NoE Bioenergy

WP4: Biogenic waste to energy

Barrier Analysis Report

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1 Background

1.1 Regulations for waste management

WP4 deals with the biogenic fraction of municipal solid waste, a material that is not intentionally produced as an energy source but is generated by every citizen every day. This municipal solid waste is rather heterogeneous and characterised by a substantial inventory of contaminants like heavy metals, halogens, alkali metals and persistent organic micro-pollutants. One of the challenges for our highly industrialised society is the safe and aftercare-free disposal of this material. That is why a number of EC directives regulate this area and these directives have already been or will in near future be adopted by national law in all EU countries.

The basis of the EU waste regulations is the Waste Framework Directive 75/442/EEC of the Council of the European Communities [European Council 1975] which has been amended several times [European Council 1991, 1996]. The directive defines waste and sets as priorities for waste management the reduction of waste, its recovery and the use of clean technologies for any treatment. The directive encourages the Member States to use waste as a source for energy. The Packaging Directive 94/62/EC [European Council 1994] requires member states to introduce systems for the return and/or collection of used packaging so that it can be recovered or recycled. The so-called IPPC Directive 96/61/EC [European Council 1996] concerning integrated pollution prevention and control demands that waste production is avoided and that where waste is produced, it is recovered or where that is technically or economically impossible, it is disposed of while avoiding or reducing any impact on the environment. This directive caused the establishment of the European IPPC Office in Seville, Spain, which co-ordinates the compilation of documents describing best available technologies (BAT) for a number of technical processes, the so-called Brefs (BAT reference documents).

According to the Council directive 1999/31/EC on the landfill of waste [European Council 1999] the disposal of untreated biodegradable waste has to be reduced and has been banned already in a number of EU countries in June 2005 with the consequence that a treatment of the waste prior to its final disposal in order to transform it into an inert material is mandatory. In most cases this is done by thermal treatment, for the time being preferentially by waste incineration in grate systems. The Waste Directive encourages the member states to use waste as a source for energy (article 3.1.(b)(ii)) and the Directive 2000/76/EC of the European Parliament and of the Council on the incineration of waste [European Parliament and Council 2000] defines the legal framework of this process.

The latter one, the so-called WID (Waste Incineration Directive) sets stringent standards for technical performance and operational conditions of plants burning any kind of waste. It also regulates the emissions into the air and the control of process residues. All old EU countries have meanwhile adopted the WID. Only few deviations from the EU standards are found in few countries: e.g. The Netherlands set a much lower NO_x limit and Germany reduced the Hg value.

For the new EU countries the course of the integration of the EU regulations into national law is laid down in the accession treatises. There are specific dates defined for reaching specific goals on the way to full implementation.

This is the political framework. Reality, however, is in most EU countries to a significant extent not yet in line with the standards set on the EU level. The adaptation of EU directives into national law leaves also room for distinctive differences. An important one in the context of bioenergy is the definition of waste and the acknowledgement of its partly biogenic nature since it has a great impact on subsidies and with that on the economy of waste-to-energy (WtE) strategies. In Germany for instance waste is not accepted as having any biogenic origin and waste incineration plants are exempted from the CO_2 trading whereas in Sweden 50 % of the power generated in waste incinerators is classified as bioenergy and for the 50 % fossil fraction CO_2 certificates are allocated. The Netherlands regard 50 % of power from waste incineration as biogenic if the conversion efficiency exceeds 30 % and in Finland even 60 % of the energy inventory of waste is considered biogenic.

WP4 is dealing with the biogenic fraction of non-hazardous municipal solid waste (MSW) that is under the regulation of the waste incineration directive. This waste does in principle not include so-called ‘clean’ biogenic waste streams like waste wood from the construction and demolition sector (which is taken care of by WP1 and WP2) or agricultural waste (covered by WP7). However, in the case of biogas generation by anaerobic digestion the spectrum of waste materials will be broadened and kitchen, restaurant, slaughterhouse and similar wet biogenic waste fractions as well as wet biomass from agricultural activities like manure will be included since the applied technology is the same for all substrates.

1.2 Generation and characteristics of MSW

An actual survey on generation of and energy recovery from MSW in the eight partner countries of the NoE supplies an impression of the potential role of waste in the bioenergy sector. The data supplied here are mainly taken from three sources: the Draft Reference Document on the Best Available Techniques for Waste Incineration published by the European IPPC Bureau [European Commission 2004], a small study prepared during the EU FP5 project UP-SWING in 2003 [Vehlow 2003], the waste and energy statistics of Eurostat, OECD, and the European Environment Information and Observation Network (EIONET) [Eurostat 2001, OECD 2005, EIONET 2005], and statistics from national administrative bodies [Umweltbundesamt 2005]. It has to be mentioned that, other than in the energy sector, the basis for waste data is poor. Many data sets found in literature and in statistics published by national and international agencies are not consistent since different countries use different classification schemes of waste and that is why the published data are often not directly comparable. The latter is especially valid for waste composition data. Hence the numbers given below should only be regarded as best estimates.

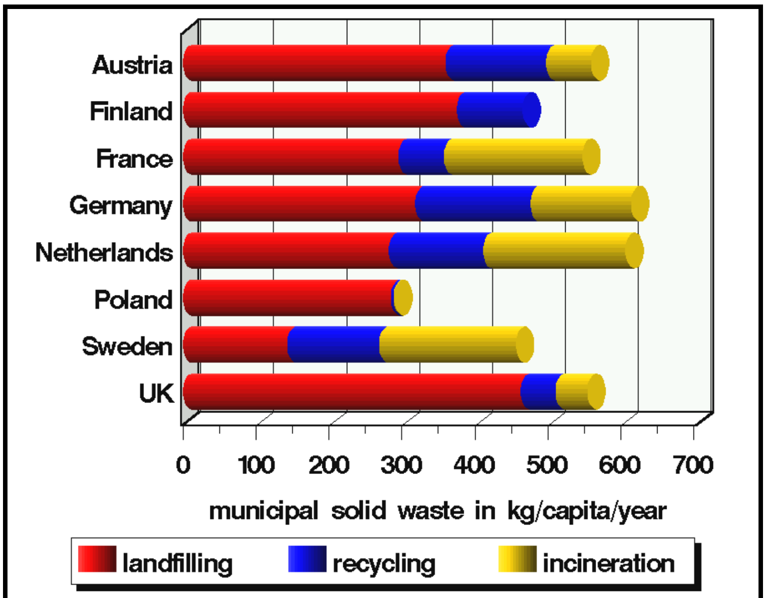

Fig. 1 Generation and disposal of municipal solid waste (2002/2003)

The waste generation per capita and year is shown in Fig. 1. It varies between 270 and 610 kg with the lowest production figure being the number for Poland and the other countries being more close to each other. The bar plot documents also the country specific disposal strategies. Finland and Poland practise almost no waste incineration and with that energy recovery, whereas The Netherlands and Sweden incinerate more than 50 % of their MSW.

The figures for the different waste management routes have to be looked upon with caution. The recycling data are often, like in the case of Germany, those waste streams which are collected for recycling. Information about the actual recycled fraction and the sorting or process residues is in most cases not available. The data do not include co-combustion of waste in industrial furnaces. Actual numbers for this application are difficult to obtain and it can be assumed that most fuel derived from waste and used today, the so-called ‘solid recovered fuel’ (SRF), is coming from well defined waste streams (e.g. light industrial waste or packaging waste) and the amount separated from mixed municipal solid waste is not very high.

Published data for waste composition broken down into fractions such as putrescibles, paper, plastics, metals and so forth have been used to calculate the energy inventory of the mixed municipal solid waste of the eight countries. There are only few more or less actual data sets found in literature and it can be disputed to what extent these are representative or even reliable [Waste 1993, IAWG 1997, Vehlow & Hunsinger 2003, Umweltbundesamt 2005, EIONET, Eurostat 2005].

Lower heating values of the single fractions have also been taken from literature [Hasselriis 1988, McGowin 1989, EER 1993, Kern 2001]. These data again are averages which have to be classified as best guesses. The fractions putrescibles, paper, paperboard, wood and leather have been classified as totally biogenic, for other fractions biogenic shares have been taken from literature [Kern 2001]. Based on these values the biogenic share of the energy inventory of waste has been calculated.

The results of these calculations - which should more be looked upon as rough estimates – have been compiled in Fig. 2. The total length of the bars represents the lower heating value of the waste, the two different colours indicate the fossil respectively the biogenic fraction of the energy inventory.

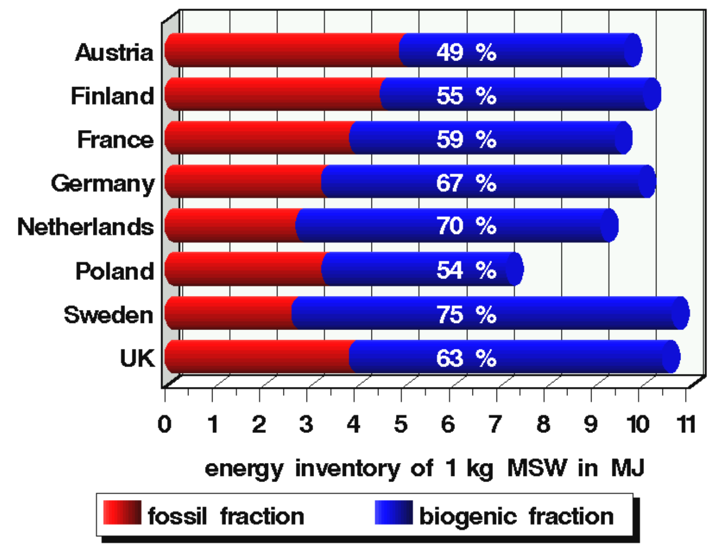

Fig. 2 Energy inventory and the contribution of biogenic waste fractions

Again Poland shows the lowest number with 7.2 MJ/kg whereas the other countries range mainly around 10 MJ/kg. A proof that this type of assessment delivers data which are not too far away from reality is the result of 10 MJ/kg for Germany. This is in line with the mean heating value of 10 MJ/kg which has been reported based on operational data from waste incineration plants [Umweltbundesamt 2001].

According to our calculations the biogenic fraction of the energy inventory of waste varies between approx. 50 % for Austria and Poland and approx. 75 % for Sweden. An average of some 60 % seems a realistic approach.
For bringing such waste heating values into perspective to those of biomass it should be remembered that the lower heating value of waste wood with a humidity of about 20 % is approx. 15 MJ/kg.

1.3 Energy recovery from waste

The following chapter is an attempt to assess the importance of waste and especially of its biogenic fraction as energy source. For this purpose only those waste fractions will be considered which are actually landfilled or incinerated. It is assumed that waste which is today diverted for recycling or composting will not be available for energy recovery. This first approach does not reflect future changes of waste management strategies in countries which have at the moment low capacities for material recycling and/or incineration like Poland or the UK. In some countries even an increase in the amount of waste available for energy recovery might be caused by a ban of composting of organic waste in open air windrow technique.

We will use state-of-the-art waste incineration plants as energy recovery facilities. The conversion efficiency of the boiler of such plants is 80 – 85 %, roughly 10 % of the energy are consumed by the operation of the plant itself [European Commission 2004, Scholz et al. 1995]. Based on these figures approx. 70 % of the energy inventory of waste should actually be available for recovery. The conversion efficiency of modern plants in case of power generation is in the order of 20 – 25 %. For the following calculations a conservative figure of 20 % will be used as average technical power recovery efficiency.

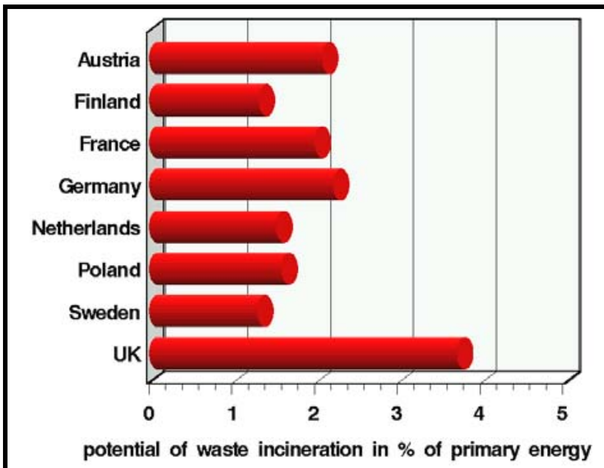

Fig. 3 Potential of energy from waste to substitute primary energy

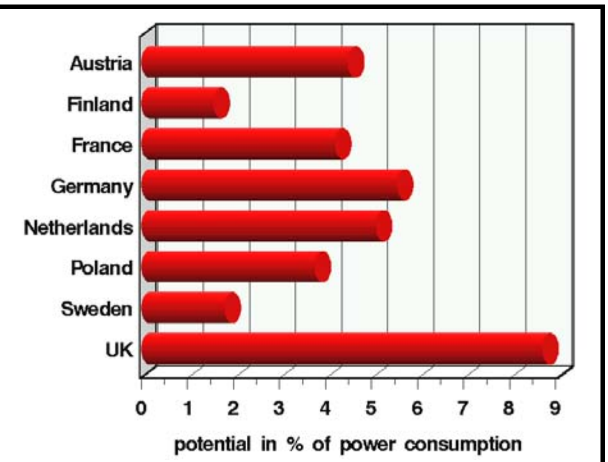

Fig. 4 Potential of energy from waste in relation to electric power consumption

With these data the potential to substitute primary energy or power by waste incineration has been calculated for the eight partner countries. The results are plotted in Fig. 3 and Fig. 4. The results of such calculation reveal a potential substitution of the primary energy demand by waste incineration in the order of 1 - 2 % for most countries. Finland and Sweden have due to climate conditions a higher energy consumption and hence a lower substitution potential. The surprisingly high potential for the UK can be explained by their high waste generation and their rather low recycling quota of only 9.6 % (compared to approx. 27 % for Germany).

The respective calculation in terms of electric power substitution shows a potential of some 2 – 5 % with UK at almost 9 % and again the Nordic countries at the lower end.

The above calculations did not take combined heat and power (CHP) scenarios into account due to the varying ratio of the two energy forms in different plants. In reality, however, CHP is the most promising way to utilise as much energy from waste as possible. It allows the operation of the waste boiler at moderate steam parameters to minimise boiler corrosion. The resulting lower conversion efficiency for electric power can be compensated by efficient use of the residual energy inventory of the steam. There are examples of modern MSW incinerators with overall energy use efficiency exceeding 70 % and in combination with heat pumps even 90 % [European Commission 2004].

Considering the fraction of biogenic energy in mixed waste (see Chapter 1.2) the above substitution potential allows an assessment of the CO_2 savings which can be accomplished if all available waste is used for substitution of fossil fuel.

Mixed municipal solid waste has an average carbon content of approx. 25 % [IAWG 1997] which is in the combustion process almost totally converted to CO_2. For a rough estimate the low concentrations of products of incomplete combustion found in the solid residues (mainly elementary C) and in the offgas (CO, VOC, ...) can be neglected.

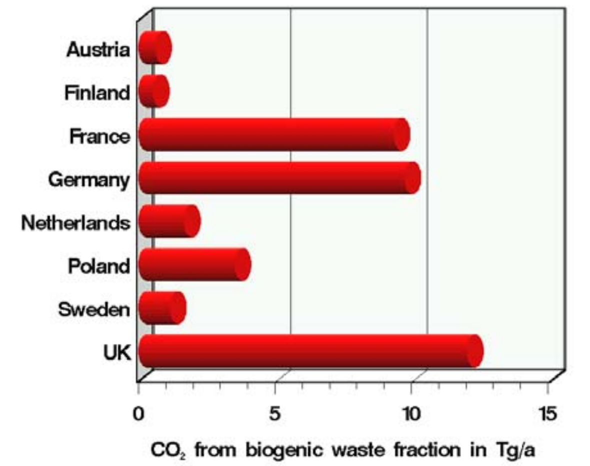

Fig. 5 Estimated climate neutral CO_2 emission from biogenic waste

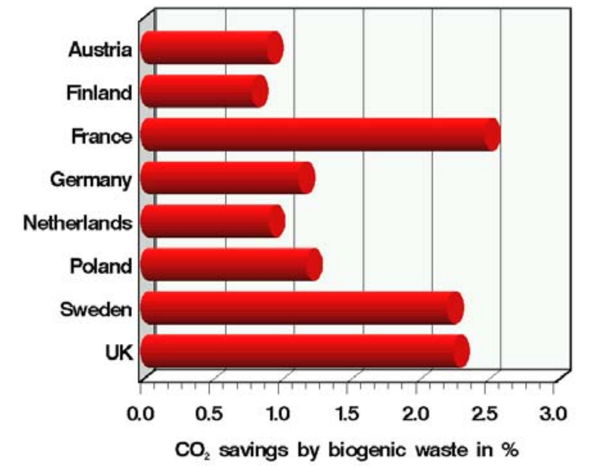

Fig. 6 Potential of energy from waste for substitution of fossil CO_2

The bar plot in Fig. 5 illustrates the release of CO_2 from the biogenic fraction of MSW available for energy recovery. The CO_2 emitted from the biogenic waste fractions has to be looked upon as originated from regenerated fuel and should be taken into account in the CO_2 statistics of the respective countries.

The data show clearly that there is a great potential of reduction of fossil CO_2 emissions if MSW is consequently used for energy recovery. The potential can be assessed if the above calculated CO_2 release from the biogenic energy fraction in waste is brought into context with the actual overall CO_2 emission taken from the latest Eurostat/OECD statistics. The results are visualised in Fig. 6 and indicate a theoretical substitution potential of approx. 1 % for five countries and more than 2 % for France, Sweden and the UK. The differences can be explained by the fact that for France and Sweden the CO_2 emission is only approx. 6 Mg per capita and year whereas for Germany, Finland and The Netherlands figures of more than 10 Mg are reported. In the case of UK we find a moderate CO_2 emission of 8.8 Mg per capita and year, high waste generation and comparably low recycling numbers.

The data presented above represent potentials which are in most countries not yet reached. However, in the EU 15 states, the landfill ban will be in force this year and that means the pretreatment of waste prior to its final disposal has to be extended. It can be envisaged that this push will to a great extent increase the thermal treatment of waste and with that the energy recovery as well. For optimised use of the energy inventory combined heat and power utilisation is the method of choice.

Hence the potential of waste for further substitution of fossil fuel in the energy market will to a much greater extent than today be exhausted in near future. That is why the energy from waste should become one of the fastest growing sectors in the bioenergy market.

2 Barrier analysis

2.1 The cost aspect

Costs are one of the major barriers in all bioenergy scenarios. In most cases the energy from biomass is more expensive compared to that from fossil fuels and thermal processes for energy recovery from waste are especially expensive. This is mainly caused by the effort in gas cleaning in order to comply with the stringent air emission limits. It seems a fair statement that most of the work in technical terms has been done during the last decade to optimise the gas cleaning and reduce its costs. Furthermore the energy recovery efficiency has been increased and this development is still going on with good success since without the revenues from energy sales such processes would be even more expensive.

However, every single aspect in waste management influences the costs, often in a difficult to be estimated way. This is true for e.g. pre-treatment processes which may change the calorific value of the waste fuel, or for the residue management strategies which may depend on country or area specific philosophy as well as on local opportunities.

The gate fee for waste incineration differs from country to country and it is sometimes difficult to get realistic numbers of the process costs. These are often obscured by cross-financing of other waste management strategies and can also be biased by various taxation schemes. Nevertheless, there is reason and also potential to improve the economy of waste treatment processes with energy recovery and in that sense the costs have more to be looked upon as a driver than as a barrier for waste to energy (WtE) processes.

2.2 Legislation related barriers

A major barrier for all kinds of recovery of bioenergy is often the different definition of biomass. In many countries biomass like waste paper (Germany), sewage sludge, black liquor (Austria, Germany) or wood treated with organic preservatives (Austria, Germany) are not acknowledged as biomass which is typically subsidised if used as energy source. There is a need to establish equal conditions in the energy market throughout the EU.

The energy recovery from waste would gain from EU wide uniform regulations in this area, too. Some countries acknowledge a certain biogenic content in municipal solid waste and set respective subsidies for power from WtE facilities. This fraction is 50 % in The Netherlands and even 60 % in Finland and Sweden. Most countries, however, do not include WtE into the list of regenerative energy sources which would obviously have a positive effect upon the economy of WtE systems, especially for thermal waste treatment processes. A similar discrepancy is found concerning the classification of landfill gas which is accepted as biofuel in some countries (e.g. Austria), in others it is not (e.g. Germany).

An important deficit in view of optimisation of WtE strategies is often an unbalanced (national) waste management system which does not present clear legislative definitions and standards for material recycling, biological treatment (composting, anaerobic digestion) and energy recovery. The major reason is a lack in detailed assessment of the ecological as well as the economical aspects of the processes, e.g. by an eco-efficiency analysis [Kicherer 2004]. Especially important in this respect are macro-economic considerations of long-term effects which are urgently needed to establish such systems. Furthermore, the legislative framework does often not allow some flexibility to react on specific local conditions. The latter is especially the case in Germany with its strict rules.

A key question which was during the last years and is still subject of several lawsuits up to the European Court is the distinction between utilisation and disposal. This requires significant changes in the basic waste related directives on the EU level, but the discussion needs to be started in order to pave the way for uniform legislation throughout the EU.

A global obstacle for bioenergy systems is the unequal treatment of electric power and heat regarding tariffs and subsidies. The German Renewable Energy Act, e.g., honours electric power from regenerative sources like biomass, wind or water (the latter only for small power plants) by higher tariffs (9 up to 48 ct/KWh, depending on the source) than that from fossil fuel, large scale water or nuclear power plants. In many other countries power from regenerative sources is subsidised, e.g. in Italy by 8, in Denmark by 10, in Hungary be 5 and in The Netherlands by 2.9 ct/KWh. In the latter country the subsidies are only granted if the energy efficiency of the plant reaches 30 %. Such subsidies are in most countries not considered for heat from biomass. However, these subsidies are not valid for large scale plants including WtE facilities. This in most countries unequal treatment impedes not only the widespread implementation of CHP in thermal waste treatment plants, it has also to be looked upon as important barrier on energy generation in small and large scale biomass plants (WP1 and WP2).

The licensing of WtE plants is in many countries (especially in the UK, but also in Germany) a time and money consuming process. This barrier is not only due to over-bureaucratically legal restrictions. In many cases like in the UK it is also caused by strong opposition of interest groups which can easily base their counter-activity on missing or not clear waste management plans and political decisions. Another, at the moment not definable influence is to be expected from the above mentioned BREF on waste incineration. The standards derived from this document may influence the licensing process in a significant way and they may also impede the implementation of novel technologies which are not yet described or accepted in the BREF document.

A further and rather important sector where coherent regulation is missing is the management of residues from thermal waste treatment. Although for air emissions, almost the same standards have been adopted throughout the EU countries, this is not the case in the residue sector. There are EU-CEN test methods for quality control of such materials but these are not yet applied in all EU countries. Furthermore, there is neither a uniform regulation of bottom ash disposal nor of its utilisation and the management of air pollution control (APC) residues is also regulated in various ways. These materials are in all countries classified as hazardous waste. They have typically to be disposed of on special and expensive disposal sites, however, in Germany they can be utilised - at much lower costs - for backfilling of caverns in salt mines.

The management of solid residues and especially the disposal of APC residues contribute substantially to the high costs of waste incineration. Especially the regulations on APC residue disposal influence significantly the selection of the gas cleaning strategy in WtE plants (compare comments in chapter 2.3).

2.2.1 Actions to overcome legislative barriers

- Studies on the suitability of different types of biomass for energy generation to strengthen arguments for a harmonised EU wide regulation of biomass categories and for acceptance of a certain fraction of biogenic inventory in MSW.
- Studies on the profits of CHP especially in WtE plants to push comparable support for heat as that for power for optimised utilisation of bioenergy
- Development of standard criteria for the disposal and / or utilisation of bottom ashes
- Further harmonisation of test methods and quality standards
- Round robin tests for comparison of existing test procedures and the relevance of standards based on them

2.3 Barriers related to sustainability

Within this barrier report, three commonly accepted forms of sustainability social sustainability (SS), economic sustainability (EcS) and environmental sustainability (ES) are utilised within the concept of sustainable development (SD) in order to place the theme of sustainability in context for this work package. A focus on the environmental components of sustainability is maintained. In this brief discussion, it is sought to address three important items. Firstly a working definition for sustainable development for this report will be provided and the prime focus on environmental sustainability will be explained utilising an approach outlined by Goodland and Daly [Goodland & Daly 1996]. Second a number of general links between ES and WtE will be established – as well as contributions of WtE to ES. Thirdly a number of difficulties in such areas will be outlined.

A dominant focus is maintained here upon the contribution WtE activities can make to ecological or environmental facets of sustainability and to challenges associated with them. Hence, if a contribution to ecological sustainability is the goal, then sustainable development can be seen as being one part of the means to reach that goal. As material flow and energy concerns are central to this work sustainable development is considered to be development without growth in throughput of matter and energy beyond regenerative and absorbtive capacities.

It is important to note that a focus on ES does not imply that the inter-linkages with the other forms of sustainability have been lost. ES is required by society in a number of ways and contributes to other forms of sustainability such as social and economic. ES itself seeks to improve human welfare and thus SS by protecting the sources of raw materials used for human needs, and furthermore ensuring that the sinks for human wastes are not exceeded in order to prevent harm to humans. Similarly, the preservation of natural resources that provide economic services (e.g. wetlands providing water filtration and purification) as well as goods traded in markets (e.g. forestry biomass) indicates contributions to EcS. Within this context, three concrete areas of ES relevant to the conversion of biogenic waste to energy are held to be relevant:

- Firstly, a very important part of ES can be deemed to translate into holding waste emissions within the assimilative capacity of the environment without impairing it.
- Secondly, ES also translates into maintaining harvest rates of renewables within regenerative rates.
- Thirdly, ES can also be approached by holding the depletion of non-renewables to the rate at which renewable substitutes can be created.

According to these arguments, areas such as the following can be discussed as being relevant to this work package:

- limiting the growth in throughput of energy and matter (a global summary contribution);
- limiting the emission of harmful substances that may, or do, harm the assimilative capacity or quality of the environment, or are perceived to contribute to harm to humans in some manner (e.g. greenhouse gas generation such as methane in landfills would fall into this category as would heavy metals release from disposed waste);
- related to the above mentioned preserving sinks and while this is clearly related to the reduction of emissions, the diversion of material from landfill (an anthropogenically confined pollution sink) into safe energy recovery, can also be seen in a physical manner;

- reducing demand for primary energy from other sources – particularly energy derived from fossil fuels;
- related to the above, reducing the demands for raw materials both non-renewable and renewable;
- contributing to reduction in leakage of renewables from the energy system.

Other thoughts that are of merit to consider are that at this point in time a great proportion of the productive and assimilative capacity of the biosphere is already utilised. As such, the limiting factor for much economic development has become natural capital as much or even more as man-made capital in many instances. In some instances this is the case already: in marine fishing fish have become limiting - rather than boats to catch them, timber is limited by remaining forests - not by saw mills, petroleum is limited by geological reserves and by the atmospheric assimilative capacity for carbon dioxide – not by refining capacity. In coming decades, it is conceivable that biofuel will become limited by available biomass – not by facilities with which to convert it to electricity, high grade energy carriers, or heat. Thus, in some way, utilisation of biogenic waste allows preservation of a resource that is expected to become scarce in the foreseeable future and it also represents an improvement in the efficiency of (already extracted) resource utilisation.

Using the concepts and context outlined in this text, the utilisation of the biological content of wastes for heat and power generation contributes to a number of the points made above. Energy from biogenic waste clearly makes some contributions to broader ES.

In this context, “sustainability-related” barriers to energy from biogenic waste are related to areas where the utilisation of the biogenic fraction does not currently contribute positively to the above areas or where there are at least remaining doubts and concerns.

In general terms, the view on sustainability outlined above points towards a necessary focus upon two aspects for WtE scenarios. The first is the generation of energy from biogenic material contained in waste streams. Here positive effects are generally perceived and no major specific barriers are perceived.

The second has to do with the need for the inertisation of the waste stream by elimination, destruction or fixation of pollutants to guarantee aftercare-free disposal. Here, concerns about sustainability of all activities are paramount. The treatment for disposal or utilisation of any kind of waste in any process has to be performed in a way that any immediate and future negative effects on human health and on the environment are definitely excluded. At present there are clear concerns that harmful substances may be liberated.

The open question for this task is the definition of secure final sinks of pollutants present in the process residues. Of paramount importance are halogen and alkali compounds and heavy metals that can are generated or liberated by combustion processes. These categories can be present in flue gases, fly ash and in bottom ashes. Special attention has to be given to the gas cleaning concept in WtE processes in this regard. The gas cleaning starts typically with a dust removal which can remove essentially all heavy metals except mercury and the particle bound organic micropollutants from the raw gas along with the fly ash stream. Chemical gas cleaning can be achieved by wet or dry methods.

Wet scrubbing systems produce the minimum amount of residues since they are operated close to stoichiometric limits. However, the effluents have to be purified from heavy metals in a waste water treatment plant and then the highly contaminated solid residues from this purification (produced at the rate of a few kg per tonne of waste) must then be disposed of within special sites. Where suitable sewerage systems are available the effluents with their high salt content, mainly chlorides but also sulphates, can be discharged. If such systems are not available, they have to be evaporated and the obtained salts have to be disposed of. Due to the high solubility of the residues, safe disposal is not an easy task. The only convincing disposal pathway at the current time appears to be within old salt mines – often in cavern backfilling. Dry scrubbing systems produce a much higher amount (factor 2-3) of similarly highly soluble salts. However, they also contain adsorbed mercury and eventually also PCDD/F. Consequently their disposal is also problematic. At present the only viable pathway again appears to be cavern backfilling as is performed in Germany.

A sound and sustainable solution for the management of water soluble residues – which are classified as hazardous waste in all countries – is still lacking. This is not only a problem in terms of environmental compatibility but also of public acceptance of the waste incineration process.

Fly ashes from waste incineration are also classified as hazardous waste. They contain less water-soluble components but carry substantial loads of thermally and water-soluble mobile heavy metals and organic micropollutants like dioxins. It is evident that an aftercare-free disposal of untreated fly ashes is also difficult and expensive. Hence there is a need for fly ash inertisation including the recovery of valuable ingredients from this residue stream.

Technical processes have been developed in the last decades for this purpose, however, in almost all countries their high costs are a strong barrier for their implementation. Another barrier (in Germany at least) is the acceptance of the disposal of gas cleaning residues in salt mines as utilisation (see above).

Whether this decision can be defended in terms of ecological sustainability (as defined previously) and acceptance remains an open question. Similarly, the potential for later remediation requirements for current disposal sites remains as a valid issue. There is reason to ask for a thorough review of existing technologies and for the eventual development of new strategies including the recovery of heavy metals and even for halogens and nutrients – e.g. phosphates. Among other things, such strategies may serve to reduce the overall costs of waste management and avoid the disposal of higher amounts of critical substances. There is a need for investigation of whether the avoided costs for disposal and aftercare make such processes cost-effective for the community in a macro-economic sense even when their products are not competitive on the market.

2.3.1 Actions concerning sustainability

- Studies for the definition of final sinks for pollutants that can guarantee aftercare-free disposal.
- Development of sustainable management processes for solid residues from WtE processes to comply with the final-sink-concept, especially for APC residues.
- Evaluation of the potential to recover substances like nutrients or valuable metals e.g. by extraction or flotation.

2.4 Barriers related to social aspects

The major barrier concerning social aspects in the WtE area is its lack of public acceptance. This started approximately 25 – 30 years ago with increasing public awareness of environmental problems. The major focus of controversy was and is waste incineration, but in principle all waste related processes suffer from more or less bad reputation. We will summarise here opposition by citizens, by interest groups and by politicians without allocating specific types to specific groups.

There are various types of opposition or non-acceptance depending on target, political view, personal involvement and philosophy of life. An unspecific one is the NIMBY syndrome which applies to most big technical complexes. This may be enforced by site-specific nuisances like noise, traffic or visual intrusion by height and eventually even design.

Then there is a specific opposition against waste treatment processes with a focus on waste incineration. The reason is mainly a presumed impact on environment and health by air pollution of heavy metals and dioxins. Indeed some 20 years ago waste incinerators were the technical plants with the highest specific air emission of pollutants – especially HCl, dioxins and some heavy metals like mercury and cadmium. Intense research, the immediate technical implementation of elaborated process understanding and legislative regulations on the national and EU level - e.g. the above mentioned EU Waste Incineration Directive - have changed the situation significantly. The air emission standards of WtE plants are meanwhile the most stringent ones for technical processes. This change in the technical performance, however, is only slowly recognised by the public.

Another type of opposition against WtE bases on the assumption that material recovery is to be preferred and, done the right way, no waste is left for treatment or disposal. This, at a first glance, convincing argument may look different if a rational technical assessment is performed on the whole integrated waste management system. First of all there must be a permanent demand or market for the recycled products and furthermore the same control of the fate of waste born pollutants has to be applied in recycling processes as is accomplished in waste incineration. Recycling and mechanical-biological treatment (MBT) processes are still less investigated in that respect and the fate as well as the effects of heavy metals, halogens and organic micro-pollutants which are present in the municipal solid waste input to these processes is often not known in detail.

Another area that needs more attention is that of occupational health. There are some investigations found in literature, which looked into the risk for labourers in waste incinerators in terms of heavy metal uptake and also some test series on the risk of pollutants and especially of fungi and micro-organisms in sorting and MBT facilities. The whole area, however, would gain from complete understanding of health risks. Such knowledge is also important in view of the public perception of waste management and with that also of WtE systems.

2.4.1 Actions concerning social aspects

- Information of the public about advantages and risks of WtE strategies
- Information of the public on the actual environmental data of technical plants and of immission data in their vicinity
- Assessment of macro-economic effects of waste management strategies to support optimum solutions according to local conditions (link WP2.1 environmental effects)
- Investigation of health effects in waste treatment facilities
- Case studies

2.5 Biomass supply related barriers

There is no generic barrier in material supply to WtE plants since waste is generated every day. This fact can be obscured by waste management systems which still base on permits to use cheap landfills. A consequence of such in former years especially in Germany practised strategy was the complaint of opponents against waste incineration that there was too much expensive incineration capacity installed and no new plants were needed. Since June 2005 the Landfill Directive banned the direct disposal of reactive waste and it became obvious that there is a shortage in WtE capacity in almost all EU countries.

An obstacle for the conversion process is of course the extreme heterogeneity of mixed solid waste and its inventory of contaminants. A particular challenge for waste incinerators is the increasing amount of special waste fractions like residues delivered from sorting or recycling plants. Although these residues may be more homogeneous than mixed waste their often-high calorific value makes them not suited for direct combustion in existing plants. Some of these waste fractions require not only changes in logistics, storage and feeding of the plant but also modifications of the process like water-cooling of the grate.

The biomass contribution to the calorific value of waste has been described above. It is not only varying by country but also by season and region but the range of its variation is also difficult to discern. These properties make it not easy to get precise information upon the actual biogenic energy inventory of waste or of ‘solid recovered fuel’ (SRF) that is fed into the process. Such knowledge would help to pave the way for legal acceptance of the biogenic energy content of the above-mentioned fuels.

If the range of variation of the biogenic share is narrow there should be no problem for its consideration in fuel classification. Otherwise, an online monitoring process would be helpful. At the moment the permanent analysis of the ^{14}C content of the CO_2 on the off-gas seems to be the only promising monitoring method. This method is rather complicated and not suited for implementation in an industrial process but it might be used for standardisation of simpler methods, which have yet to be developed.

A different approach to get full acceptance of the biogenic energy share in waste is the production of a fuel from waste which is totally existing of or at least highly enriched in biogenic matter (‘biogenic SRF’). Such development is, however, only to be recommended if the resulting process is cheap and does not solely depend on subsidies to be economically viable.

2.5.1 RTD goals for biomass supply

- Development of strategies to achieve homogenous feeding from non-homogenous fuel e.g. by replacement of the established bunker-crane system
- Development of simple methods for documentation of the biogenic fraction of a material, e.g. by ^{14}C analysis (scientific standardisation)
- Development of production processes for biogenic SRF from waste

2.6 Technology related barriers

Harmful ingredients like halogens, phosphorous, sulphur, alkali and heavy metals in MSW respectively in SRF are the major reason for special technical measures in thermal WtE processes. The partitioning and behaviour of the pollutants is well understood in conventional mass burn waste incineration systems but less known in pyrolysis and gasification processes and to some extent even hardly investigated in co-combustion scenarios in utility boilers and industrial processes. Especially for the latter ones the emission effect but eventually even more the effect on the process itself and on the product quality needs more investigation.

Another area which is not well documented in terms of pollutant behaviour is anaerobic digestion. Although the inventory of harmful ingredients in the feedstock of this process should be lower than that in municipal solid waste it is necessary to understand the fate of critical elements and compounds in this process in order to establish sound disposal routes of its residues.

Although the fundamentals of the implemented technical processes are known, process control, eco-efficient off-gas cleaning and residue management are still no easy tasks. Process control is an area where research institutes and industry are permanently developing new concepts. The main challenge is the control of transient processes like start-up and shut-down of plants, fluctuations of the calorific value of the fuel, or failures in the feeding system. For this purpose a better understanding is needed to enable the fast online monitoring of such events and to develop fast acting countermeasures.

Numerous efficient technologies are available for cleaning of off-gas from combustion plants. This is not to that extent the case for gasification and pyrolysis processes. Especially the removal of tar and sticky fly ashes at elevated temperatures needs further R&D effort.

After most countries have adopted the Council Directive 96/62/EC on Ambient Air Quality Assessment and Management [European Council 1996] measurements have pointed out that in many urban areas the PM10 concentration in the ambient air is often exceeding the standard. This special air quality problem is currently being tackled. Although an allocation of the main sources is difficult and traffic may contribute much more than WtE systems this issue has to be looked upon in more detail.

The importance of adequate residue management has already been discussed in terms of its effect on the sustainability of the entire waste management system in chapter 2.3.

Another risk caused mainly by halogens, phosphates and alkali compounds is corrosion and fouling in the boiler and wear of refractory material in combustion processes, which requires high maintenance expenditures.

The same harmful ingredients have also to be taken care of in biological treatment like anaerobic digestion for biogas production. Here is a wide field for further research. Many small plants which are momentarily built up on single farms in some countries like Germany and Austria and which are heavily subsidised have to be classified as simple technology which would gain from further development.

In the area of gaseous fuels from waste one of the open questions is the prediction of landfill gas evolution over time from old landfill sites and from the direct disposal of residues of MBT processes.

For the WtE processes used today different maturity and operation experience has to be stated. The advantage of waste incineration in grate systems is the long-term experience from operation of thousands of such systems. Much less experience exists for the operation of pyrolysis and gasification for energy recovery from waste and also the effects of co-combustion of waste or SRF on the operation of, maintenance in, and products from industrial processes need more fundamental investigation. This can also be stated for anaerobic digestion plants as soon as waste fractions are fed in. Such lack of knowledge is an obstacle to select the best-suited WtE process in a given scenario.

Further, the various WtE processes have different optimum throughput capacities. For large-scale application the conventional European mass burners with combustion on grate systems have advantages in terms of their economy. Other technologies are better suited for smaller throughputs. There is often too little knowledge to decide upon the optimum size for a defined waste stream and a required operation mode on a rational basis. Hence effort should be spent on the development of small-scale WtE for mixed waste, but also for special waste fractions.

The final area where more detailed information would be welcome is the evaluation of total process chains in different scenarios. A broad assessment which takes type of waste, collection strategy, logistics, storage, pre-treatment, and different treatment processes - anaerobic treatment, thermal treatment, co-treatment – into account would facilitate the establishment of optimised WtE systems and/or optimised waste management strategies. A task for the same purpose, which would contribute to the same goal as such assessment, is the demonstration of successful WtE strategies in full scale. A promising approach - also in view of public information - is a standardised investigation program of existing full-scale plants which includes not only complete mass stream analysis but also all costs associated with the operation and maintenance of the plant, with the consumption of energy and consumables and finally with the management of all residues.

2.6.1 RTD goals for technology improvement

- Development of optimised process control strategies for transient operation conditions for all WtE processes including combustion
- Basic research on corrosion effects in conventional WtE processes and co-combustion scenarios
- Increasing the efficiency of electric power generation by higher steam parameters without increasing the risk of boiler corrosion
- High temperature removal of fine dust for gas turbine application in gasification
- Compilation of experiences with different WtE systems
- Evaluation of eco-efficiency of WtE systems and the influence of fuel and plant size, especially to explore the potential of small-scale technologies
- Studies for process chain optimisation
- Demonstration of optimised WtE strategies and case studies (success stories)

3 Topics for joint research

3.1 General remarks

The barrier analysis resulted in a multitude of single RTD goals characterised by different quality. The structure selected for the barrier analysis implicates that the same RTD goals show up various times. The activities and RTD goals derived from the analysis of the different types of barriers are used as basis to compile a list of prioritised research topics which

- help to overcame major barriers outlined above,
- are important for the optimisation of WtE scenarios in the biogenic waste sector for the EU or various EU member countries,
- look promising in terms of business opportunities,
- match the expertise and equipment and meet the interest of at least more than two partners, and
- look promising for integrated research activities.

A more thorough analysis reveals the option to cluster the above listed activities and RTD goals under the five topics

- residue management in WtE and biomass systems,
- assessment of macro-economy of waste management strategies,
- control of pollutants in WtE processes,
- fine particle monitoring and removal,
- eco-efficient small-scale WtE systems, and
- profits of CHP in WtE scenarios.

In most cases a data collection via theoretical studies, review of literature and internal workshops / seminars was proposed as a first step to analyse the problem and lay the basis for technological developments. The projects are designed to make best use of the expertise of the NoE partners and try to establish efficient joint research. Most projects will gain from the inclusion of other partners but this will be decided once more detailed proposals are elaborated.

3.2 Residue management in WtE and biomass systems

The management of the residues from WtE processes is expensive and often not performed in a sustainable way. This is also valid for other biomass processes. To improve the situation strategies and technologies for the inertisation or utilisation of residues from thermal and also biological WtE processes will be developed. In terms of recovery special attention has to be directed to nutrients like phosphorous or potassium. A prerequisit of the project is the definition of the final destination of pollutants like heavy metals, their separation and their safe disposal.

The main ash streams of the various thermal conversion processes and even more the gas cleaning residues contain critical components like soluble salts, heavy metals and organic pollutants which complicate their management. There is no consistent regulation, neither for their disposal nor for their eventual utilisation.

On the basis of a profound knowledge of the fate of pollutants and building on the definition of their final sinks the potential of utilisation or inertisation of single residues has to be elaborated. It is obvious that there is no single solution or one optimal process. Each residue calls for its specific treatment. On top of that local conditions like available and suited disposal sites or interest in utilisation and respective markets for the products require the development of different treatment processes even for the same type of residue. Literature lists a number of processes which are either in use, which are tested in full scale or which have been operated in demonstration plants already.

A proposed project has to start with a literature review and an overview of the current practise of residue management in the EU. Under consideration of the standards and quality requirements for utilisation and disposal scenarios in the partner countries best suited scenarios will be presented. In addition to the theoretical work new technical processes have to be developed for special applications, e.g. for nutrient recovery.

The project has also importance for WP1.

3.3 Assessment of macro-economy of waste management strategies

The competition between recycling and energy recovery and with that the fact, that many waste management strategies are un-balanced has been identified above as one of the major barriers. Missing or unclear political decisions in this area cause not only an inefficient use of energy in waste treatment systems but are also obstacles in view of public perception of WtE processes.

For overcoming theses barriers a thorough assessment of the macro-economy of waste management strategies is proposed. Suited tools for starting are case studies and the documentation of existing well balanced systems. The assessment should include the entire chain of waste treatment from collection through pre-treatment, recycling and recovery down to the final disposal of in most cases hazardous process residues. Depending on local conditions the study should also explore the advantages of different energy recovery systems as for example comparing thermal and biological treatment and the best option to utilise the recovered energy. The potential of novel technologies especially in decentralized and small scale scenarios is another item to be examined more in detail.

A first attempt in the outlined direction has already been started in a small study on the profits of combined heat and power in WtE in the partner countries of the NoE. (WP2.1 in parallel for environmental and climate effects)

The project has importance for WP1 and for WP2.2.

3.4 Control of pollutants in WtE processes

As soon as waste is used as fuel the control of pollutants associated with the waste derived fuel is mandatory. This requires not only the knowledge of the inventory of pollutants in the fuel but also the complete understanding of the fate of these pollutants in the total process chain and their appearance in the various residues. Furthermore the eventual formation of secondary pollutants and their fate has to be considered.

Such knowledge is available for the conventional waste incineration process and for conventional utility boilers (link to WP1), but less developed for some novel processes, for the co-treatment of waste fuel in utility boilers or other industrial processes and also not for biological processes.

A second and mainly open question is that of the final sink for the various residues which depends not only on their pollutant load but even more on the speciation and the properties of the single pollutants.

There is a lot of information available but in most cases the data are not complete or not comparable. A first step to improve the situation could be a workshop with presentations of experts for the different WtE processes which allows a synopsis and should entail a comparative study to document the state-of-the-art and disclose eventual research need for special fuels, processes, residues, or pollutants. Waste fuels from various sources like municipalities, building and food industry, or agriculture with a significant biogenic fraction will be taken into account in view of their major contaminants.

The project should especially concentrate on the underestimated soluble salts which seem to be the greater problem in view of their final destination than heavy metals (which can be stabilised) or organic pollutants (which can be destroyed).

The results of such studies help to design pollution minimised WtE solutions on the basis of local conditions in terms of type of waste to be treated, required process capacity and energy utilisation options.

The project has also importance for WP1.

3.5 Fine particles monitoring and removal

The emission of fine particles with diameters in the low µm and nm range has become a topic of concern since the Council Directive on Air Quality has been adopted in national law in most countries. For conventional MSW incinerators first measurements of the dust emission indicated no major problems with fine particles. This may be different in other biomass combustion or gasification systems.

It is envisaged to launch a project starting with a review which tries to correlate ambient air quality data with presumed influence of installed WtE plants. A second step should be a monitoring campaign on selected WtE plants with different conversion technology and different APC systems. In this campaign also biomass plants should be included. A parallel third step is the selection of efficient and low-cost fine particle abatement systems. In this area technological development – at least adaptation of existing technology – has to be considered.

Especially for gasification systems operated with gas turbines the deposition of fine particles at high temperatures is a challenge. This aspect should be covered in the project.

The project has also importance for WP1.

3.6 Eco-efficient small-scale WtE systems

For conventional waste incineration systems large scale is more economic than small scale. The decrease in throughput goes along with a progression in treatment costs which is mainly caused by the complex air pollution control system. Hence in areas with low population density thermal waste treatment and WtE can be rather expensive. There are novel technologies like pyrolysis and gasification plants which have lower optimum capacities than European mass burners in grate technology. For the time being these technologies seem not to be competitive in Europe. However, if small-scale WtE plants are needed or if special waste streams have to be treated, this might not be the case. A not well investigated case is the anaerobic digestion of wet waste and biomass, which should also be promising in small scale.

It is intended to launch a program for the assessment of the best suited WtE technology for small scale application considering all technologies. The study will compare currently used technologies. It will investigate their potential as stand-alone systems and also consider the combination with de-centralised pre-treatment processes which serve big central WtE plants. Municipal waste as well as wet organic waste and wet biomass from agriculture like manure will be taken into account. The latter process is thought to be technically optimised concerning its application, its energy efficiency and its residue management.

An eventual program will be conducted in close co-operation with WP2.2 and WP7.

3.7 Profits of CHP in WtE scenarios

Many countries subsidise power generation from biogenic sources but the utilisation of heat is in most countries not acknowledged at all. One consequence is the development of waste boilers which operate at high steam parameters for increasing the power efficiency. Such practise is expensive and often entailing problems with boiler corrosion. A better use of the energy would be enabled by consequent combined heat and power utilisation. It is intended to compile the state-of-the-art in this sector, to study successful cases and to assess the potential in the EU. A joint publication which covers part of that topic is in preparation.

The project has also importance for WP5 and WP2.2.

4 Future steps

All of these projects have a link to other WPs and it is the task of the WP leaders to review all proposals and to identify crosscutting activities.

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