Biogenic Waste to Energy – an Overview

J. Vehlow
Forschungszentrum Karlsruhe
Institute for Technical Chemistry - Division of Thermal Waste Treatment

A Brief History of Waste Disposal

As long as people lived in small settlements and relied manly on self-hunted game and self-grown food waste was no problem for society and the more so not for the environment. Things changed rapidly as soon as the first urban-like settlements 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. Offensive smell must have been an annoying effect, but a further aspect associated with waste disposal should have attracted attention in many places, too: the pollution of the rare and precious water resources. In the Indus valley culture at least the waste water problem was solved by the city-wide installation of sewer systems, a solution which was also very well developed in the big cities of the Roman Empire. In Greece the first public dump site was operated by the city of Athens around 500 B.C. [U.S. EPA 2005].

Another and from today's perspective rather modern looking strategy is delivered in the Holy Bible for the city of Jerusalem: at about 1000 B.C. the garbage was carried through the Dung Gate to the Kidron creek where it was burnt in a permanently supported fire [Holy Bible]. It is also mentioned that the ashes were either spread on the nearby graveyard or on the acres of Bethlehem.

Fig. 1 Waste disposal in a medieval European town

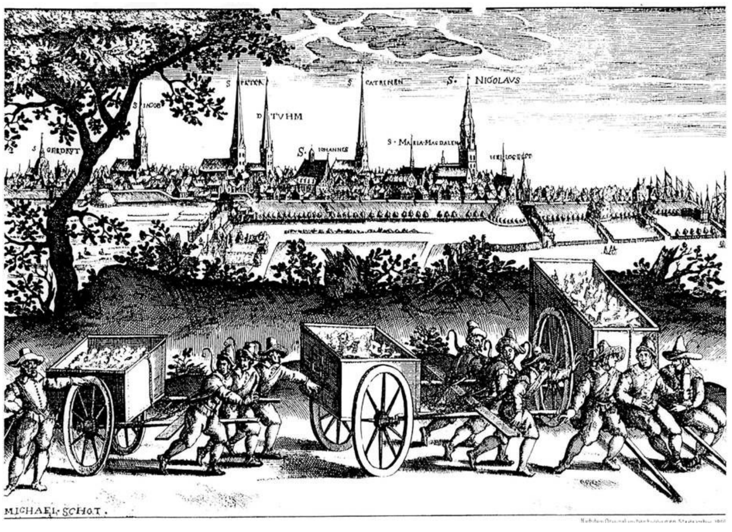

Fig. 2 Prisoners hauling waste out of Hamburg (ca. 1600)

With the decline of the Roman Empire the advances of civilisation and the high quality of urban life could not be supported any longer. Most European cities re-developed to small villages and during the Middle Ages people got rid of their waste by throwing it out of the window or the door directly on the streets (see Fig. 1) and waiting for the next rain to take care of the transportation out of town.

An advantage was the uncontrolled dumping outside the city walls but it is reported that at 1400 garbage piled up so high outside Paris city gates that it interfered with the city defence [U.S. EPA 2005]. A higher quality of waste disposal can be seen in the already early practice of distributing the waste on the acres around the settlements and thus using the organic fraction and also the alkali, sulphate and phosphorous inventory in ashes as fertiliser. With this we see the first attempt to utilise the biogenic inventory in waste.

First ideas of the risk waste imposes on the water quality came up at various places and the English Parliament banned disposal of garbage in public water ways and ditches in 1388. But these were singular regulations. Almost all over Europe the careless treatment of waste and the general severe lack in hygiene promoted the spreading of all kinds of germs with the consequence of a series of epidemics like plague and cholera which rolled over Europe in the 16th century and depopulating large areas.

However, already in 1507 when the plague stroke Hamburg in Germany the medical doctor Johannes Bökel wrote a ‘Pestilence order for Hamburg’ and pointed out that there might be a direct influence of the hygiene in the city and the epidemic. This decree caused other cities to re-organise their waste disposal but not so Hamburg. It needed another plague epidemic in 1597 to initiate a controlled waste management operated by prisoners who had to haul the waste out of the city to the villages around where it was used as fertiliser (see Fig. 2) [Frilling & Mischer 1994]..

Starting at 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. Even around 1900 landfilling and picking up valuables by hand at the landfill site were estimated as state-of-the-art waste disposal practice as is documented by the picture in Fig. 3 taken at a Vienna landfill. Another ‘modern’ waste treatment at that time was the feeding of pigs at the landfill as can be seen in Fig. 4 which has been taken at the same landfill as Fig. 3 [de Fodor 1911]. Experts pointed out, that 75 pigs could consume one ton of waste per day.

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

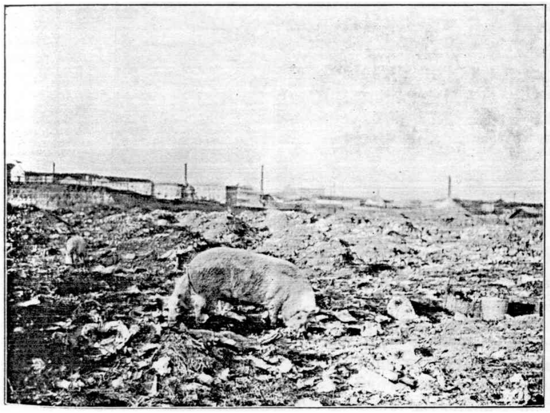

Fig. 4 ‘Utilisation’ of organic waste by pigs at a Vienna landfill [1900]

Although landfilling is worldwide still the prevailing waste disposal strategy and scavenging is common practice in many poor countries even today the growing awareness of the health risk which is associated with the handling of raw waste initiated a movement towards more safe practices. Two different approaches were followed: an organised separate collection of waste fractions and an inertisation by combustion in dedicated plants.

An example for the first strategy is Berlin where a ‘Three-Container-System’ was implemented in 1907in the borough Charlottenburg. For kitchen waste, recyclables (paper, textiles, glass, metals), and ashes and other garbage separate bins were provided which were collected in a car with three respective compartments (see Fig. 5 and Fig. 6) [de Fodor 1911].

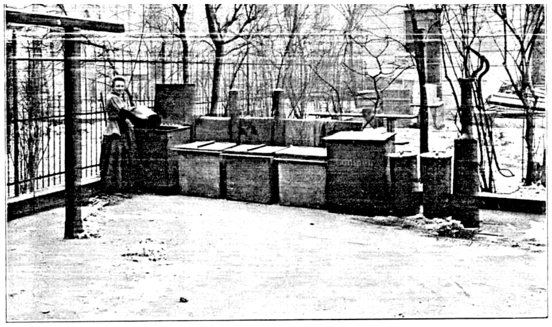

Fig. 5 'Three-Container-System' in Berlin (1900)

Fig. 6 'Three-Container-System' collection car in Berlin [1900]

At the same time sorting plants were built to recover a large list of valuables ranging from textiles, leather, paper, wood, bones, and various and metal glass sorts. The example shown in Fig. 7 is from Munich [de Fodor 1911] and looks not that much different from sorting plants operated today all over Europe. It will not be discussed here whether this is an indicator of the advanced technology at that time or of a lack in further development.

Fig. 7 Sorting plant in Munich-Puchheim (1907)

The second waste disposal strategy was initiated in the second half of the 19th century when a campaign started in the UK for waste incineration to ensure an effective destruction of any germs in the municipal waste. In 1870 the first waste incinerator was brought into operation in Paddington, a borough of London, and especially medical doctors convinced complaining citizens that the smell from the waste incinerator was far less endangering their health than the handling and disposal of raw waste.

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. 8) [Zwahr 1996]. Very soon many of the Central European big cities had shifted to waste incineration. The Kopenhagen incinerator shown Fig. 9 is a good example of the strategy followed that time in waste incineration. This plants was located in the middle of the city, it generated electric power and delivered heat to a neighbouring hospital. Its bottom ashes were used to build bricks for utilisation in the building sector. Although such concept looks rather modern the applied technology, the low heating value of the waste which required in most cases co-combustion of coal, and the emission as well as the residue quality were far beyond the standards required and achieved today.

Fig. 8 First continental waste incinerator Hamburg Bullerdeich (1896)

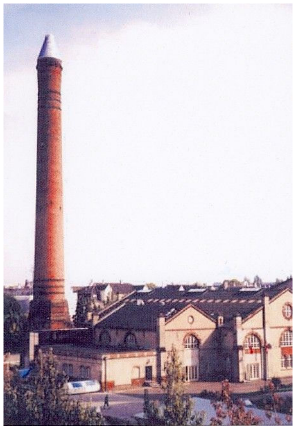

Fig. 9 First Danish waste incinerator in Kopenhagen-Frederiksberg (1910)

This was the starting point some 100 years ago. Meanwhile our life style is quite different due to the technological as well as the socio-economic development. Accelerating urbanisation in industrial centres, rapid increase in traffic and especially the almost unlimited utilisation of fossil fuel have changed our living conditions, the quality of our environment and last not least the composition of our waste to a great extent – the latter ones mainly in an unwanted direction. Especially the penetration of all facets of our daily life by plastics after World War II created new problems caused for waste disposal: plastics are not biologically degradable and stay with that for ever on landfill sites.

One major problem for the lasting of our achieved well being is still the sound disposal of municipal solid waste in a way which does neither endanger human health nor the environment and which does not require any aftercare. The options to reach this goal will mainly be discussed using Europe as an example. First of all from these countries we have the best records on waste management, further on they have the most complete – and most stringent – legislative regulation which will also briefly be discussed. A special focus will be the biogenic fraction in the waste which causes problems in disposal and may have some beneficial aspects in waste-to-energy systems.

The European Union (EU) as a partly highly industrialised and partly densely populated area has taken action more than 30 years ago already to tackle the waste problem and to harmonise the waste management practice in its area.. However, the EU is still expanding and new member states need time to implement the EU regulations into national law. That is why today waste is not yet managed in a uniform way in Europe and several countries are still in a transition phase.

In the following the description of the waste management situation in the EU and its regulation will be used as example to discuss the actual performance or the actions needed in other parts of the world. The term waste is in this report a synonym for municipal solid waste although to some extent the basis of the used numbers is not totally clear.

The Waste Problem Today

Waste Generation in the EU and World Wide

In historical times waste was that material which was of no longer use and was discarded. Today even the definition of waste is controversially discussed [OECD 1996]. In our context we will stay with the simple definition given above.

Valid data on waste generation found in literature have to be looked upon critically. Due to different statistics applied in the different countries the reliability of such data is often rather poor. Published numbers may contain residential waste only, they may imply market and public cleansing waste or not, commercial and industrial waste may be included or not, they may indicate waste which is collected by the public waste management system only, etc.. On top of that political or other biases may complicate the interpretation and interfere seriously with any comparison between countries. Generally, such data are rather old and eventually outdated. One surprising effect is that sometimes data are found in international data sources like Eurostat or OECD which are not available in the statistical offices of the single states.

For this report waste generation data are taken from data bases of the Statistical Office of the European Communities Eurostat [Eurostat 2005], the European Environment Information and Observation Network (EIONET) [EIONET 2005], the OECD [OECD 2002], of the UN statistical offices [UN 2005] and a number of national agencies. The selected European countries are the 25 EU members supplemented by Norway, Switzerland and by the future member states Romania and Bulgaria. For these countries the data base is mainly from 2001 – 2003. For the other countries data.from the 90th of the last century had to be used. It can be assumed that many of the published numbers reflect only the situation in the major cities and that for the rural areas there is no record and most likely also no organised waste disposal.

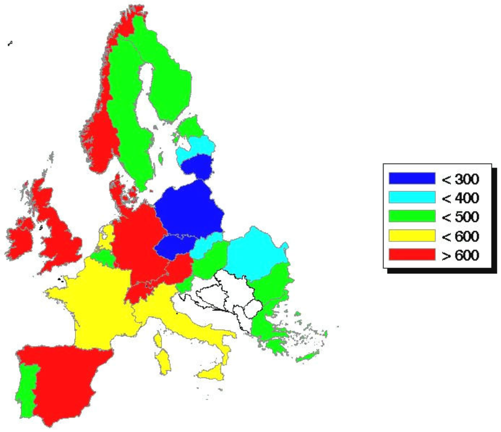

Fig. 10 Waste generation in kg/cap./y in Europe

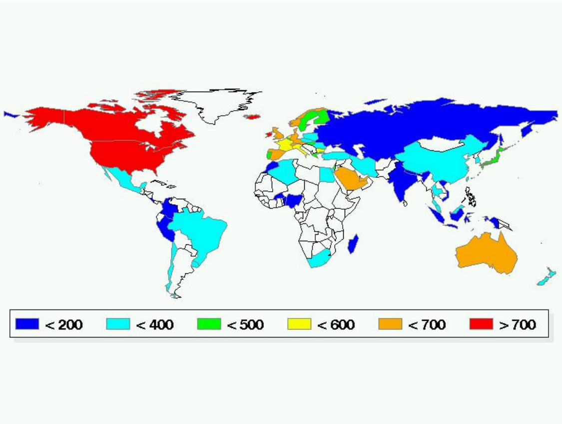

Fig. 11 Waste generation in selected countries in kg/cap./y

According to the above cited data bases the average waste generation in Europe is 525 kg/cap/y. The scattering of the individual numbers is substantial and ranges from 260 kg/cap/y for Poland to 732 kg/cap/y for Ireland. The distribution of waste generation per capita and year is shown in Fig. 10. The same type of graph in Fig. 11 comprises the waste generation in 74 countries all over the world. This graph documents a much wider spread of data with lowest numbers below 100 and the highest close to 1000 kg per capita and year.

A closer look onto the world wide distribution of waste generation numbers gives evidence that the amount of waste a person produces depends strongly on the living conditions, on the cultural, social, economic, and industrial status in a region. It seems rather difficult to define a single parameter which accounts for all influences but it seems obvious that the major influence is associated with the state of economic power and that the gross domestic product (GDP) can be used as a first approach to this parameter. The plot of waste generation as a function of the GDP is depicted in Fig. 12 and documents indeed the above assumed correlation. The GDP and other country specific data are taken from the World Factbook [CIA 2005].

Although there is suspicion that especially for the developing and emerging countries the waste generation data do mainly reflect the situation in the major cities and that in rural areas the situation may be quite different this correlation points out that the poor people cannot afford to throw things away and that the rich ones live in a surplus society. In fact it can be shown that in the past also in the today highly industrialised countries the waste generation increased with time and with the increasing economic well being [Vehlow 1998].

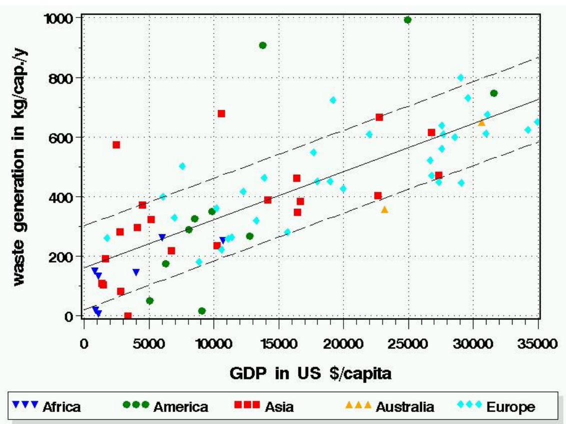

Fig. 12 Correlation between waste generation and GDP for 74 countries

Waste Composition

As diverted as the waste generation numbers is the composition of municipal solid waste in various countries in the world. In many high industrialised Western countries we find approx. 20 - 25 % of organic or putrescible fraction, some 30 - 40 % of paper and paper board, 5 – 15 % of plastics, and up to 10 – 15 % of metal and glass. An example of such waste composition is shown for Germany in the left graph of Fig. 13. The term ‘others’ comprises minerals like ashes and undefined fine waste items.

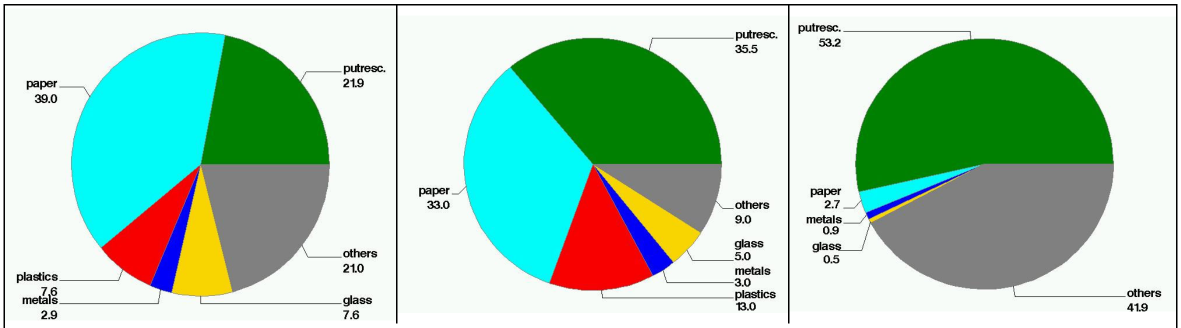

Fig. 13 Waste composition for Germany (left), Japan (centre), and Vietnam (right)

In East Asian industrialised countries people live less from fabricated food and hence the putrescible fraction is much higher whereas paper, plastics, and metal and glass are approx. in the same order of magnitude as in Western countries. As an example the waste composition of Japan is shown in the central graph of Fig. 13. In very poor countries like Vietnam (right graph in Fig. 13) there is very little paper, plastics, metal, or glass but a lot of ashes.

These examples give reason to expect also a correlation between the economic situation and the waste composition in a certain country. It is obvious that the quality of waste composition data sets is even more suspicious then that of waste generation data, nevertheless, the available data sets show a certain consistency if correlated with the GDP. Fig. 14 documents – in spite of the great scattering - a rather good correlation between the putrescible waste fraction and the GDP with a high percentage in the poor and a low one in the rich countries. A similar well established correlation is seen for the paper fraction (see Fig. 15) which increases strongly with the economic power.

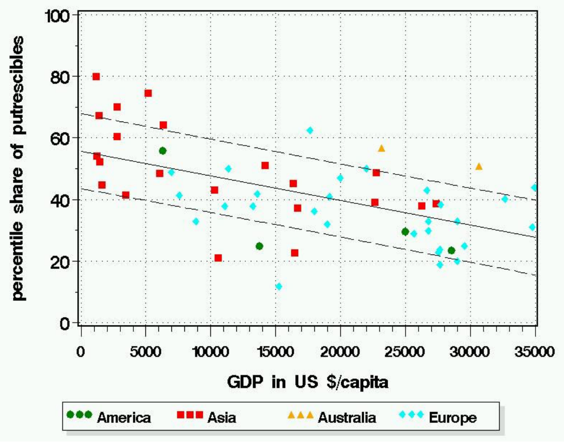

Fig. 14 Percentile share of the putrescible fraction as a function of the GDP

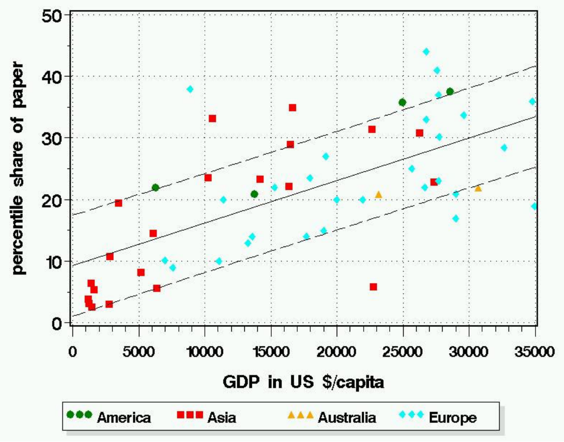

Fig. 15 Percentile share of the paper fraction as a function of the GDP

Waste Management – Theorie and Practice

The Waste Management Hierarchy

The historical mission of waste management to secure hygienic conditions in urban areas is – at least in Central Europe - fulfilled by now. Today three other aspects became more prominent and are the challenges of a sustainable waste management system:

- protection of man and environment,
- conservation of resources (energy, material, land), and
- aftercare-free waste management.

In this context usually a hierarchy of waste management strategies based on prevention, reuse, recycling, composting/anaerobic digestion, energy recovery, and disposal is discussed. Considering the variability of waste streams it seems evident that there is no standard answer to the problem. Practicable waste management systems have to take all local peculiarities and conditions into account and have to balance the ecological benefits and the economical expenses of the implemented measures. However, such hierarchy can be a useful tool in establishing integrated waste management systems [ISWMG 1997]. This is often ignored in political discussions and some proposals in that area seem rather born by faith than by rational consideration. A good example is the controversial debate concerning the priority of material recycling versus energy recovery of waste plastics.

Legislative Regulations on Waste Management in the EU

In the EU the waste management sector is almost totally regulated by EU Directives which have already been or will in near future be adopted by all member states. This practice started very early in the 70th of the last century already and resulted in a harmonisation of national regulations in terms of management strategies, technological measures, and environmental standards.

The fundamental Framework Directive on Waste Disposal 75/442/EEC was issued in 1975 [European Council 1975]. It gives general advises on waste management and disposal. Its objectives are the prohibition of uncontrolled discarding, discharge and disposal of waste and the promotion of prevention, recycling and conversion of wastes with a view to their reuse.

Under the umbrella of this Framework Directive a number of directives have been decided upon which regulate the disposal and/or recycling of specific waste streams, among others

- sewage sludge,
- packaging waste,
- ELV (end of life vehicles),
- WEEE (waste from electrical and electronic equipment),
- PCBs and PCTs,
- batteries and accumulators.

Two other directives are of fundamental importance: the Landfill Directive 1999/31/EC for the management of municipal solid waste [European Council 1999] and the Hazardous Waste Directive 91/689/EEC for hazardous waste [European Council 1991] which will not be discussed here. The Landfill Directive is intended to prevent or reduce the adverse effects of the landfill of waste on the environment, in particular on surface water, groundwater, soil, air and human health and sets up 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 targets are a reduction of biogenic waste compared to the situation in 1995 by

- 25 % in 2006,
- 50 % in 2009, and
- 75 % in 2016.

Measures to achieve those targets should include in particular, recycling, composting, biogas production or materials and energy recovery. Consequently this Directive did not only promote recycling and composting but even more waste incineration which is for the time being the only proven and efficient technology to destroy organic matter.

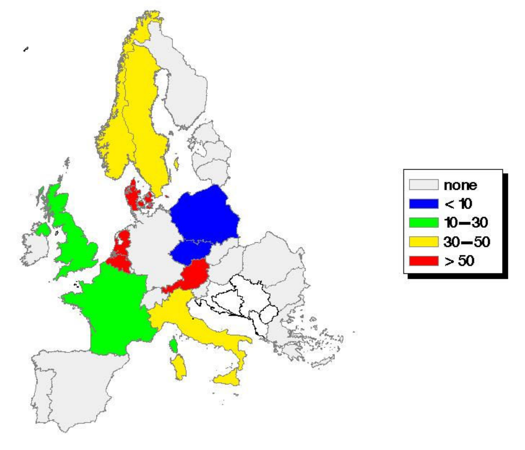

Fig. 16 Landfill tax in Europe in €/Mg

The newly accessed countries have transitional periods for full adoption of these EU regulations. Some countries, among those Germany at the 1st of June 2005, have already enacted a landfill ban for biogenic waste. The consequence is that the – expensive – waste incineration plants which suffered in former years from over-capacity due to cheap landfill sites are running at full load. An efficient instrument to divert biogenic waste from landfills is the landfill tax which is in some countries imposed on untreated waste going to disposal sites. **Error! Reference source not found.** visualises the differentiation between the EU countries. Whereas countries like Germany or Switzerland have issued respective legal acts which prevent the disposal on reactive waste others impose up to 85 €

(e.g. The Netherlands) per Mg of waste going to a landfill. The UK has implemented a floating tax which increases from year to year.

Practice of Waste Disposal

It is obvious that the citizen's potential in preventing waste is limited since our lifestyle, our logistics, and our hygienic regulations require a certain kind of packaging and hence create waste. Prevention is more a challenge for industry and producers to care for low-waste design of products. A certain success in that area has to be admitted since at least in Europe the annual waste generation was almost constant during the last years which means that we accomplished a decoupling of waste generation and economic growth.

Most industrialised countries implemented extensive programs to divert and recycle all kinds of waste fractions starting with paper, glass, and metals and ending with plastics. The situation in Europe is depicted in Fig. 17. The map gives the percentile fraction of the waste stream which has been separated for recycling and contains hence also the rejects from the sorting and the residues from the recycling process. It is seen that recycling is in many countries well established. Belgium, Germany, Sweden and Switzerland apply recycling to more than 30 % of their waste. In the eastern part of Europe recycling is not yet well developed but will significantly increase in future driven by the respective EU directives.

Although in parts very successful, some politically promoted programs pointed out to be very expensive. Essential prerequisites for a successful recycling are high quality products and stable markets. Furthermore, all sorting and recycling processes have to comply with health and environment protection standards, they have to care for the safe disposal of their process residues, and finally they have to consider economic constraints.

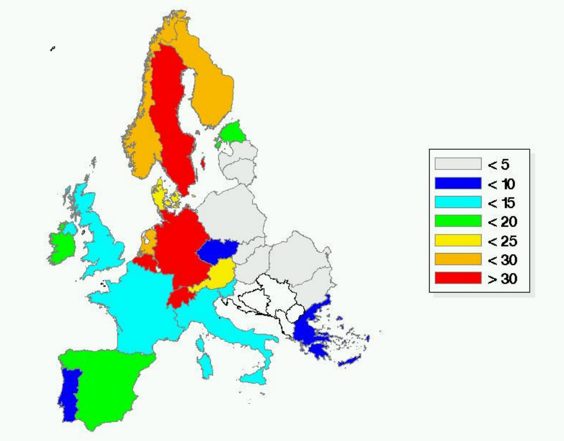

Fig. 17 Percentile waste share diverted for recycling in European countries

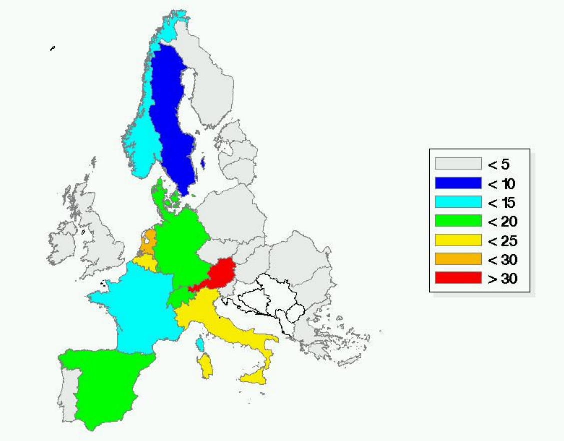

Fig. 18 Percentile waste share diverted for composting in European countries

In poor regions in the world manual sorting and recycling mainly by people scavenging on landfills is common practice. From the local economic as well as employment point of view this activity may be beneficial and for the time being this might be the only way to start any activity in waste management at all in developing countries. The health risk associated with treating raw waste, however, calls for precaution and at least for protection measures.

The recycling or utilisation of the biogenic waste fraction is typically done by composting. As for recycling the major obstacle for a success of this treatment strategy is the compost quality and the only way to guarantee this is source separation, the separate collection of the organic waste fraction. And again as for recycling the health and environmental effects have to be investigated more in detail. Volatile organic compounds, e.g. the effective greenhouse gas methane, and the risk of fugitive bacteria, spores, and other infectious species are major problems, minor handicaps are offensive smell and the space required for a composting facility.

The current situation in Europe is shown in Fig. 18. The share of composting varies from almost zero to more than 30 % in Austria. Most applications are daily cover on landfills and fertilising of public park grounds. In this case the organic matter is mainly source separated garden waste. A wide spread application in agriculture is not seen due to the suspicious and not constant contamination level in compost from municipal waste.

A number of countries promote as an alternative treatment of the biogenic waste fraction anaerobic digestion. This technology is widely used for treatment of sewage sludge from municipal waste water treatment plants. For biogenic waste there seems to be a need for technical development and process improvement. However, this technology looks promising for areas e.g. in East Asia where the waste contains high amounts of organic matter – in most cases with high humidity.

Energy recovery by waste incineration has been used – as reported above already - since more than 100 years to disinfect and inertise the waste stream, to reduce its volume and hence to save space on the landfill. A number of densely populated industrialised countries (e.g. Japan, Switzerland, Denmark) practice combustion and dispose of almost all of their waste remaining after material recycling by this technology. Other states in Europe and America have a lower combustion rate but this is assumed to increase due to the principle of inertisation prior to disposal.

The status of modern waste combustion, its potential to inertise the waste stream, its contribution to energy production, and especially its environmental compatibility will briefly be discussed in the following chapter.

Regardless of philosophical or political perceptions and technical efforts: all waste management systems need a landfill for final disposal. For centuries land filling was pure dumping of trash on sites close to the settlements. There are two major obstacles associated with land filling of untreated waste: its decomposition generates

- landfill gases, especially methane, which contribute to the greenhouse effect and
- leachates containing heavy metals and salts which may pollute the groundwater.

Such impacts have to be minimised and hence siting and operating a sanitary landfill has meanwhile become an expensive task. In calculating the total cost of landfilling the high expenses for aftercare measures on the filled and closed landfill must be considered. That is why there is a tendency to be seen in many regions (e.g. in Europe [European Commission 1997]) to ban the disposal of reactive materials on a landfill.

4 Status of Modern Waste Combustion

4.1 Objectives and Technology

The major aims of municipal solid waste combustion can be summarised as follows:

- destruction of organic pollutants,
- volatilisation of harmful inorganic waste ingredients and their separation in small residue streams, or
- inertisation of inorganic waste ingredients in the grate ashes,
- utilisation of the energy inventory of the waste,
- compliance with the respective air emission regulations, and
- minimisation of technical effort and process costs.

Especially the last topic in the list requires an optimisation of the entire process and it seems obvious that the best way for cost reduction is the consequent application of primary measures or so-called head-end techniques [Vogg 1993] which means technologies improving the combustion process itself and not relying on secondary measures. Such strategies, however, base on a detailed knowledge of all processes and require an excellent combustion control. The objectives of waste combustion following such principles are visualised in Fig. 11.

Today there are more than 2500 waste combustion plants in operation world-wide. The predominant technology is the combustion on a grate with more than 1000 units [Sakai 1996]. A grate system, the so-called European mass burner, requires almost no waste pre-treatment and enables self-sustained combustion of waste with lower heating values between approx. 6 and 15 MJ/kg. This range can be extended to higher heating values if water cooled grates are used. In some countries, especially in Japan, the combustion in fluidised bed systems is practised, too. This technology requires in most cases a size reduction and some metal removal. Less than 100 units are in operation world-wide.

A scheme of a waste combustion plant, a European mass burner equipped with a reciprocating grate, is shown in Fig. 12. The facility comprises a furnace, a boiler and an air pollution control system with a filter, a two-stage wet scrubber and a catalyst for nitrogen oxides abatement. Often a polishing stage (e.g. charcoal filter or jet stream injection) is installed at the back end for safe compliance with the emission limits, especially those of mercury and dioxins.

4.2 Quality of Bottom Ashes

During the combustion inside the combustion chamber the fuel bed material is heated up to temperatures of typically 800 - >900 °C. This temperature guarantees a very good burnout of the bottom ashes. The residual carbon level can be kept well below 1 wt-% and the PCDD/F concentrations are in the order of 1 - 5 ng(I-TE)/kg which resembles values analysed in Central European natural surface soils.

The high fuel bed temperature volatilises thermally mobile heavy metals out of the fuel bed. It causes also an efficient sintering which transforms the inorganic material into stable crystalline phases and fixes the remaining heavy metals in these phases [Schneider 1994]. Well sintered bottom ashes have an elution stability which enables their utilisation as secondary building material. Fig. 13 displays results of the German DEV S4 leaching test on 26 bottom ash samples from full scale waste combustion plants, standardised to the German limits for utilisation in road construction [Pfrang-Stotz 1995]. To give an idea about the relevance of the environmental quality of such materials in relation to conventional building materials the respective test results for concrete samples are included in the bar graph. A comparison makes evident that bottom ashes have the potential to replace conventional building materials with only marginal influence on the environment.

4.3 Recovery of Energy

The recovery of energy is an important aspect of waste combustion. There is not only an economic incentive to make profit with the selling of energy, the energy from waste is to a great extent also regenerative since only the carbon in plastics is originated from fossil sources. In Central Europe approximately 50 - 70 % of the energy inventory of the waste can be attributed to regenerative fuel.

The total energy efficiency of a waste combustion plant is of course lower than that of a power plant due to the energy consumption of all subsidiary units and due to the - for the sake of corrosion - low boiler parameter. If only electricity is produced, the efficiency is 20 - 24 %. In the case of co-generation, with additional utilisation of heat, the total efficiency can reach more than 70 %. The contribution of energy from waste to the production of electric power in industrialised countries is rather low. The respective number for Germany which incinerates approx. 25 % of its municipal solid waste is almost 1 %. If all waste would be burnt approx. 5 % of the electricity could be substituted.

In middle-income and in developing countries the situation is more favourable as demonstrated by the data compiled in Table 1. The theoretical contributions look promising but in reality those portions will not be reached. It has to be considered that for the near future waste combustion should only be implemented in densely populated areas. Furthermore, the low heating value of the waste in many areas makes the combustion difficult and calls for extra strategies, e.g. the co-combustion of other waste streams like wood, shredder residues or even of coal.

4.4 Environmental Quality of Air Emission

The combustion of one ton of waste requires approx. 4000 - 4500 m3 of air. Hence air pollution control is an important aspect in waste combustion. Modern technology guarantees the almost total abatement of acid gases and of volatile heavy metals. All heavy metals with the exception of mercury (Hg) are removed from the flue gas if an efficient dust precipitation is installed. The filter ashes need to be disposed of on special and save disposal sites or they have to be inertised. Hg is trapped in the acid scrubber of a wet scrubbing system and can be recovered. In dry systems its adsorption is improved by the addition of charcoal to the reagent. Hence waste combustion prevents heavy metals in the waste stream efficiently from entering the environment.

Pollutants of special concern and of highest public interest are polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F). The potential of waste combustion for the destruction of even thermally stable organic compounds is extremely high. All PCDD/F and other organic species present in the waste are totally destroyed inside the combustion chamber. The PCDD/F found in the flue gas are formed in the boiler from products of incomplete combustion [Vogg 1986]. This reaction can to a great extent be suppressed by an improved burnout which is achieved by good combustion control. High calorific values of the waste are promoting the effect. Combined with modern abatement technology waste combustion is a real sink for PCDD/F since it prevents far more than 90 % of the PCDD/F load in the waste from entering the environment - which is the case in any other waste disposal option [Vogg1993].

The air emission standards are of similar stringency all over the world and the emission out of modern waste combustion plants, regardless of the type of applied gas cleaning strategy, is extremely low. A compilation of typical stack emissions, ambient air concentrations (for Germany) and calculated immission concentrations in Table 2 indicates that waste combustion has only a marginal influence on the air quality. The last column points out that in most cases the resulting air quality at the location where the plume from waste combustion is reaching the ground is only increased by a small percentage of the situation in the ambient air without that additional impact.

In this context it seems necessary to discuss the fundamentals of setting and of complying with air emission standards. E.g. in many regulations the air emission limit for NOx is 200 mg/m3 measured as NO2. The respective raw gas concentration in a modern waste combustion plant is in the order of 500 mg/m3. Such emission levels would in most countries care for a contribution of approx. 1 % to the total NOx emission. It seems questionable whether the expenses for investment (approx. 50 US-$ per ton of annual capacity) and operation (approx. 10 US-$/ton) can be justified by an achieved reduction in NOx emission contribution from 1 down to 0.2 %.

Most installations of air pollution control systems are rather complex and make waste combustion expensive. At the moment even in industrialised regions there is a tendency to simplify the technology of such plants without changing their environmental compatibility significantly. Primary measures or the above already addressed head-end techniques are the most powerful tools to minimise the cost of waste combustion [Vogg 1993]. New designs rely more on a perfect combustion control in order to minimise the formation of pollutants in the flue gas, or, if this is not feasible, on an abatement as soon as possible in the chain of aggregates in the waste combustion plant [Vehlow 1996]. The principle of best available technology (BAT) is slowly replaced by that of best available technology not entailing excessive cost (BATNEEC). During the last years joint efforts of research and industry have significantly improved the economy of waste combustion. Modern European plants are meanwhile able to treat 1 ton of waste at a total cost of less than 100 €.

5 Conclusions and Recommendations

Waste disposal is one of the big problems associated with the ongoing urbanisation in the world. Waste generation and waste quality are strongly influenced by the economic situation in a certain region. In industrialised and densely populated areas waste disposal is or is going to be regulated in order to reach sustainable solutions. The major aims are to reduce the waste stream and to recover and recycle as many fractions as possible. Such strategies have to be considered with care due to their economy and to their ecological effects before they are adopted in other regions of the world.

Waste combustion is widely used in industrialised regions rather to inertise the waste stream prior to its disposal than to utilise the energy. More than 100 years of experience have converted this process from the former source into an efficient sink of pollutants present in the waste stream.

In middle-income and in developing countries both aspects, the inertisation as well as the energy recovery, can be useful if a simple, robust and low-cost combustion technology is implemented. In such areas where there is often also a need to build up new power plants, a combination of both processes looks rather promising.

6 References

CIA (1999) World Factbook. Available at: *http://www.odci.gov/cia/publications/factbook/country-frame.html*

de Fodor E. (1911) *Elektrizität aus Kehrricht*. Budapest: K.U.K. Hofbuchhandlung von Julius Benkö,

EIONET (2005) European Environment Information and Observation Network (EIONET): Wastebase. http://waste.eionet.eu.int/wastebase/

European Commission (2005) *Integrated Pollution Prevention and Control (IPPC) Reference Document on the Best Available Techniques of Waste Incineration*. Institute for Prospective Technological Studies, European IPPC Bureau, Seville, Spain, July 2005

European Council (1975) Framework Directive on waste disposal. Council Directive 75/442/EEC of 15 July 1975. *Official Journal of the European Communities L 194 , 25/07/1975 P. 0039 – 0041*

Amendments: Council Directive 91/156/EEC of 18 March 1991;
Council Directive 91/692/EEC of 23 December 1991;
Commission Decision 96/350/EC of 24 May 1996;
Council Directive 96/59/EC of 16 September 1996

European Council (1991) Council Directive 91/689/EEC of 12 December 1991 on hazardous waste. *Official Journal of the European Communities L 377 of 31.12.1991*

Amended by Commission Directive 94/31/EC of 27 July 1994 [Official Journal L 168 of 02.07.1994].

European Council (1999) Council Directive 1999/31/EC of 26. April 1999 on the landfill of waste. *Official Journal of the European Communities, 16.7.199, L182*

Amendments: Council Decision 2003/33/EC of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC. *Official Journal L 11 of 16.01.2003*

Commission Decision 2000/738 of 17 November 2000 concerning a questionnaire for Member States' reports on the implementation of Directive 1999/31/EC on the landfill of waste. *Official Journal of the European Communities L 298 of 25.11.2000*

European Parliament and Council (2000) Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste. *Official Journal of the European Communities, 28.12.2000, L332/91*

Eurostat (2005) Waste generated and treated in Europe. http://epp.eurostat.cec.eu.int/cache/ITY_OFFPUB/KS-69-05-755/EN/KS-69-05-755-EN.PDF

Holy Bible. First Book of Kings, 15, 13; Second Book of Chronicles, 15, 60; 30, 14

Hunsinger, H., Kreisz, S., Seifert, H. & Vehlow, J. (1998). Verfahren zur Beschickung der Verbrennungseinheit eines Kohlekraftwerks. *DE-OS 19 723 145 (10.12.1998)*

IAWG (1997) International Ash Working Group: Chandler A.J., Eighmy T.T., Hartlén J., Hjelmar O., Kosson D.S., Sawell S.E., van der Sloot H.A. & Vehlow J. *Municipal Solid Waste Incinerator Residues*. Amsterdam: Elsevier

ISWMG (1997) Integrated Solid Waste Management Group of the IEA. *InfoSheet No. 1 to 8*

OECD (1996) OECD Waste Management Policy Group Discussion Paper on Guidance for Distinguishing Waste from Non-Waste, ENV/EPOC/WMP(96)1, 23. 2. 1996

OECD (2002) OECD Environmental data 2002

UN (2005) UNSD/UNEP 2001 and 2004 questionnaires on Environment statistics, Waste section

U.S. EPA (2005) Milestones in Garbage. http://www.epa.gov/epaoswer/non-hw/muncpl/timeline_alt.htm#9

Vehlow J. (1996) Simple, reliable and yet efficient - modern strategies in waste incineration. *UTA Technology and Environment, 2/96*, 144

Vehlow J (1998) Waste Management Systems in Industrialized and Developing Countries - Generation, Quality, Disposal. In: *Environmental Engineering and Renewable Energy (ed. Gavasci, R. & Zandaryaa S.) Elsevier, Amsterdam, NL,* 405

Vogg H. & Vehlow J. (1993), Low Pollutant Waste Incineration - A Systems Approach to Emissions and Residues. *Interdisciplinary Science Reviews, 18*, 199

Zwahr H. (1996) 100 Jahre thermische Müllverwertung in Deutschland. *VGB Kraftwerkstechnik, 76*, 126