not only general criteria for the acceptance of waste for each landfill class, but also the methods to be used for the sampling and testing of waste. Each country is obliged to define procedures and to set standards that have to be met by a material to be accepted as a specific class of landfill.

The acceptance criteria are based first of all on leaching tests according to the standardized procedures of the European Committee on Standardization (CEN: Comité Européen de Normalisation).[8] The Council Decision contains limit leaching values for two liquid–solid ratios (*L/S*): *L/S* = 2 l/kg and *L/S* = 10 l/kg. There are also limits for some parameters describing the organic inventory of waste, such as total organic carbon (TOC), dissolved organic carbon (DOC), and concentrations of groups of organic compounds. On top of these, mechanical parameter standards have to be set by the national authorities.

The acceptance criteria at a landfill for inert waste and those for granular nonhazardous waste in cells that also accept stable nonreactive hazardous waste are compiled in Table 1. Acceptance standards of organic constituents for an inert landfill are listed in Table 2.

For granular hazardous waste to be accepted at landfills for nonhazardous waste, the same leaching criteria are applied as for granular nonhazardous waste which is landfilled in the same cell as stable nonreactive hazardous waste (see Table 1). For this waste, however, additional limiting criteria are:

Table 3. Emission data set in the Waste Incineration Directive and the respective daily average regulations in Germany and the Netherlands

Substance	EU 2000/76/EC (daily)	EU 2000/76/EC (half-hourly)	Germany 17. BImSchV	Netherlands
Dust	10	30	10	5
CO	50	100	50	50
TOC	10	20	10	10
HCl	10	60	10	10
HF	1	4	1	1
SO_2	50	200	50	40
NO_x (as NO_2)	200	400	200	70

Data are in mg/m^3 (273 K, 101.3 kPa, 11 vol% O_2, dry)
TOC, total organic carbon; CO carbon monooxide

- a TOC value of 5% (a higher value may be admitted by the competent authority, provided that the DOC value of 800 mg/kg is achieved at $L/S = 10$ l/kg),
- a minimum pH value of 6, and
- the acid neutralization capacity (ANC) must be evaluated.

For hazardous landfills, the following additional criteria must be met:

- a TOC value of 6% (a higher value may be admitted by the competent authority, provided that the DOC value of 1000 mg/kg is achieved at $L/S = 10$ l/kg) or
- alternatively a loss on ignition (LOI) value of 10% and
- the ANC must be evaluated.

These criteria are guidelines for the respective regulations in the member countries and some countries have already used these limits as new standards (e.g., the United Kingdom).

An efficient instrument used in some EU countries to divert biogenic waste from landfills is a landfill tax, which is imposed on untreated waste going to disposal sites. In Austria and the Netherlands, this tax exceeds 80 €/Mg, which almost doubles the typical landfill fee of approximately 100 €/Mg in these countries. Sweden and Denmark charge around 50 €/Mg as tax; in the UK the tax of 30 €/Mg will increase annually by approximately €4.30. Other countries, such as Germany, rely on legislative regulations that guarantee compliance with the respective targets of the Landfill Directive. In Germany, national regulation has enforced a landfill ban for reactive waste since June 1, 2005.

Regulation of waste incineration

Waste incineration had – and in some countries still has – a bad reputation in terms of its presumed ecological impact. Hence this disposal route has been regulated since the 1980s and 1990s in various directives. A continuous strengthening of standards, mainly those on air emissions, resulted in Directive 2000/76/EC of the European Parliament and of the Council on the incineration of waste, the so-called Waste Incineration Directive,[9] which was published on December 28, 2000. This directive sets standards for the operation of MSW and hazardous waste incineration plants in terms of temperature, residence time, energy recovery, and air emission values. It also contains specific provisions for the co-combustion of waste in cement kilns and power plants and concentration limits for liquid effluents from wet flue gas cleaning. Rather general statements concerning residues from waste incineration or co-combustion are included: these should be minimized and utilized as far as possible.

Table 3 compiles the daily and the half-hourly averaged emission data for off-gas species to be monitored continuously, as given in the Waste Incineration Directive. The emission values can still be regarded as being complied with if not more than 3% of the values per year exceed the respective limits. National authorities may set limits below the EU values, as documented by the included respective daily average data of the German and Dutch emission regulations.

Heavy metals and polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/F), commonly referred to as dioxins, have to be measured periodically in sampling campaigns lasting 0.5–8 h each. The respective limits to be met are – again with those in Germany and the Netherlands – compiled in Table 4.

The Waste Incineration Directive had to be adopted in the EU 15 countries by national law at the latest by December 28, 2002. In Germany and in the Netherlands, the respective legislative regulations had already been in place prior to the release of this Directive and it can be stated that in these countries all operating waste incineration or co-combustion plants comply with them.

Waste disposal practice

In the EU, the generation of MSW ranges from approximately 250 kg per person per year in Poland to 66 kg per person per year in Spain, with the new member states being at the lower end of this range. The data compiled in Table 5 are taken from the EU statistical office Eurostat.[10]

Most countries, especially many old EU members, have implemented extensive programs to divert and recycle all

Table 4. Average emission data to be measured over a sampling period of between 0.5 and 8h in the Waste Incineration Directive and the respective regulations in Germany and the Netherlands for species not continuously monitored

Substance	EU 2000/76/EC	Germany 17. BImSchV	Netherlands
Hg (mg/m^3)	0.05	0.03	0.05
Cd + Tl (mg/m^3)	0.05	0.05	0.05
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V (mg/m^3)	0.5	0.5	0.5
PCDD/F ng(I-TE)/m^3	0.1	0.1	0.1

Data are measured at 273 K, 101.3 kPa, 11 vol% O_2, dry
PCDD/F, polychlorinated dibenzo-*p*-dioxins and dibenzofurans
I-TE, international toxicity equivalents

Table 5. Per capita generation of municipal solid waste (MSW) and the recycled (REC), incinerated (INC), and landfilled (LF) fractions for selected countries in 2004

Country	MSW (kg/year)	REC (%)	INC (%)	LF (%)
Austria	627	58	22	20
Belgium	469	57	33	10
Czech Republic	278	6	14	80
Denmark	696	42	54	4
Estonia	449	37	0	63
Finland	455	30	10	60
France	567	29	33	38
Germany	600	59	24	17
Greece	433	8	0	92
Italy	538	32	11	57
Netherlands	624	64	34	2
Poland	256	5	1	94
Portugal	434	5	22	73
Spain	662	39	6	55
Sweden	464	44	47	9
United Kingdom	600	23	8	69

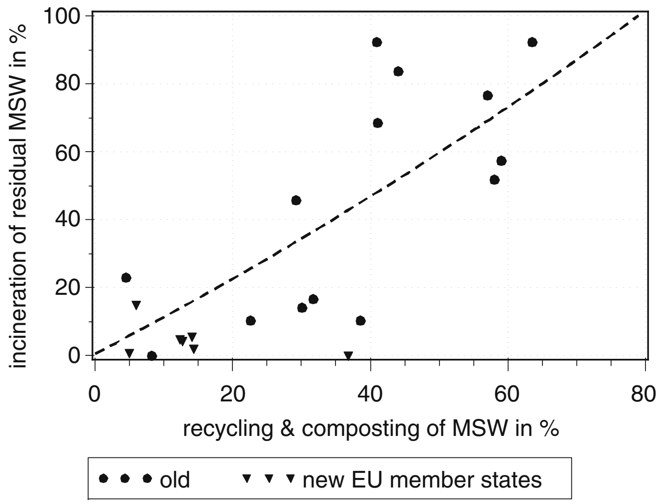

Fig. 6. Recycled fraction of municipal solid waste (*MSW*) and incinerated fraction of waste that is left over after all reuse and recycling measures have been carried out (in EU countries)

kinds of waste fractions such as paper, glass, metals, plastics, and organic fractions, the latter items for composting or anaerobic digestion. Recycling quotas, which are for several materials such as packaging waste or end-of-life vehicles laid down in legislative regulations, reach almost 60% in Germany and Austria. In the new member states and in some southern countries with low recycling levels, a significant increase – driven by EU directives – will be seen in the future.

Composting is included in the recycling figures shown in Table 5. This strategy is mainly applied in Austria (36%) and in the Netherlands (23%); Germany and France compost about 15% of their MSW, but in most other countries the composting rate is well below 10%.

For the residual waste, the leftovers after all recycling activities have been carried out, the preferred inertization process prior to final disposal is incineration. The respective data for 2004 are included in Table 5. Countries such as Denmark, the Netherlands, and Sweden already incinerate almost all of their residual waste and the level for Germany is expected to reach almost 40% in 2006 after the landfill ban was fully enacted on June 1, 2005. Hence, several countries have already over-fulfilled the demands of the Landfill Directive. The intensive application of waste incineration in these countries will most likely soon be noted in other member states that have still to meet the Landfill Directive's targets.

The development of the system in the EU is a good example of the equally important role that recycling and waste incineration play in an integrated and sustainable waste management system. Contrary to the claims of the opponents of incineration, those countries which practice incineration to a great extent have also established a high level of recycling. In Fig. 6 the percentage of incineration of residual waste – that MSW fraction which is left over after all recycling activities have been carried out – is plotted for 21 EU countries against the fraction of MSW that is recycled or composted. The graph documents that a number of old EU member states which practice recycling and/or composting to a great extent, also incinerate the major part of the residual waste. Such a strategy is promoted by the EU landfill directive and will most likely in the future also be followed by the new EU members and those old EU members which are today still characterized by low recycling as well as low incineration rates.

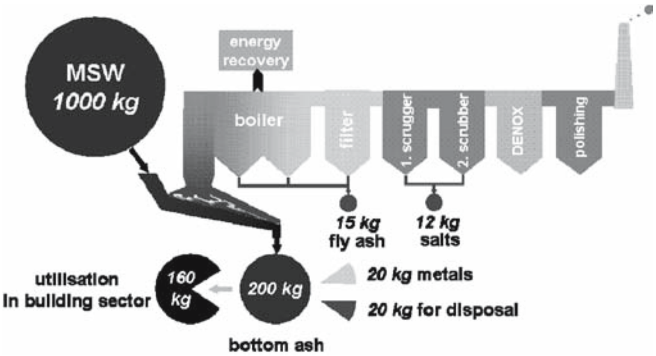

Fig. 7. Mass flow in a modern waste incineration plant. (Approximate values; DENOX, NOx abatement system)

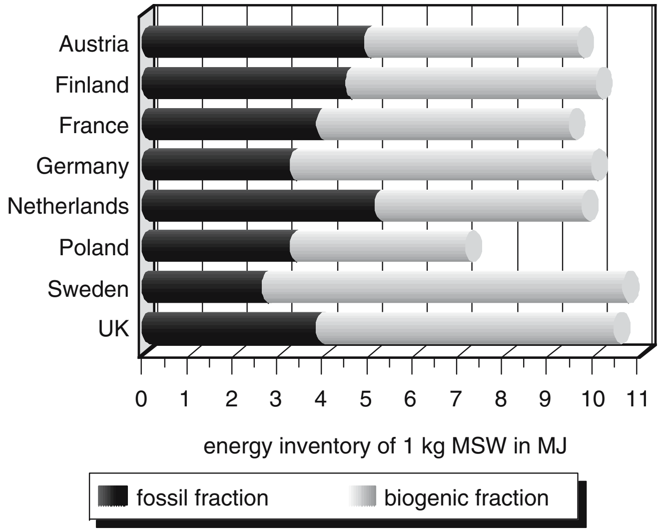

Fig. 8. Lower heating value and its biogenic fraction in the MSW of selected EU countries

Recovery of materials and energy by waste incineration

Material recovery

One of the goals of waste management is the conservation of resources, not only by material recycling but also by the recovery of the energy inventory of the residual waste. The Waste Incineration Directive makes energy recovery mandatory and in fact all modern waste incineration plants in the EU are equipped with a boiler and a respective energy conversion system, depending on the operation's 'product': steam, heat, power, or combined heat and power (CHP).

However, waste incineration plants do also contribute to material recovery, although this fact is often overlooked. The typical mass flow of a state-of-the-art waste incinerator is depicted in Fig. 7. The graph documents that a significant fraction of the residues has the potential to be utilized as well.[11] This applies first of all to the major residue stream, the bottom ashes, which represent 15%–25% of the waste fed into the furnace and approximately 80%–90% of the total solid residues.

Separation of ferrous and nonferrous metals from bottom ashes is routinely performed and is, for the nonferrous metals especially, a profitable business. The ashes that are left over after separation of metal scrap and bulky material can – after pretreatment – be utilized in the building sector. The Netherlands, for example, uses almost 100% of this material in road construction; the respective level in Germany is approximately 80%. Other EU countries apply the same strategy to a lesser extent, but this is likely to grow in the future.

Energy inventory and its biogenic fraction

If the composition of the MSW is known, its calorific value can be calculated approximately using published data of heating values of single waste fractions.[12–16] From such calculations, it can be concluded that the average lower heating value in the highly industrialized old EU member states is of the order of 10 MJ/kg.[17] For eight EU countries, the results of such calculations are compiled in Fig. 8. The values range from approximately 7 MJ/kg in Poland to more than 11 MJ/kg in Sweden. The accuracy of such data has been estimated to be approximately ± 10%. The figures obtained are well in line with average heating values calculated on annual averages of, for example, German waste incineration plants.

The waste composition data allow also the identification and quantification of the energy inventory in MSW, which is supplied by the organic MSW fractions comprising food and garden waste, wood, paper, and partly also by textiles and diapers. The bar plot in Fig. 8 visualizes this biogenic energy fraction in MSW separately. An overview for all EU countries – although in some cases based on rather vague data – reveals an average biogenic energy inventory in MSW of 55% ± 9%, the range being from 36% in the Czech Republic to 74% in Sweden.[15,17]

The fact that a certain fraction of the energy in MSW is of biogenic origin has meanwhile been acknowledged by some EU countries, such as the Netherlands and Finland. In these countries, power generated in waste incineration plants is rewarded by tariffs subsidized according to their national regenerative energy acts.

Energy recovery

MSW in the EU is mainly burnt in dedicated combustion facilities, preferentially in European mass burners, which are based on grate technology. Co-combustion of MSW in utility boilers and industrial furnaces plays an important role in some countries, such as Germany, in the concepts of waste management. However, although large efforts are made to standardize the quality of waste-derived solid fuels, this strategy focuses mainly on defined waste fractions from the commercial and light industrial sector. For the time being, the market for such secondary fuel is unlikely to be

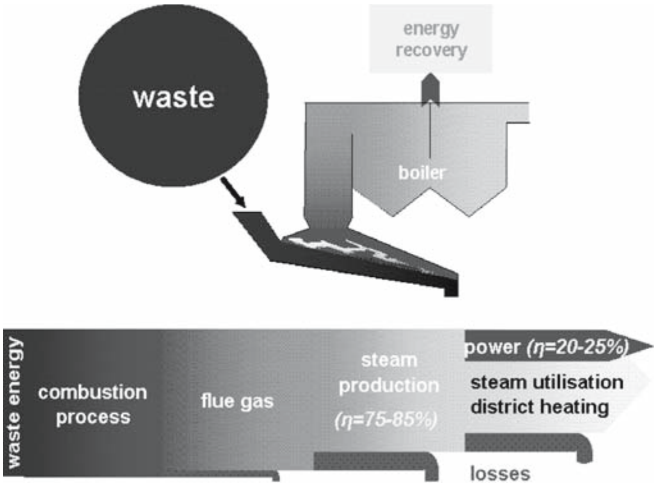

Fig. 9. Energy flow in a modern waste incinerator

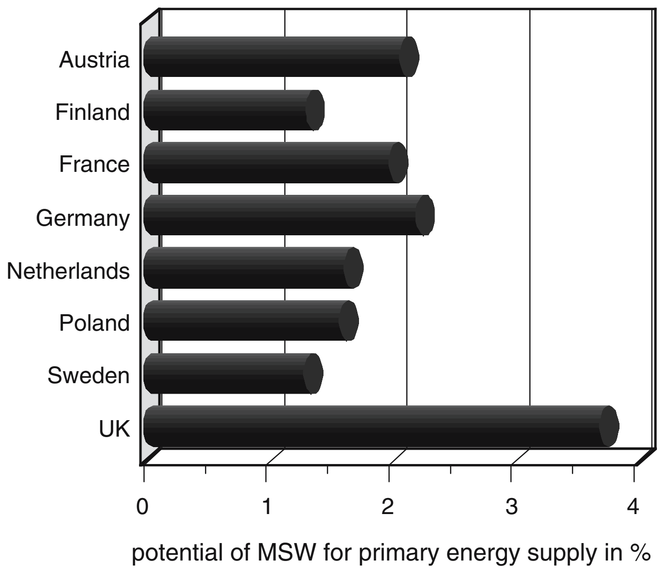

Fig. 10. Potential of primary energy supply from MSW for selected EU countries

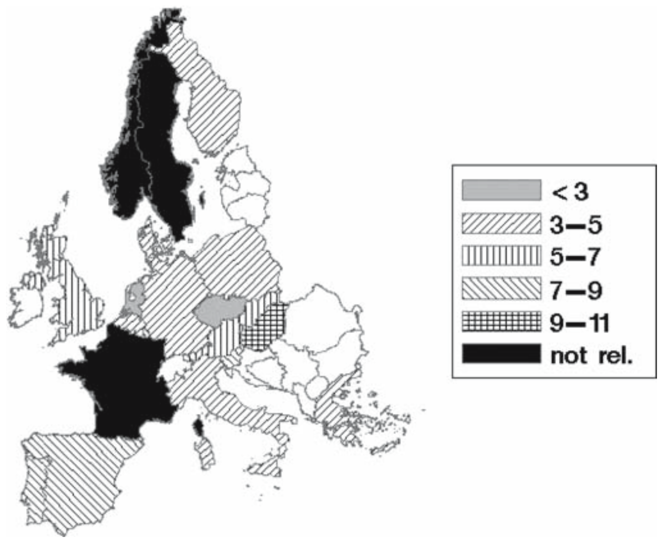

Fig. 11. Potential of MSW to replace fossil fuel in the power market for selected EU countries (percentage of power supply). *Not rel.*, not relevant

stable and the role that this so-called solid recovered fuel (SRF) will play in the waste as well as in the energy market is still difficult to predict. The major problems are uncertainties concerning the fate of waste-borne pollutants as well as the economics of such a practice.[18]

A modern waste incinerator has a high potential for energy recovery, as is depicted in Fig. 9.[19] Its primary or boiler efficiency is of the order of 80% or more and the power efficiency amounts to 20%–25%; in modern plants with boilers made from high corrosion resistant alloys, the power efficiency can become greater than 30%. The best strategy, however, is combined heat and power (CHP). In such configurations, the overall energy efficiency can reach more than 60%.

As was pointed out in Table 5, waste incineration is meanwhile an important part of the waste management strategy in most of the old EU countries and also in Switzerland and it has to be assumed that the Landfill Directive will be a strong driver for the promotion of waste incineration all over the EU.

Energy substitution by waste incineration

The potential of MSW incineration to supply primary energy can be calculated based on the amount of MSW that is available for waste-to-energy processes, its calorific value, and the primary energy consumption in a given country. For this calculation, a boiler efficiency of 70% is assumed for the waste incineration plant. A further assumption is that the waste that is today recycled or composted will also in the future not be available for energy recovery. The actual primary energy consumption has been taken from the World Factbook.[20] It is obvious that through such an exercise only rough estimates can be obtained, however, they give an impression of the order of magnitude of the substitution potential.

For the eight countries that have already been selected for the calculation of the calorific value of MSW, such a calculation has been executed; the results are shown in Fig. 10. The bar plot indicates a substitution potential of between 1% and 2%. The estimate for the UK seems to be too high since in that country a much higher rate of recycling is expected in the future.

A similar calculation has been carried out in view of the potential of MSW to replace fossil fuel in the power market using an energy efficiency of 20%. The results are shown in Fig. 11. The graph documents that even in highly industrialized countries such as Belgium, Denmark, Germany, and Italy 3%–5% of the fossil power could be replaced by waste incineration, a share that should not be underestimated. For the time being, this potential is not exhausted. The actual

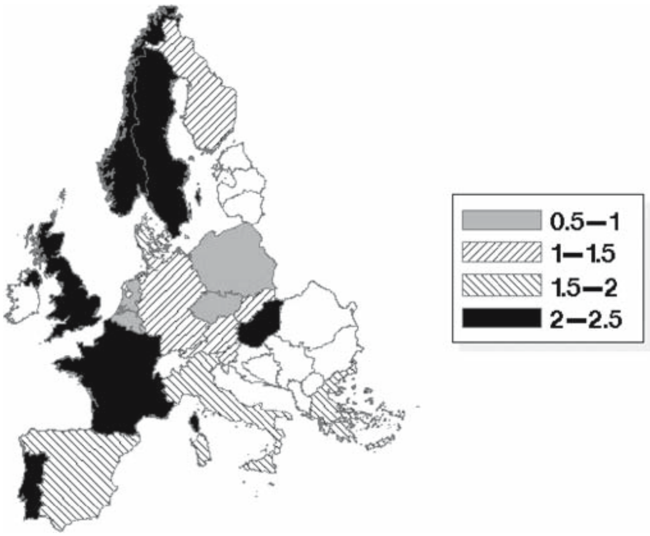

Fig. 12. Estimates of regenerative CO_2 emission from MSW incineration as a percentage of the total annual CO_2 emission in selected EU countries

figure for Germany is of the order of 0.7%,[21] but it has to be expected that here, in the Netherlands, and in other countries, much higher values will be achieved in due course.

There are a number of countries where fossil fuel plays a minor role, since their main source for power generation is water (e.g., Norway, Sweden, and Switzerland) or nuclear power (France). In these countries the calculated power substitution figures have no relevance.

Climate relevance of waste incineration

Apart from the option of achieving higher revenues for the exported energy if the biogenic energy inventory is acknowledged, there is another beneficial consequence of the biogenic waste fraction: the CO_2 emitted from the combustion of this fraction is climate neutral. That means countries which approve that waste contains a biogenic fraction should also include waste incineration in their CO_2 balance. An estimate on the basis of the above-presented figures indicates that the amount of regenerative CO_2 emitted from incineration plants in an energy-optimized waste management scenario can contribute significantly to the reduction targets that the single states agreed to when they signed the Kyoto Protocol. Ranges of the amount of regenerative CO_2 emitted in European countries if all the unrecycled MSW were combusted are shown in Fig. 12 in percent of the total annual CO_2 emission in that country. As can be seen, in some countries values exceeding 2% can be achieved.

These data are basic estimates and will in reality not be attainable. However, it should be kept in mind that the generation of energy from MSW – in case of optimized utilization, e.g., by CHP – accounts for approximately the same emission of CO_2 per energy unit as generation from lignite. Hence the above considerations illustrate the order of magnitude of substitution of energy from fossil sources and the savings of fossil CO_2 emission associated with such a strategy.

This does not mean that the above figures allow a valid estimation how much CO_2 a certain country can save if it optimizes its waste management system in view of maximum energy recovery. A more precise assessment requires a detailed analysis of the installed energy supply system in terms of types of fuel, the technology applied, and differentiation between base and peak load plants.

Conclusions and outlook

Waste disposal has been a problem since early times because of the health risk associated with the handling of such material. This risk has been recognized and various strategies have been developed for waste disposal, starting with routine use as fertilizer in agriculture in medieval times to the first incineration activities in the last quarter of the 19th century.

Today more health- and environment-friendly waste management strategies have been developed. These are based mainly on a hierarchy following the philosophy of avoidance, reuse, material recycling, material and energy recovery, inertization, and final disposal. The EU has taken early action in this direction with the effect that waste management is almost totally regulated by EU Directives, with the consequence that this area is already more or less harmonized in all old EU countries and will soon be so in the new member states.

The principles of fundamental EU regulations such as the Framework and the Landfill Directive are:

- reduction of waste generation,
- increase of material recycling and recovery,
- energy recovery, and
- reduction of direct disposal of organic waste.

Material recycling has the highest priority and is, consequently, well developed in most EU countries. High recycling quota in the domestic sector are established for paper, metals, glass, and packaging materials. Nevertheless, in some southern countries and of course in the new member states, a further increase in recycling will be reached over the coming years.

Especially problematic for recycling as well as for disposal is the organic waste fraction. Composting is a widely utilized sink for organic waste, however, it can only be recommended if a thorough separation can be guaranteed. An emerging technology is anaerobic digestion, which looks rather promising in combination with sewage sludge and wet biomass from agriculture.

Waste-to-energy concepts based on waste incineration are gaining in importance in the EU. Since the major target of the Landfill Directive is prevention of the direct disposal of reactive and organic waste, a number of countries, first of all the Netherlands, Denmark, and Germany, have installed a high capacity of waste incineration plants, mainly based on grate furnaces and equipped with boilers for energy recovery.

A rough estimate indicates that the biogenic fraction of municipal solid waste accounts for more than 50% of its energy inventory. Hence an intensive utilization of energy from waste could result in a substantial substitution of fossil energy sources by biogenic waste fractions, with the benefit of a marked reduction in fossil CO_2 emissions. For countries such as Germany, a reduction potential exceeding 1% of total emissions can be achieved. This aspect gains in importance in view of the current discussion on climate change and global warming and has already been adopted by a number of EU countries which substitute power exported from waste incinerators by bonus tariffs.

From the perspective of sustainable waste disposal as well as from the perspective of the promotion of bioenergy, the consequent exploitation of energy from waste is the most efficient way to fulfill the EU regulations on waste management with beneficial effects on energy supply and climate change. On the EU level, energy from waste is already an important player in the bioenergy sector and will most likely gain in importance as soon as all countries have adopted the EU Landfill Directive.

This effect of waste management will be accomplished in line with further extension of recycling activities. It can be shown that – at least in the EU – countries with high incineration capacity have also a high share of recycling. Energy recovery is and will be using only waste fractions that are left over after all other reuse, recycling, and recovery efforts have been undertaken. To decide on the right balance among all waste management options is not an easy task and will be one focus in the future work of the EU Bioenergy Network of Excellence in order to promote the use of bioenergy in Europe.

Acknowledgments This article was written in cooperation with the Bioenergy Network of Excellence (NoE). Sponsored by the European Commission's Directorate General for Research, Bioenergy NoE is a partnership of eight leading bioenergy institutes that are integrating their expertise and activities to foster excellence in European bioenergy RD&D. For more information about Bioenergy NoE, please visit the website: www.bioenergynoe.org.

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