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THE INCINERATION OF WASTE IN EUROPE: ISSUES AND PERSPECTIVES

A Report Prepared by IPTS
for the Committee for Environment, Public Health and Consumer Protection
of the European Parliament

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PREFACE

In 1996, the Chairman of the Committee for Environment, Health and Consumer Protection of the European Parliament requested IPTS to perform a study titled "*The Recycling Industry in the European Union: Impediments and Prospects*". In 1997, following one of the conclusions of this study, he requested a follow up study from IPTS. The new report, titled "*The Legal Definition of Waste and its Impact on Waste Management in Europe*" aimed at providing the reader with a better understanding of the practical consequences of the legal definition of waste on waste management in Europe and in particular on the recycling, treatment and disposal of wastes. In 1998, he requested two studies related to waste management from IPTS. One deals with the management of electric and electronic waste, while this one covers the issues related to the incineration of waste. With this mandate, as in the previous studies, IPTS contacted a large number of actors concerned and provided a platform for exposing all the main positions relevant for this debate in Europe. IPTS contacted in particular the various services of the European Commission concerned, most industrial actors and NGOs. The views expressed in this study do not necessarily reflect those of the European Commission.

The specificity of IPTS is the observation and follow up of technological change, in the broad sense, in order to get a better understanding of its links with economy and society. IPTS carries out this task with scientific rigor in fields such as energy, environment, information technology or food and health. At the same time the Institute carries out research to improve the understanding of the impacts of new technologies and more generally the relationship between technology, economy and society.

The present work fits the mandate of the IPTS in its task of providing lights to the European policy makers about selected topics. It is also particularly timely. At the dawn of the European Monetary Union and of a truly single market, it is necessary to tackle potential legal barriers to trade while ensuring the best possible level of environmental protection to the European citizens. Waste management is a pan-European societal problem, close to the citizen, fully relevant to the quest for sustainability.

While waste prevention, the first priority of the European waste management policy, has so far failed to deliver substantial results, attention is focussing on waste treatment and disposal. Recovery, including recycling, is on the increase due to regulatory pressure. However, significant environmental, economic and health issues keep arising around the two unavoidable waste disposal options: landfill and incineration. However, incineration can allow recovery. The European Commission is now involved in preparing new legislation on both options in an effort to improve the regulatory situation, and address the most burning issues.

IPTS wishes to thank all the experts who responded to the successive calls for contributions made during this difficult study. The amount and high quality of input received has permitted, we hope, the production of a useful document. In view of the complexity of the matter, we hope this report will provide a sound basis for policy discussions at EU level in the area of waste management.

IPTS, March 1999

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EXECUTIVE SUMMARY

Incineration (including combustion, gasification and pyrolysis) is but one family of options for the disposal and recovery of waste. Today, landfilling remains the most widely used waste disposal option across the European Union (EU). However, a majority of actors expects an incineration and co-incineration to take an increasing role in the medium term due to forthcoming regulatory restrictions in landfilling. Dedicated municipal solid waste incineration capacity throughout the EU is estimated to be 45 million tonnes/year.

The incineration of waste is a complex issue and the scientific background behind the various options is still far from clear. Four main dimensions can be identified: technological, environmental, economic and social.

The incineration of waste can be performed using various technologies. Most of the dedicated municipal solid waste incineration occurs inside grate furnaces. Other technologies exist such as fluidised beds. Each of these technologies has numerous variations in order to optimise the processes for specific conditions. The co-incineration of wastes substituting other fuels in industrial facilities such as cement kilns, steel works or power plants is also popular and occurs under other technical conditions than in dedicated waste incinerators. This causes intense commercial competition and many debates about the emission limits applied to the various facilities. Additionally, thermolysis, a technology which had failed in the past, appears to be preparing a come-back in the waste management field, thanks to new combinations of proven process steps.

Each of these options has different advantages and disadvantages, but the combination of commercial competition and regulatory pressure imposes a continuous improvement of environmental profiles and recovery efficiencies. For example, all new waste incinerators recover energy, but many existing ones still do not and flue gas cleaning is becoming both more effective and more widespread. It is therefore not possible to adopt a uniform attitude vis-à-vis the incineration of waste. In order to use each technology in the best possible way, the pre-treatment of waste can be very important. The European waste legislation regards the selective collection of waste as beneficial to the subsequent management of the waste streams, be it by incineration or by other means, but the opinions of the various actors are more nuanced.

A number of environmental issues are linked to the incineration of waste. The most publicly sensitive ones are related to atmospheric emissions of dioxins and heavy metals, now largely addressed by flue gas treatment. The management of ashes and slag also requires caution because of high heavy metal content. Cement kilns avoid the problems of ash and slag disposal as most minerals get trapped in the clinker and are recovered as raw material but some issues still remain on smokestack emissions. Debate continues about the potential release of heavy metals from concrete on the long-term. Slags and ashes are often used (reportedly safely) for certain civil engineering applications.

From an economic standpoint, the cost of incineration across the EU is still very variable but is still rising in general due to the increasingly stringent emission limit requirements. For state-of-the-art facilities, costs appear to be stabilising. In some European countries, a functioning market for the incineration of wastes in different types of facilities has emerged. Overall, there is now a drive to maximise energy recovery in all the forms of incineration of waste, generating income.

Waste management has a significant cost, making waste prevention always desirable. Considering the large investment necessary to achieve an adequate waste management system, long-term economic and legal stability are also required.

The incineration of wastes is currently covered by three directives, one for hazardous wastes and two for municipal wastes. However, they leave a number of other unregulated. In order to actualise and bring coherence to the European regulatory scene, to close the existing regulatory loopholes and to be more comprehensive in the control of emission limit values, a new directive is being proposed, replacing the two directives on municipal waste.

The public image of the incineration of waste in the EU is still by and large a reflection of the existing worst cases and its broad acceptance remains low. However, locally, state-of-the-art facilities have gained public acceptance. Where possible, this has provided the extra benefit of developing heat recovery for district heating because facilities could be located near populated areas (e.g. Copenhagen). In order to increase the number of these positive cases, more efforts must be made to highlight responsibilities and improve communication. More factual information about waste management, including the specific merits of good installations, must reach the public and decision-making must take public preferences into account. Where this has been achieved, efficient and well received waste management systems were established.

Today, the wide variety of materials covered by the notion of "waste" in the European Union are increasingly perceived as a resource to be used as efficiently as possible. Various economic actors are already competing for it resulting in a rise of efficiencies for material and energy recovery in incineration. If proper regulatory safeguards are in place that maintain a certain flexibility and the use of decision support tools such as life-cycle assessment spreads, this trend should lead to the natural optimisation of waste management in Europe. Any sound waste management approach should match the various types of waste to the available technical options for recovery and treatment in order to find the best overall combination. The global objective is to find the best possible use for waste while minimising adverse effects on public health and the environment.

1. Introduction

The aim of the European waste policy is to minimize the adverse impacts of waste handling and disposal on public health and the environment. The best strategy to adopt in waste management is undoubtedly the prevention of waste generation. This has been recognized by the European waste management strategy, but so far to little avail beyond the continuous progress made by industry to provide an increasing level of service per kg of raw materials used. Other options must therefore be called upon to manage the waste produced. Incineration and landfilling are the main final disposal options, even if incineration is increasingly performed with energy and metal scrap recovery.

It is important to bear in mind that **incineration is only one of the options available for the management of waste**. As a consequence, **its merits must be weighed against those of the other options before taking waste management decisions** which generally bear significant economic and environmental costs. Incineration (term used here to cover the thermal treatment of wastes including combustion, gasification and pyrolysis), just as landfilling, composting or other options, has to fit locally within a coherent integrated waste management strategy. **The challenge is to find the right mix of options for every case** in order to maximize recovery and minimize adverse impacts.

Considering the number of factors to be taken into account, the best waste management solution for every community must be developed on a case-by-case basis, within the frame of clear general principles and guidelines that apply across the whole of the European Union. The amount and nature of waste generated, the surface area to be served, the geography and geology of the area, the investment capacity available, the existence of production and waste management infrastructures, the presence of industrial combustion facilities, the attitude of the local population, are examples of typical parameters to take into account.

In spite of the improvement of techniques and technologies for the incineration of waste over the last 25 years, **this option for the disposal and recovery of waste remains politically controversial**, both in the European Union and worldwide. Competing economic sectors, concerns about global climate change, fears of the public for long-term human health, environmental considerations and local community management issues interfere and fuel endless debates. Nevertheless, sooner or later, hard decisions must be taken and consensus must be found.

This study limits itself to the analysis of the issues raised by the current practice in the incineration of wastes in the European Union, with an emphasis on municipal solid wastes. It first presents an attempt at defining the size of the practice in the European union. It then goes on to cover important technological elements before reviewing the main issues raised by the incineration of wastes. Finally, the study provides a general analysis of the problem and proposes a few elements of discussion.

2. The incineration of waste in the European Union

Because municipal solid waste (MSW) is self-combusting, its incineration is an old practice in Europe. The first dedicated waste incinerators were built more than a century ago (1876) in Great Britain to eliminate waste while avoiding the deleterious effects of rotting organic material. Today, the incineration of waste has gone a long way, but in the hierarchy defined in the European waste management strategy, it comes (even with energy recovery) with a lower priority than prevention and material recycling. Disposal comes last, but, as shown below, landfilling remains by far the number one option overall for waste disposal in Europe, collecting more than 70% of the MSW. The overall share of incineration appears to remain limited to less than 20% (see Table 1).

Because of increasing concerns about groundwater contamination, the decreasing availability of land in many areas, aesthetic and public health issues for landfills, incineration has remained a valid disposal method both for municipal and industrial waste. It is widely expected to increase its share of the waste treatment and disposal market because of the recovery targets introduced by the European Packaging Directive and by the forthcoming limitations introduced by the future European landfill directive.

Additionally, beyond MSW, many waste streams can be used as energy sources: general industrial wastes, hospital waste, used tyres, car shredder residues, spent coffe grounds, used automotive oil filters, and so on. Many of these wastes are hazardous. They originate from very diverse sources and have very specific characteristics. As a result, those that are burned are often incinerated in special installations (see section 3.3.4) and involve different actors than those involved with MSW. Because of this diversity, comprehensive statistics on hazardous waste incineration are very difficult to obtain.

Over the last few years, waste incineration has attracted a lot of negative attention from the public, largely because of a scare of dioxins. Important national differences exist. Table 2 presents a statistical overview of the incineration of municipal solid waste in the European Union. It shows that today, most MSW incinerators recover energy. The only incinerators without energy recovery that remain are concentrated in Belgium, France and Italy and their days are numbered.

The incineration of waste does not only occur in dedicated installations. An increasing proportion of both hazardous and non-hazardous waste is being used by combustion installations in existing industrial sectors in replacement of fossil fuels. Currently, the main sector concerned is cement production, followed by power plants. While the latter alternative only aims at recovering the energy content of the waste under the form of electricity and/or heat, the former recovers both the energy from the organic fraction (to contribute to driving the process) and the minerals remaining after combustion as raw material in the clinker. Around 12% of the energy used in the EU for cement production comes from waste.

In these installations, waste is burned alongside other fuels, giving rise to the terms “co-combustion” and “co-incineration”. While people in industry prefer to use the term “co-combustion”, referring to the process, the European Commission has formally agreed to use the term “co-incineration” to highlight the fact that wastes are being burned. Therefore, this report will follow the official terminology of the European Commission on this point.

Table 1: The disposal of municipal solid waste in the European Union.

Country	Total estimated MSW production (in M t)	% Landfilled	% Incinerated
Austria[1]	2.78 (1996)	32	16
Belgium[2]	4.00 (1997)	42	35
Denmark[3]	2.77 (1996)	15	56
Finland[4]	3.10 (1990)	77	2
France[2]	33.00 (1997)	60	30
Germany[2]	40.00 (1993)	62	28
Greece[4]	3.20 (1992)	93	0
Ireland[5]	1.85 (1995)	100	0
Italy[2]	26.0 (1997)	85	8
Luxembourg[5]	0.30 (1995)	24	48
Portugal[5]	3.60 (1995)	86	0
Spain[6]	15.20 (1997)	85	8
Sweden[2]	3.60 (1996)	31	39
The Netherlands[2]	14.20 (1997)	69	20
United Kingdom	40.00 (1997)[7]	85[8]	8[8]
European Union	**133.55 (1996)[9]**	**71**	**18**

Because of the generally poor reliability and comparability of waste statistics, the figures presented here are merely indicative.

[1] Source: Austrian Environment Ministry, January 22, 1999
[2] Source: Energy from waste plants: databook of European sites, Juniper Consultancy, November 1997; for NL, different statistics co-exist (e.g. 52% landfilled and 31% incinerated)
[3] Source: Ministry of Environment and Energy, DK
[4] Estimations adapted from Eurostat, 1997
[5] Source: European Environmental Agency, Waste Topic Center, 1998
[6] Source: Mr Martinez de Hurtado Gil, Spanish Ministry of the Environment, 20 January, 1999
[7] Source: see footnote 2; estimated 25 Mt from household waste only
[8] ENDS Daily, 1998
[9] Data on MSW production from APME, 1998, not the sum of the column (193.23 Mt); % calculated from the table.

Table 2: Estimated installed dedicated incineration capacity and levels of energy recovery for municipal solid waste in the European Union

(Sources: ISWA, 1997; Eurostat, 1997; EEWC/Juniper, 1997, unless otherwise indicated)

Country	Total number of MSW incinerators		Total estimated incineration capacity (Mt/yr)		Estimated percentage with energy recovery (%)
Sources:	ISWA	Other	ISWA	Other	
Austria[10]		3		0.5	100
Belgium	n. av.	18	n. av.	2.5	78
Denmark	34	26	2.6	2.9	100
Finland[11]	n. av.	1	n. av.	0.07	100
France	95	79	9.5	10.8	72
Germany	36	51	9.6	13.5	100
Greece[12]	n. av.	0	n. av.	0	-
Ireland	n. av.	0	n. av.	0	-
Italy	15	22	2.1	2.2	91
Luxembourg[13]	n. av.	1	n. av.	0.15	100
Portugal	n. av.	0	n. av.	0	-
Spain[14]		9		1.13	100
Sweden	21	15	1.8	2.1	100
The Netherlands	6	11	2.3	5.7	100
United Kingdom	12	7	1.7	2.1	100
European Union	**n. av.**	**243**	**n.av.**	**43.7**	**88.5**

n. av.: not available - : not applicable

While the explanatory memorandum on the proposed directive on incineration indicates the existence of 437 municipal waste incinerators in the EU, a Juniper Consultancy study enumerates only 275. Likewise, the estimated incineration capacities are 39.8 Mt/yr and 47 Mt/yr respectively for the EU as a whole. This may be explained by the fact that:

1. The Juniper study was completed in 1997, while the data used by the Commission originate from a 1992 TNO study and
2. The Juniper study excluded the facilities treating less than 30 000 t/yr.

Because of their poor ability to comply with existing environmental legislation, most small plants are expected to have disappeared. Today, energy from waste is estimated to deliver 43 000 GWh/yr in the EU, or 1.8% of inland energy consumption[15].

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[10] Source: ARA, January 14,1999;
[11] Source: H. Nygard, Ekorosk, Finland, Workshop on fuel and energy recovery, Brussels, Nov. 26, 1998
[12] Source: Juniper Consultancy, UK, Energy from waste plants: Databook of European Sites, Nov. 1997
[13] Source: Juniper Consultancy, UK, Energy from waste plants: Databook of European Sites, Nov. 1997
[14] Source: Mr Martinez de Hurtado Gil, Spanish Ministry of the Environment, 20 January, 1999
[15] Source: PODS/EEWC, 15 January 1999,

3. Important technical considerations

3.1 Technology and practice, two crucial factors

As we have seen, there are a number of combustible waste categories requiring disposal of which municipal solid waste (MSW) and non-hazardous industrial waste (NHIW) form the great bulk of the tonnage; other categories only represent a small part of the total. For historical reasons MSW has been the category that has been burned most in the past despite NHIW often having better fuel characteristics. However, both MSW and NHIW have poorer combustion characteristics than fossil fuels. All wastes therefore need to be burned in specifically designed combustors.

The nature and amounts of emissions and residues from the incineration of waste depend largely from (i) the nature of the waste treated and sometimes the presence of a pre-treatment (e.g. for recycling), (ii) the technologies used and (iii) the operating conditions in the facility. One overall parameter is that the combustion temperature should be in the range 850°C to 1100°C. The lower limit is that necessary to ensure complete destruction of harmful organic chemicals and the upper limit is that above which the production of thermal NOx becomes unacceptably high.

Various types of incinerators are currently manufactured. The choice of technology depends on the combustibility and characterization of the wastes as liquid, sludge or solid. Gases will not be considered here. The most suitable technology can then be identified based on the specifications of the waste (see sections 3.2 and 3.3).

Waste can also be burned in combination with other fuels in existing industrial processes: this is co-incineration. In that case, it is either burned in power plants, blast furnaces, lime kilns or in cement kilns, which are large rotary kilns operated at high temperatures. In all cases, the characteristics of the pre-treated waste feed must be compatible with the industrial processes considered in order to maintain operational and product quality criteria (see section 3.4). The emission standards of these processes are different than for dedicated incinerators. This is a key issue in the debate.

3.2 Key features of a waste incinerator

A waste incinerator is not an isolated furnace, but a complete industrial installation containing most or all of the following features:

- Waste storage and handling
- Waste feeding
- Combustion in the furnace
- Heat recovery followed by steam and electricity production
- Air pollution control (flue gas treatment)
- Residue (ash and wastewater) handling

The combustion stage itself is proceeding in several sub-stages:

- Drying
- Heating up and release of volatile substances from the combustible material

- Ignition and oxidation of volatile substances
- Char burn out: combustion of solid carbon in the presence of oxygen.

3.3 The main technologies

The incineration of waste is far from being always performed under the same conditions. It is not our purpose to provide here an extensive coverage of the technology, but a few basic elements are useful to understand some of the issues raised around the thermal treatment of waste. The technology is constantly evolving in order to meet ever stricter environmental standards. Currently, the main technological advances introduced include on the one hand those that increase combustion and energy production efficiency, and, on the other hand, those that improve the efficiency of end-of-pipe emissions control. In all types of furnaces, energy recovery occurs through a boiler located after the combustion chamber or integrated to its exhaust. The boiler uses circulating water to recover the heat from the combustion gases in the form of steam or hot water. A number of different designs are used to that effect (e.g. water wall, bundles of water filled steel tubes, …).

3.3.1 Grate furnaces

Grate furnace incinerators are by far the most common technology for the incineration of MSW. They perform the so-called mass burn which requires minimal pre-processing (such as sizing, shredding, etc.) and occurs in facilities of varying size (from 50 to more than 2000 tonnes of waste per day) usually fed continuously. The waste streams they receive are not always very consistent.

As indicated by their name, grate furnace incinerators consist of a furnace in which the waste burns over a grate. They usually operate in a gas temperature range of 750°C to 1000°C. Air for combustion is supplied by fans or blowers under and over the grates. The main variations in this technology are associated with the design of the grates (either fixed or moving). The moving grates are designed to increase mixing and air flow in the mass of burning waste in order to achieve a more complete combustion. These variations result in significant differences in terms of gaseous emissions from the incinerators and in both quantity and quality of the ashes produced. The large excess (in the order of 100%) of air needed for the satisfactory combustion of wastes in these furnaces has two main disadvantages: energy loss in the stack through the gases and need for a large boiler volume to handle the extra volume of gases.

3.3.2 Rotary kiln furnaces

Rotary kiln waste incinerators are not so popular for the mass incineration of waste in Europe but are commonly used for the incineration of hazardous wastes. A rotary kiln rotates the waste in a cylindrical furnace in order to optimize mixing and provide a uniform burn. It usually operates in a gas temperature range of 800°C to 1000°C, possibly with a post-combustion chamber reaching temperatures of 850°C to 1200°C, and resists well to high temperatures. Gases, liquids, pastes, solids and even some items that are somewhat bulky can be handled in large quantities by rotary kilns. Even though they are mostly used in a continuous mode, they can also be operated in batch mode. Small ones can even be mobile and allow on-site treatments.

3.3.3 Fluidised bed furnaces

This technology consists in a bed of sand kept in a fluid motion by hot air flowing upwards through it. This air is also used as primary combustion air. Fluidized beds for waste incineration typically operate in a maximum temperature range of 750°C to 1000°C, more typically from 750°C to 850°C and they have a high combustion efficiency.

Two main types of fluidised beds are used in Europe for the combustion of waste. In 'bubbling' beds, air velocity is maintained close to the maximum above which bed material is carried away. In 'circulating' beds, air velocity is high enough to entrain part of the bed material which is then captured and returned to the bed. This second design allows more fuel to be burned in the bed because more heat can be carried out of the bed by the recirculated material. In terms of efficiency of energy recovery, fluidised bed combustors have an advantage over grate furnaces because they can operate with only 30-40% excess air.

Fluidised beds can handle liquids, solids, pastes and gases as long as they can be injected through nozzles and neither melt nor slag. This bars the incineration of bulky items but has the advantage of maintaining a more uniform temperature in the furnace. This is why they are mostly used for refuse-derived fuel (RDF) after significant pre-treatment. RDF is a material proceeding from waste specially prepared so that it can be used as a fuel. It has been processed and brought to known specifications for combustion (e.g. calorific value, ash content, particle size) even though it does not fulfill the stringent criteria of fuels and remains legally a waste. RDF is mostly pre-treated municipal solid waste. In rare cases, fluidized beds are also used for the incineration of municipal solid waste but their presence is expected to grow in the next few years (see Table 8).

3.3.4 Other incinerators

Waste incineration can also occur in a more selective manner in smaller facilities dedicated to specific kinds of wastes or to specially pre-treated waste. These specialized forms of waste incineration are often performed in commercial or industrial tailor-made facilities that usually receive consistent waste streams. As a result, they usually benefit from optimized operating conditions and treat much smaller tonnages of waste that the mass burn facilities.

One of the designs used is the "starved air" or "two-stage" incinerator in which wastes are partially burned and partially pyrolysed at the front end of a hearth with the resulting char being fully burned out at the back end. These incinerators are usually ram-fed in a discontinuous fashion. One use for these plants is to burn hospital waste. Another design is based on the principle of a rotary kiln, often water cooled, which is popular for burning hazardous wastes as they can burn sludges and liquids as well as solids. Catalytic combustors are special furnaces that rely on a catalyst to burn wastes with low organic concentration.

3.3.5 Co-incineration

Wastes can also be burned in other installations than dedicated waste incinerators. These industrial facilities face few technical barriers to take advantage of the calorific value and/or of the mineral content of the waste provided it is pre-treated to suit the process. The main limitations derive from the composition of the waste and its possible contamination with elements that can impact the quality of the industrial products. In practice, the main industrial candidates to incinerate waste, besides the waste incinerators, are the steam and electricity producers, the blast furnaces, the lime kilns and the cement kilns.

The primary objective of the waste incinerators was traditionally to stabilize and reduce the volume of wastes. However, energy recovery has now also become an essential objective. The primary objective of the candidates to co-incineration is the production of industrial products such as energy, iron, lime or cement. The cement producers prefer to talk about “co-processing” because they use the mineral fraction of the wastes as raw material for the clinker. In short, one can say that while the dedicated incinerator must adapt to the waste, the co-incinerators adapt the waste they take to their processes (see also section 4.1.5).

The industrial actors involved in co-incineration have specific requirements for the waste they use. The energy producers want to obtain or maintain as high as possible a thermal conversion efficiency while the cement and steel producers also need to preserve the quality of their products. This imposes both process requirements and specific characteristics on the waste to be used such as calorific value, ash content, chlorine content or metals content. For example, the presence of chlorine in the waste feed is a major concern for co-incineration because it leads to the accelerated corrosion of the facilities, and in the case of cements it ends up as an undesirable impurity of the clinker. In the case of heavy metals, while cadmium or nickel from wastes may be interesting for the production of certain steel alloys, copper is mostly a nuisance for the quality of the product. An energy producer is not at all interested in the metal content of the waste for its electricity production while a cement producer wants calcium, silicium, iron and aluminium. However, all are concerned about the emission of heavy metals to the environment. Each can therefore best take advantage of different types of wastes. Section 3.5 proposes a schematic comparison of the various technical options for the incineration of waste.

3.3.6 Thermolysis and gasification

Unlike the classic waste combustion technologies, thermolysis, another word for the scientific term ‘pyrolysis’, is a thermal physico-chemical pre-treatment in the absence of oxygen. It does not achieve a complete oxidation of the waste. In the non-integrated (single) thermolysis processes, the closed reactor produces combustible gases containing condensable hydrocarbons and a solid (char). These products can be burned elsewhere. In the integrated processes, both gas and solid are directly burned or gasified (syngas). This leads some people to consider thermolysis as a recycling technology not to be considered in a discussion about the incineration of waste[16]. Others consider that non-integrated thermolysis is a pre-treatment of waste[17]. It is a more complex process than incineration.

During thermolysis, the organic matter is decomposed by external heat (450-750°C). In modern installations, about 10% of the energy generated by thermolysis is thus used to provide the process heat. Classic incinerators can also be operated locally, close to the grates, in a deficit of oxygen and perform thermolysis to some extent.

[16] D. Uhlig, DSD, , January 21, 1999
[17] Comité Thermolyse de Ciney, January 23, 1999,

Gasification is a thermal degradation of organic matter in the presence of a few percent of oxygen. This process has long been used for biomass in some European countries but is newly being developed for municipal solid waste. The main interest of gasification is to allow, besides the classic combustion and steam generation, the use of gas turbines with electricity generation efficiencies much higher than those achieved by steam turbines. R&D in this area is continuing.

The technology for thermolysis and gasification is still considered by many people as lacking industrial maturity but a number of small capacity plants (~30 000 t/year) are in operation or in start up phase in Germany. In spite of a number of plant failures in the past, novel combinations of better proven process steps (e.g. thermolysis + gasification) are giving this technology a new lease of life[18].

One of the main advantages of thermolysis is its capacity to produce combustible gases and a sort of char that can be used in industrial operations. Typically[19], 1 tonne of thermolized municipal solid waste produces approximately 200 kg of water during pre-drying, 390 kg of hot gases (calorific value: 13 MJ/kg) and 410 kg of solid residue containing 240 kg char (17 MJ/kg) and 160 kg minerals and metals. These values may vary according to the MSW treated and to process conditions: for example, a higher temperature will lead to a higher production of gas and will leave less solids. The solid carbon residue is like a char or a low volatile high ash bituminous coal, poor in sulfur but contaminated with some heavy metals.

Regardless of the process, after screening to separate ferrous, non-ferrous metals and minerals, the char can be sent to a combustion or to a gasification unit in an integrated process or washed with water in order to be stored. In the non-integrated process, the char is an alternative fuel for cement works, lime industry, steel works or classic power plant. The design size of integrated facilities is large (more than 100 000 tonnes per year). Non-integrated facilities are smaller (typically less than 50 000 tonnes per year) and are adapted to conditions of dispersed waste generation.

Unlike the classic grate incinerators, which require to operate close to their nominal capacity (60-100%) to avoid problems, thermolysis installations can reportedly operate in a wider range of capacity (40% to 150%). If this technology gains acceptance, this could provide the flexibility to adapt to variations such as seasonal tourist populations or changes in waste management systems. In spite of the recent progress in the development of this technology, many voices call for further demonstration of the merits of thermolysis at industrial scale. A number of uncertainties about cost and final residues also need to be addressed. Nevertheless purchasing intentions for these technologies in Europe appear to be increasing (see section 5.3).

3.4 Emissions and residues

Combustion thermally decomposes matter through oxidation, thereby reducing and minimizing the volume of wastes, and destroying their pathogenicity along with the part of their toxicity linked to organic compounds. It can be applied to industrial, municipal, and hazardous wastes, provided that they contain organic material since it is primarily organic substances that can undergo and sustain thermal oxidation.

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[18] Prof. A. Fontana, 1 February 1999, .
[19] Prof. A. Fontana and Dr G. Jung, 25 January 1999,

After combustion, wastes are converted into CO_2, water, ash and small amounts of a wide range of volatile and solid residues (e.g. CO, soot,…). Depending on the composition of the initial waste (and sometimes of the fuels used to support combustion), compounds containing halogens, sulfur, nitrogen and metals may be produced. These compounds, are deleterious to the atmosphere, and highly regulated (emissions limits). Thus, to meet regulations, incinerators need to be equipped with end-of-pipe devices such as scrubbers, precipitators, filtration units or membranes. The nature and amount of these emissions depend to a large extent on the nature of the waste, but also on the conditions of combustion (physical properties of the waste, level of oxygen present, turbulence, temperature, duration, and so on). Good combustion combines the advantages of minimising boiler fouling and corrosion as well as the emission of most undesirable organic substances.

Besides water, there are essentially four types of emissions to the atmosphere from the incineration of waste:
- gases: CO, CO_2, NOx, SO_2, HCl, HF, …
- mineral dust: fly ash
- heavy metals: Pb, Cu, Hg, Cd, Ni, As, etc…
- organic molecules: soot, PAH and other hydrocarbons, D/F, volatile organic carbons, etc…

Flue gas treatments are in place to reduce all these emissions.

Gases, like in the case of any other combustion facility, may contribute to global warming (see section 4.1.2), acidification and to a small extent to ozone depletion and to tropospheric smog. They also have effects on human health (e.g. irritation of the lungs by breathing sulphur oxides) and corrode the boilers.

The main danger from the organic molecules released in the flue gas lies in potential effects on human health (e.g. volatile organic compounds). These effects can be direct or indirect by bioaccumulation and biomagnification through the food chain, and are difficult to quantify (e.g. dioxins). However, organic compounds can be destroyed either by heat, photodegradation or biodegradation. Therefore, a complete oxidation is essential.

Heavy metals are of concern for their human toxicity and ecotoxicity. However, to be able to exert this toxicity, they must be bioavailable. For example, lead dissolved in water can exert its neurotoxicity while cadmium or chromium in steel alloys used for furniture are not a public health hazard because they are fixed and not bioavailable. However, unlike organic molecules, heavy metals cannot be destroyed. All efforts must therefore be made to avoid the presence of heavy metals in wastes, but for the unavoidable fraction, the heavy metals present in wastes must be returned to the environment in a non-bioavailable form, i.e. non breathable and non leachable. One way to avoid these issues is to use pre-treatment and classification in order to stop as much of the heavy metals as possible from entering the furnaces in the first place. During incineration of waste, part of the heavy metals go to the flue gas and part to the solids (ashes, slag,…). The distribution between the various phases depends on the metal itself, the amount of metal entering the process and the conditions in the process. It is therefore difficult to give precise a priori indications in this respect, but certain heavy metals are more volatile than others (e.g. mercury, cadmium, …). The capture of these metals is usually performed in flue gas treatment leading to the highly hazardous character of flue gas treatment residues. Immobilisation of the collected dust, ashes and slags after combustion is possible but expensive.

Very fine mineral dust (fly ash), and in particular the famous PM10 (particles of less than 10 microns) is mostly a problem for the lungs if breathed and should therefore be captured and fixed. Apart from the gases, all the other flue gas contaminants are bound to each other and form particles because of their electrostatic and adsorption properties. Bottom ash is a coarser type of mineral dust removed from the bottom of the furnaces.

While in the case of dedicated waste incineration all the mineral elements in the emissions come from the waste and the combustion air, in the case of co-incineration, they also come from the other fuels used and in the case of cement production mainly from the raw materials used. The exact nature of emissions is also a function of process conditions (e.g. amount of air, process temperature, time).

For example, in a cement kiln, gas temperatures are typically 800°C to 1200°C higher than in a waste incinerator. This creates conditions that are much more favorable to the formation of thermal NOx from the combustion air. This chemical reaction cannot be avoided. Therefore, NOx production in a cement kiln is largely independent from the presence of waste. Along similar lines, flue gas concentrations of non-volatile heavy metals and often SO_2 from a cement kiln are usually more related to natural levels in the raw materials and fuels used than to the waste, as long as the waste is fed at the flame end of the kiln.

If process conditions have allowed an efficient combustion, solid residues contain little organic matter but concentrate most of the heavy metals that entered the process. The main environmental issue to solve here is to avoid a remobilisation (in particular leaching) of the heavy metals. Therefore, use of this material as ballast or road building material, or landfilling must not allow their leaching. This is usually not perceived by the technical experts as difficult. Fixation of the heavy metals can be performed by vitrification, sintering or fixation in concrete blocks. This latter technique is commonly used in landfills to fix fly ashes. In cement kilns, the non-volatile fraction of the metals entering the process gets trapped and fixed in the clinker (e.g. lead) and the volatile metals such as mercury and thallium must be caught in the flue gas. Cement naturally contains variable levels of heavy metals from the raw materials and existing studies indicate minimal leaching of heavy metals from cement blocks. Therefore, limited input of heavy metals from waste is unlikely to raise serious issues. However, this should not be an open door for wastes containing high levels of heavy metals and the controversy on this point between incinerators and cement producers is still very alive. A better recognition of standard leaching methods followed by solid environmental safety assessments are needed in this area.

On the other hand, because thermolysis functions in a closed reactor, there are no emissions at the thermolysis step. Atmospheric emissions occur downstream, when the char or the gas are burned. Washing and sorting the solid after the thermolysis step produces a char with a chlorine bleed and a separation of metals and minerals before the energy recovery step (combustion, co-incineration or gasification). Moreover, an efficient combustion of the chars, due to their characteristics, is possible with low excess of air. When the thermolysis char is burned in a cement kiln, the ashes are entrapped in the clinker.

Ash production by the various incineration technologies varies. While cement kilns do not produce any ash (most of the minerals are incorporated into the clinker, but dust is collected in the flue gas and may have to be landfilled), the other alternatives produce from from 10% to 30% depending on the nature of the waste and the efficiency of thermal destruction.

Considering the variations in waste and in technologies, the gaseous emissions are difficult to compare in general. However, a few rules of thumb can be given:

- The higher the process temperature, the higher the production of NOx.
- The higher the sulphur content of the input (waste, raw materials), the higher the production of sulphur oxides (this may be different in cement kilns). The same holds true for volatile heavy metals such as mercury.
- Also, the better the combustion (according to the 3T rule: time, temperature and turbulence) the less soot and organic carbon in the flue gas.
- For dioxins, the higher the combustion temperature and the faster the cooling of the flue gases to less than 200°C, and the less dioxins will be formed.

3.5 Comparisons

The general advantages of the incineration of wastes are the "hygienisation" and reduction in the volume of waste to be disposed of, the ability to handle both hazardous and non-hazardous wastes (even though this is usually in different facilities and it is sometimes forbidden for incinerators to burn both, such as in France) and the possibility to recover energy, albeit to varying degrees according to the option considered. The main common draw back is a propensity to pollute the atmosphere and often the generation of hazardous residues.

The integrated thermolysis process produces less volume of ultimate residues than other forms of incineration due to ashes vitrification and inertisation. The recovery of metals and minerals before combustion decreases also the amount of ashes to be landfilled. Clean metals issued from these processes can be directly recycled, as is often done with the scrap recovered from incinerators.

Table 3 summarizes the main elements that are useful in any comparison of the various technological options for the incineration of waste.

At this point, it must be noted that the waste incinerators operating today in the EU are far from all being equal. Thanks to co-generation of heat and power where there is a market, state-of-the-art incinerators are now able to deliver high rates of energy recovery with minimal atmospheric emissions. The destruction of waste without any energy recovery will eventually disappear completely.

Table 3: Relative merits of dedicated waste incineration, co-incineration, thermolysis, fuel fired electricity production and cement production.

Technique	Advantages	Costs and Disadvantages
Dedicated waste incineration	• Rapid inertisation of waste • Reduction of volume by up to 90% • No need for pre-treatment • Can be located near large waste generation centers, and therefore reduce transport needs compared to landfills and facilitate the possibility of district heating • Unlike landfills, do not produce methane • Recovery of ferrous and non-ferrous metal scrap in many incinerators • Recovery of energy in most incinerators. In these cases, waste replaces fossil fuels. • Long-term security for waste handling • Low sensitivity to input variability	• Problems to operate below capacity for grate furnaces • Ashes, slags and flue-gas residues to be disposed of, often as hazardous waste, usually by landfilling • In the case of energy recovery, the average electricity production efficiency is only about half of what is achieved in fuel or coal power plants (in the order of 20% instead of 40%). New plants are better (30%) and total efficiency can be boosted to about 75% in combined heat and power systems, but the applicability of these systems remains limited. • High investment and operating costs and long lead times before an incinerator becomes operational. • Once installed, creates a high inertia in waste management decisions because of the high investment costs involved and the need for long-term waste supply contracts to fill the capacity.
Thermolysis	• Reportedly more flexible than traditional incineration • Recovery of gas, char and metals • Char can be stored • Reportedly, small capacity overall cheaper (<75000 t/yr)	• Further technology development needed • Today, problematic mineral residues, especially for char in non-integrated thermolysis • Not very well suited to large tonnages (>200 000 t/yr) • Non-integrated thermolysis requires a third party for the recovery of the coke. • Liquid effluents in non-integrated thermolysis
Steam (and electricity) production	• Waste replaces non renewable fuel • Takes advantage of investments made anyway for other purposes	• Waste needs to be pre-treated • Process requirements need to be respected • Commitment to dispose of waste essentially commercial, no long-term guarantee
Cement production	• Waste replaces non renewable fuels and/or clinker raw materials • Strong organics destruction capacity • Little residue to dispose of because the mineral fraction is used as raw material in the cement • Can handle waste with no calorific value as raw material • Can be allowed to handle hazardous and non hazardous wastes • Takes advantage of investments made anyway for other purposes	• Not all wastes can be used, except if a thermolysis pre-treatment is done • Waste needs to be prepared to specifications • Release of volatile heavy metals (e.g. Hg, Tl, Cd) • Product specifications and process requirements need to be respected • Different requirements for wet and dry processes. • Commitment to dispose of waste essentially commercial, no long-term guarantee

4. Issues

4.1 Environment and health issues

4.1.1 Dioxins and furans

One of the most burning public issues around the incineration of wastes is that of the possible production and release of polychlorinated di-benzo dioxins and polychlorinated di-benzo furans (noted dioxins and furans, or D/F below) by waste incinerators and other combustion installations. The reason for this state of affairs is that dioxins and furans at high doses have been identified as bioaccumulative cancer-causing agents in some mammals.

Up until the mid-1990's, in the European Union, the main sources of dioxins and furans have been steel furnaces and waste incinerators. Today, due to improved technology and the increasing use of flue gas cleaning systems, the contribution of incinerators to the release of D/F has decreased, and still is decreasing significantly across the EU. National differences remain, mainly due to the existence of older installations.

Dioxins and furans released by the incineration of waste can have three types of origin. First, they may come from D/F already present in the waste which escaped destruction due to insufficient incineration temperatures (<800°C). This is now rare. Second, D/F may be formed at temperatures of 500 to 700°C in the gas phase if organic molecules and chlorine donors (such as NaCl, PVC, HCl) are present. Thirdly, D/F can be formed by a variety of solid phase mechanisms at less than 500°C on particles flowing through the incinerator (e.g. soot). Certain metals can catalyze the formation of D/F at these low temperatures (e.g. in particular Cu at 400°C). For example, fly ash in its cooling phase can provide an ideal ground for the formation of D/F.

Therefore, the important parameters controlling the formation of D/F are the combustion conditions, the rate of cooling after combustion and content of sulfur or metals (in particular copper) in the feed waste. Studies[20] have shown that good combustion conditions and a fast cooling before the particulate filter kept the amount of D/F released down. Soot is favorable to their formation and a lot of D/F is associated to particles. There does not appear to be a relationship between the amount of chlorine present in the feed and the amount of D/F emitted. Sulfur dioxide appears to contribute to suppress the formation of D/F as shown by co-combustion tests with high sulfur coal.

D/F remain difficult (and expensive) to monitor. Therefore, enforcement of the related legislation is difficult. No real time monitoring exists so far and the available analytical methods show a limited reliability and comparability. As a result, the best strategy to follow in order to monitor likely D/F emissions is the monitoring of combustion conditions. In any case, today, D/F emissions can be reliably reduced to less than 0.1 ng/Nm^3 at low cost.

Recently, analytical results for dioxins in the meat of French cows were used to scare the public and put pressure on the authorities to enforce the emission standards required for incinerators. Three non-compliant facilities were closed. Similar events had happened in the Netherlands and Germany

[20] See Gullet, B., and Seeker, R., Chlorinated dioxin and furan formation, control and monitoring, Presentation at the ICCR meeting, Research Triangle Park, USA, September 17, 1997

more than a decade ago. However, today, state-of-the-art incinerators and co-incineration facilities are D/F sinks. In spite of the difficulty to quantify harm to human health[21] and the uncertainty in the data, adverse effects from D/F have been reported. A community-wide approach would significantly contribute to definitely solving the issue.

4.1.2 Heavy metals and salts

As we have seen in section 3.6, heavy metals cannot be destroyed, even by combustion but they end up in the residues. Their volatility and leachability are influenced by the conditions of incineration and some tend to escape through the smokestack. In order to avoid adverse effects on human health and the environment, two options are available. The first and preferrable option, is to remove them as far as possible from the waste before incineration. Because the scope for this first option is limited, the second option is therefore to decrease their bioavailability. When waste is thermally treated, the only possibility is to transform the metals into a solid, non leachable form. This means that (a) atmospheric emissions must be decreased as much as possible by capture from the flue gas and (b) that the metals in the solid phase (ashes, slag, …) are in a stable chemical state (which they should normally be). While it would be interesting to recover the metals in a metallic form for recycling, recent technological developments in this direction[22] still fall short of a widespread solution to this problem.

Heavy metals can be grouped into various classes, each with its specific issues. Metals such as cadmium (Cd), chromium (Cr), mercury (Hg) or lead (Pb) can be highly toxic. However, while Cd and Cr recovery can be interesting in metallurgy, uses for Hg and Pb are decreasing fast. For Hg, uses in thermometers and batteries are disappearing and will hopefully result in lower concentrations in waste in the long-term. For Pb, uses in pipes and gasoline are ending while use in accumulators is likely to decrease dramatically in the next few years thanks to emerging battery technologies.

Copper (Cu) and nickel (Ni) tend to be less toxic than Cd, Hg or Pb, but they are potent catalysts and contribute to a complex organic chemistry in the flue gases of combustion plants. In particular, they can contribute to the post-formation of dioxins in the flue gases. In terms of recovery, Cu is undesirable in steel making but, along with Ni, it is potentially worth being recovered for use in the non-ferrous metals industry.

Iron (Fe) and aluminium (Al) are less toxic and can also act as catalysts. However, they are essential elements for cement making and get captured in the clinker, contributing as raw material. In general, studies have shown that leaching of metals from cement mortar is very limited and does not appear to be a cause of concern during service life, but some controversy goes on.

This list is far from being exhaustive but illustrates the diversity of issues raised by the various metals present in wastes (and other materials such as coal, minerals, etc) and the possibilities to match specific wastes with certain combustion facilities for an optimum result (e.g. high Ni waste to blast furnaces, high Fe and Al to cement kilns,…). Metals are present in a relatively high concentrations in ashes and slags, but this is insufficient to make them attractive for metal recovery

[21] Rabl, A., Spadaro, J. and McGavran, P., D., Effets sur la santé de la pollution atmosphérique due aux incinérateurs: une perspective, Ecole des Mines de Paris, Novembre 1997
[22] CT Fluapur Process, CT Environment Ltd, Switzerland

because they are often in undesirable chemical forms and because they are mixed. A lot of research is currently being carried out to improve the recoverability of the metals and other minerals.

4.1.3 CO_2 emissions and global warming

Obviously, incinerating waste generates CO_2. However, the source of this CO_2 is both renewable (from paper, wood, vegetable residues and other biological material) and non renewable (mostly from plastics). The debate is therefore open on determining to what extent the incineration of waste contributes to the greenhouse effect. In the general production of CO_2 by our economies, the amount is likely to be negligible. This debate has opened a discussion to determine to what extent energy produced from waste can be called renewable energy and can be used to achieve CO_2 reduction objectives.

Several perspectives can be taken here. First, **the landfill versus incineration perspective**. If the waste that is burned was sent to landfills, it would produce methane, a much more potent greenhouse gas than CO_2. Most landfills do not collect methane and those that do only achieve low rates of recovery (typically <30%). As a result, a British study[23] has shown that contribution to global warming from incinerated waste is lower than that from the same amount of landfilled waste.

Second, **the relative energy recovery perspective**. Here, one can compare the amount of CO_2 emitted by producing 1 kWh of electricity using waste to that emitted by producing the same kWh in "classic" power plants. In this perspective, the incineration of waste is usually at a disadvantage because of the generally low efficiency of its electricity production. This disadvantage decreases, or can even in some cases disappear completely[24] if combined heat and power production, like in the city of Copenhagen but also possible for power plants, is considered. So far, district heating from incinerators is not very widespread across the EU, in part because low public acceptance tends to "exile" waste incinerators to sites far from urban centers where the heat could be used, but this can be addressed (see section 4.3). When wastes are burned in co-incineration, they also replace fossil fuels, with the corresponding benefits.

Third, **the intrinsic perspective**. If one considers that CO_2 from biomass does not lead to a net generation of CO_2, the only net contribution from the incineration of waste is from its non renewable fraction (synthetic chemicals and plastics), but this replaces the use of other fossil fuels. The large fraction of biological material in wastes and the fact that waste generation cannot be stopped (i.e. waste can be seen as a "renewable" resource) leads some people to call energy from waste "renewable energy".

Another point that can be raised is the saving in transport and processing energy that can be made if wastes are used for energy recovery locally versus fossil fuels that must be brought in from far away and manufactured. In any case, continuous efforts must be made to increase the efficiency of energy recovery in all the processes using wastes. CO_2 is not a major issue in waste incineration.

[23] UK Royal Commission on Environmental Pollution, May 1993
[24] Mr F. Martinez de Hurtado Gil, Spanish Environment Ministry, 20 January 1999,

4.1.4 NOx, SOx, other emissions and emission control

Combustion conditions influence the type of emissions produced. For example, high temperature combustion (>1400°C) increases the emission of thermal NOx from atmospheric nitrogen. The presence of chlorine or sulphur in the waste will cause the emission of HCl and SOx, but in cement plants equipped with a cyclone pre-heater kiln, they will be to a large extent neutralized by the basic raw materials. NOx, SOx and HCl contribute to the acidification of rain.

In view of the environmental and health concerns raised by all the emissions from combustion installations, European and national environmental regulations have set emission limit standards. The immediate response of the operators of combustion installations was to apply end-of-pipe flue gas treatment systems to reduce specific emissions: dust, SO_2, etc… The array of technologies implemented is large: post-combustion chambers, dry and wet scrubbers, electrostatic precipitators, cyclones, activated carbon filters, bag filters, etc… These processes use energy to transfer the air-borne pollution to a solid phase. The wet scrubbers transfer the contaminants to a water phase that needs further treatment. All flue gas treatments impact negatively on the energy balance of the systems that burn waste.

4.1.5 Blending

The pre-treatment of waste includes sorting, classification and blending. Blending is the mixing of wastes of various characteristics to decrease the variability of the waste stream to be burned and meet pre-determined specifications. In other words, blending makes waste more suitable for the process to which it is destined. This is why blending is often performed before co-incineration. For traditional fuel production, the blending of coal is a common operation.

In the European legislation, blending is mentioned in the framework directive on waste (75/442/EEC) as a disposal operation. For hazardous wastes, in order to avoid that highly hazardous wastes be "blended away" and escape more appropriate treatment, blending is prohibited, both with other hazardous wastes and with non-hazardous wastes, but the possibility for derogations remains open. However, care must be taken that in such cases, the problematic waste stream should be appraised and the various treatment alternatives evaluated beforehand. This waste should then be sent to the best available treatment option.

Blending is a highly controversial activity because in a number of cases it has been used as a way to dilute highly contaminated waste streams and process them through less stringent environmental requirements. Blending also decreases the traceability of waste streams, and as such is criticized by those who plead for maintaining different directives for hazardous and non-hazardous wastes (see section 4.4.2). Of course, as almost anything, blending can be used both appropriately and unduly.

4.2 Economic issues

4.2.1 The cost of incineration

The cost of incineration is an ill-defined concept. Large variations between countries and facilities exist depending on the size of the facility, its age, the environmental standards applied, the technology used, income from sales of energy or recyclable materials, etc… However, European harmonization is at work and differences should keep decreasing over the next 10 to 20 years.

The trend towards ever stricter emission controls has led to significant increases in the cost of incineration. Certain industrial actors[25] judge some cost increases excessive in relation to the environmental benefits obtained. However, the cost of incineration seem to be getting close to its maximum[26], and in some cases there even seems to be scope for decrease. In recent state-of-the-art facilities of some northern European countries, the lion's share of investment goes to flue gas cleaning: typically 1/3 for furnace and boiler and 2/3 for flue gas cleaning (e.g. a minimum of 40% in the Netherlands[27]). Reportedly, this is not the case in countries such as the UK, France or Spain, where the current cost of state-of-the-art flue gas cleaning seems to reach only about 20% of the cost of the furnace[28]. This could be due to differences in the technology used, the newer systems becoming ever cheaper for the same efficiency.

So far, income from sales of energy or recovered materials has remained limited, even if countries like the UK or Italy subsidise electricity from waste. This means that large amounts of money are still needed to finance the building and operation of waste incinerators. For industrial wastes, industries generally cover the entire cost of treatment and disposal of their wastes. Interestingly, increases in the cost of incineration does not always result in an increase in the price of waste incineration services[29]. For example, underused dedicated waste incinerators in Germany reportedly practice very aggressive pricing policies, sometimes with the help of regional authorities. One must also note that end-of-pipe environmental solutions always lead to a decrease in the efficiency of potential energy recovery.

According to some sources[30], the use of non-integrated thermolysis followed by the combustion of the char (and eventually the gas) as fuel in cement kilns could sometimes be cheaper than incineration in dedicated incinerators.

In terms of the viability of an incineration scheme, another important parameter is the relative cost of alternative waste treatment and disposal options. Figure 1 presents a few cost estimates for municipal waste incineration in the EU.

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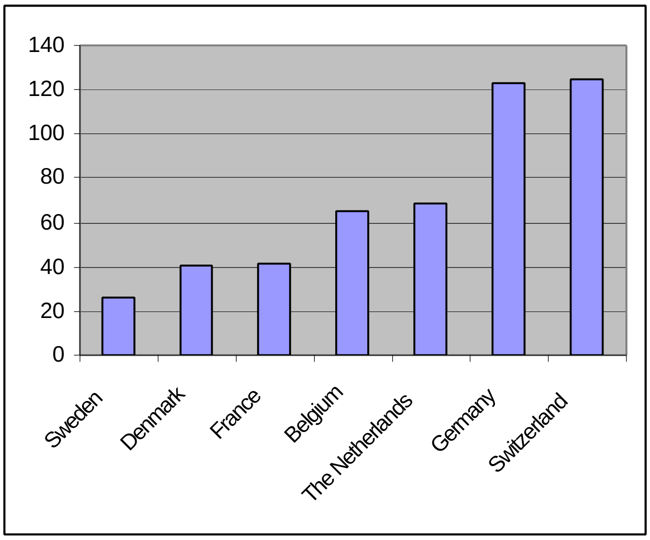
[25] Mr M. Frankenhaeuser, Borealis, January 1999
[26] Press information from Juniper consultancy, UK, December 1998.
[27] From Mr. W. Seddon-Brown, PODS, January 13, 1999.
[28] Mr G. Loram, UK, and Mr H. de Chefdebien, Vice-President of SNIDE, F, February 1999.
[29] Ms I. Conche, TERIS, F, January 21, 1999
[30] Prof. A. Fontana and Dr G. Jung, ULB, B, 25 January 1999

Figure 1: Actual average cost of incineration for municipal solid waste in selected European countries (€/tonne, source Juniper Consultancy Ltd, UK, 1998)



For some countries, the data presented in Figure 1 do not show the cost of MSW incineration in a state-of-the-art facility. For example, the current cost of incineration in a state-of-the-art facility in France is reported to be in the order of 70 €/tonne[31].

4.2.2 Economic relevance of waste reduction

In view of the large costs associated to waste management in general and to waste incineration in particular, the reduction of the amounts of waste generated delivers immediate economic benefits, without speaking about the associated environmental benefits. Of course, the higher the price people have to pay to get rid of their wastes, the more incentive they have not to generate them. All the actors agree on this point. However, two main factors contribute to limit progress towards reducing waste generation. The first is thermodynamics: zero waste processes cannot exist (entropy is always increasing). Therefore, human activity will always generate waste.

The second is regulatory. While it is relatively easy to set targets for recycling rates or for emission limits applicable to designated facilities, it is not so easy to design and legislate controllable waste reduction objectives. This is because there is a multitude of factors controlling potential waste reduction, and they are dispersed at all levels of economic and social life. Nice extra wrappings added in the shops or at home for Christmas gifts are clearly unnecessary packaging. Can they easily be legislated away?

A third factor may also come into play. A number of economic actors involved in waste management do not have any interest in seeing the amounts of waste (following the broad European legal definition) generated decrease because the amount of waste, scrap, residues and other waste-derived materials they handle could decrease and their profits suffer. One case in point is the existing waste incinerators. Their economic health lies for a large part in the amount of material they process because they get paid per tonne processed. Reducing waste would reduce the amount of material they process. One only has to see how some waste incinerators which have become oversized in

[31] Mr H. de Chefdebien, Vice-President of SNIDE, F, February 26, 1999

Germany because of mandatory separation of waste at source for recycling are struggling for survival. This is reportedly compounded by the future entry into force of regulations excluding most organic wastes from landfills. In some cases, this seems to have led landfill operators to lower their prices and catch as much waste as possible (away from incinerators) to maximize profit before the restrictions[32]. However, in many places such as France or Spain, incineration capacity is perceived by the actors to be still largely insufficient[33].

This explains why so far, most progress in this area has come from process and product optimisation and the implementation of cleaner technologies in Industry. The implementation of "Best Available Techniques" (BAT) following the introduction of the European IPPC directive (99/61/EC) is expected to contribute to a reduction of industrial waste generation on the long-term, but probably to a smaller extent than regulatory restrictions on landfilling and the general increase in the cost of waste management.

4.2.3 Commercial competition

In the cases where there is commercial competition for a given waste between waste incinerators and industrial players practicing co-incineration, the latter often benefit from an economic advantage. While the dedicated waste incinerator only has costs and needs to be paid for its service, the industries involved in co-incineration are replacing an existing fuel cost by waste, for which they are often paid. The higher the price of fossil fuels, the larger this advantage. Indeed, they need to build and operate proper waste handling facilities that have a cost, but they can generally undercut the price asked by the incinerators for eliminating the waste. Co-incineration plants have already made their investments and they have a flexibility in operation which allows them to continue to operate even if waste should not be available. They also usually benefit from a high energy recovery efficiency.

Some industrial facilities also operate less expensive pollution control devices than waste incinerators. As a result, they tend to set their prices relatively to the prices practiced by the dedicated waste incinerators in order to maximize profit. Nevertheless, because of technical limitations (in particular chlorine content) and limited capacity, they cannot take all the available waste. It is difficult to know which fraction of the waste would be technically unsuitable for co-incineration, but, considering the robustness of the cement manufacturing process and the possibilities of pre-treatment, it is likely to be small. In any case, the pursuit of profit in waste management should under no circumstances lead to compromises on the environmental profile of waste treatment.

An emerging factor can contribute to offset this situation. In a competitive market, in order to provide maximum convenience for their clients, and to capture as much of the waste as possible, the actors involved in waste combustion can become involved in waste management at large and offer one-stop solutions to their clients. This way, they have an economic incentive to develop recycling and recovery activities that generate income from the sale of the products obtained (e.g. energy, basic raw materials, recycled solvents). However, electricity recovered from waste in the EU appears to be often paid less than that produced by the traditional power plants[34]. In the UK and Italy, on the other hand, electricity from waste incinerators is paid well above market rates.

[32] Mr F. Martinez de Hurtado Gil, Spanish Environment Ministry, 20 January 1999,
[33] Mr H. de Chefdebien, Vice-President of SNIDE, France, January 22, 1999,
[34] Press information from Juniper Consultancy, UK, December 1998

Under such circumstances, a dedicated waste management company may prepare waste streams meeting certain specifications and sell them for co-incineration. In parallel, a company involved in co-incineration may send pre-treated fractions, undesirable for its own process, to a waste management company. Such examples already exist in Europe and use market mechanisms to optimize globally the management of waste.

However, national institutional structures can be a major barrier to this sort of developments, in particular if responsibilities for waste management remain fragmented in the hands of municipalities. The waste incinerators operated by public authorities seldom participate in this type of "multi-service" market developments because of administrative rigidities and of their dependence on a different economic logic than private or semi-private operators. In general, across Europe, markets are private for hazardous wastes and public for municipal solid wastes[35]. Hazardous waste treatment facilities are usually also privately owned and do not hold concessions. As a result, the hazardous waste market is significantly more liberal than the municipal solid waste market and hazardous waste treatment is not supported by public funding.

At this point, it must be said that dedicated waste incinerators offer a higher long-term guarantee for the treatment of waste than other industrial sectors for which the use of waste is "opportunistic", and usually follows economic considerations. A flexible market within a clearly regulated frame can help direct each waste towards the optimal management option.

4.2.4 Fairness

In the context presented above, it is difficult to resolve the issue of fairness of competition between the various actors involved in waste management. Fairness can be evaluated in different perspectives according to the objectives pursued.

In an **environmental protection perspective**, all emissions should be reduced to their no-impact level, irrespective of their source or of the economic impact on the sources. One approach can be to set comparable emission levels for single emissions for all sectors. To be meaningful, these limits must be established in terms of fluxes of contaminants. While attractive in principle, this approach has the draw back to imply widely different costs for the reduction of emissions according to their origin. The economic efficiency of the total reduction is not taken into account. Another approach, introduced in European policy by the IPPC directive, is to look for a global reduction of all emissions at each industrial site. In this approach, there is an incentive to use the "Best Available Technique", providing the best result overall without necessarily achieving the same individual emission limit values for all. Because the IPPC approach focuses of the rate of improvement, a few critics say the IPPC approach gives an unfair advantage to those who pollute most because it is generally easier to achieve a given percentage of reduction in emissions on a dirty facility than on one which already meets stringent environmental standards (law of diminishing returns). This approach provides some degree of optimization along techno-economic lines but a safety net of emission limit values for contaminants of particular concern (e.g. mercury) can be combined with this approach. A third approach is to use tradeable emission permits, which undoubtedly allow to minimize the cost of emission reductions but raise issues about the fairness of their attribution at the start (again, an

[35] EURITS, March 4, 1999

“unfair”(?) advantage at the start to those who pollute most). Today, the directive on large combustion plants (not waste) allows the release of higher fluxes of the same contaminants (NOx, SOx, …) than the directives related to the incineration of waste and the coherence of European policy can be questioned on that point.

In a **static and local economic perspective**, local employers must be preserved. Therefore, the ones will defend their incinerators, the others their cement kilns or their power plants, depending on which is where. This perspective can play at local, regional, national and European level, with different outcomes according to the level considered. These days, for example, the Asian crisis has led to a large cement production overcapacity in Asia. Current low transport costs could allow Asian cement to reach Europe at a cost well below European production cost. Increased economic pressure on European cement kilns because of tighter environmental regulations can therefore encourage multinational cement companies to close European sites.

Thirdly, the **social perspective** also has different dimensions. In the “quality of life” dimension, on the one hand, the famous “NIMBY syndrome” (NIMBY is the acronym for “not in my back-yard”) translates the fact that nobody wants to bear the unavoidable nuisances inherent to waste management or other heavy industrial activities. In the “socio-economic” dimension, on the other hand, people want to benefit from the economic activities of our society (jobs at an incinerator, a power plant or a cement kiln, taxes paid by these activitis to the municipalities,…). Again, at this point, interests will diverge according to the current position of the actors, their flexibility in terms of employment, their geographical mobility and other factors. Again here, different levels at which the issue is considered may lead to different conclusions.

In any case, the debate about the fairness of the competition between cement kilns and dedicated incinerators is currently very hot. Existing European waste legislation sets emission standards for all waste incinerators while it sets standards for co-incineration only in the case of hazardous wastes. The proposed revised legislation for the incineration of waste calls for identical emission standards for waste-related emissions for both waste incinerators and cement kilns using waste. A resolution of the dispute will likely be achieved when one of the perspectives presented above will be chosen by all the main actors concerned and applied according to the main European policy objectives.

4.3 Social issues

Because the public image of the incineration of waste in the EU is by and large a reflection of the worst existing cases, acceptance for this option is still low. Recently, in Europe, projects for waste incineration facilities have often been plagued by the “NIMBY syndrome”. In other words, European populations do not want to live near a waste incinerator because of the fear of toxic emissions such as dioxins. This creates difficulties to open new facilities and creates a dilemma. It may favor the survival of existing facilities to the detriment of new installations with better technology and cleaner credentials, even though recent outcries in France led to the closure of threenon-compliant waste incinerators. In the Netherlands, for example, it led to the better but expensive provisions for cleaning flue gases of dioxins and other contaminants.

The NIMBY syndrome may also translate in the “NIMEY syndrome” (NIMEY is the acronym for “not in my election year”) for local elected representatives who fear for their re-election if they get involved in such controversial projects. This may result in delays to the improvement of existing situations.

The same applies to landfill sites. As a result, social pressure may create difficulties to set up waste management infrastructures. A possible positive outcome of these restrictions in the possibilities to open new waste disposal and elimination facilities is the creation of incentives for waste reduction, undoubtedly the most difficult but ultimately the best thing to do. The Dutch approach has been to prohibit the landfilling of all waste that can be recycled such as paper, textiles, rubble, tyres, white and brown goods, etc...

In these debates, it is important that the public be given its own responsibility. The life-style of the population has important consequences on the generation of waste. There, if communication is efficient, the public is more likely to accept the nuisances it causes. On a psychological point of view, it may also be easier to "sell" the installation of smaller units, closer to the citizens and less anonymous. In a community where a large waste incineration facility is installed, people may have the feeling it is mostly "other people's wastes" that are burned and acceptability may result very low.

However, locally, state-of-the-art facilities have gained public acceptance. Existing experience in local communities[36] shows that extensive public consultation demonstrating the existence of a coherent waste management plan dramatically increases the public acceptance of solutions, including energy from waste facilities. Of course, those who live nearby are concerned about the health impacts and the transport effects of these facilities. However, in a concrete case in the UK, public preference emerged for small strategically located facilities versus a cheaper single large mass burn energy from waste facility. In the city of Copenhagen, thanks to a combination of very strict environmental standards and a high level of transparency, the population has accepted the installation of an incinerator very close to the city center. This has delivered the combined advantages of minimising transport costs while allowing district heating, resulting in an overall excellent energy balance.

In these good cases, more efforts for communication and responsibilisation must be made. More factual information about waste management must reach the public and decision-making must take public preferences into account. Political positions in this area should be avoided as far as possible.

[36] Mr G. Tombs, UK, 23 January 1999,

4.4 Regulatory issues

4.4.1. Definitions

In the European waste management strategy, the incineration of waste is mostly placed at the bottom two levels of the accepted waste management hierarchy under "energy recovery" and "disposal". The cases of co-incineration may sometimes correspond in part to material recycling. The European legislation regarding the incineration of waste consists currently of three directives (Directive 89/369/EEC, 89/429/EEC and 94/67/EEC) and a new directive is proposed.

Council directives 89/369/EEC and 89/429/EEC cover the prevention of air pollution from new and existing[37] municipal waste incineration plants respectively. The definition of "municipal waste-incineration plant" for the purpose of these directives is given in Table 5.

In Article 2, directive 89/369/EEC gives the emission limit values for new municipal waste incineration plants (see Table 4).

Table 4: Emission limit values for new municipal waste incineration plants (directive 89/369/EEC) in mg/nm^3

(273K, 101.3 kPa, 11% O_2 or 9% CO_2, dry gas)

Pollutant	Nominal capacity of plant		
	Less than 1 t/h	**From 1 to 3 t/h**	**More than 3 t/h**
Total dust	200	100	30
Heavy metals			
* Pb+Cr+Cu+Mn	-	5	5
* Ni+As	-	1	1
* Cd and Hg	-	0.2	0.2
Sulphur dioxide (SO_2)	-	300	300
Hydrofluoric acid (HF)	-	4	2
Hydrochloric acid (HCl)	250	100	50

Some derogations can be obtained for nominal capacities of less than 1 t/h. Other requirements include:

- reaching at least 850°C for 2 seconds in the presence of at least 6% oxygen for the combustion gas
- less than 100 mg/nm^3 CO in the combustion gases
- less than 20 mg/nm^3 (as C) organic compounds in the combustion gases.

This directive also lays down monitoring requirements and minimum technical prescriptions.

[37] First authorization to operate granted before December 1, 1990

Table 5: Comparison of the various European legal definitions of "*incineration plant*"

Directives 89/369/EEC and 89/429/EEC	Directive 94/67/EEC	Proposed directive
"Any technical equipment used for the treatment of municipal waste by incineration , with or without recovery of the combustion heat generated, but excluding plants used specifically for the incineration of sewage sludge, chemical, toxic and dangerous waste, medical waste from hospitals or other types of special waste, on land or at sea, even if these plants may burn municipal waste as well. *This definition covers the site and the entire installation comprising the incinerator, its waste, fuel and air supply systems, and the devices and systems for checking incineration operations and continuously recording and monitoring incineration conditions".*	*"Any technical equipment used for the incineration by oxidation of hazardous wastes, with or without recovery of the combustion heat generated, including pre-treatment as well as pyrolysis or other thermal processes, e.g. plasma processes, in so far as their products are subsequently incinerated. This includes plants burning such wastes as a regular or additional fuel for any industrial process.* *This definition covers the site and the entire installation comprising the waste reception, storage and pre-treatment facilities, the incinerator, its wastes, fuel and air supply systems, exhaust gas and wastewater treatment facilities, and devices and systems for controlling incineration operations and continuously recording and monitoring incineration conditions.* *The following plants are not covered by this definition:* *- incinerators for animal carcases or remains,* *- incinerators for infectious clinical waste provided that such waste is not rendered hazardous as a result of the presence of other constituents listed in Annex II to directive 91/689/EEC, or* *- municipal waste incinerators also burning infectious clinical waste which is not mixed with other wastes which are rendered hazardous as a result of one of the other properties listed in Annex III to Directive 91/689/EEC".*	*"Any stationary or mobile technical unit and equipment dedicated for the thermal treatment of wastes, with or without recovery of the combustion heat generated. This includes the incineration by oxidation of wastes as well as pyrolysis, gasification or other thermal treatment processes, such as plasma process, in so far as the products of the treatment are subsequently incinerated.* *This definition covers the site and the entire plant including all incineration lines, waste reception, storage, on site pre-treatment facilities; its waste-, fuel- and air-supply systems; the boiler; facilities for the treatment or storage of the residues, exhaust gas and wastewater; the stack; devices and systems for controlling incineration operations, recording and monitoring incineration conditions".*

Directive 89/429/EEC gives a schedule for the emissions from existing waste incineration plants to reach the limit values specified for new waste incineration plants in directive 89/369/EEC. For plants with a nominal capacity exceeding 6 t/h, compliance had to be reached by 1 December 1996. For the other plants, full compliance must be reached by 1 December 2000.

Directive 94/67/EEC covers the incineration of hazardous waste. The definition of "waste-incineration plant" for the purpose of this directive is given in Table 4.

This definition, unlike that for the previous two directives, covers explicitly the case of co-incineration and introduces the famous "40% rule". This rule requires that emissions from co-incineration plants and hazardous waste incinerators be identical in the case when more than 40% of the heat released in the the co-incineration plants comes from hazardous waste. In the case when less than 40% of the heat released comes from hazardous waste, a formula is applied (Annex II of the directive) according to which the emissions from the hazardous waste fraction of the fuel must be the same as in the case of a dedicated hazardous waste incinerator. This arrangement did not settle the debate between the cement kiln operators and operators from waste incinerators[38]. For the general incineration of wastes, a number of European cement kilns already operate under the same standards as those of the (non-hazardous) waste incinerators[39] but the vast majority does not.

A proposal for a new directive on the incineration of waste has just been published (O.J. C372 of Dec. 2, 1998, pp 11-26). The purpose of this new text is to improve the protection of human health and the environment by adapting the legislation to technological progress and incorporating advances in international agreements on the release of certain pollutants, in particular heavy metals. This new text also wants to address gaps and limitations in the existing legislation. For example, the existing European legislation does not cover the incineration of many wastes such as sewage sludge and others. There is also a feeling that the existing regulation of the co-incineration of wastes is not consistent. Additionally, dioxin and furan emissions from the incineration of non-hazardous wastes are still not regulated at European level. Increasing restrictions on landfills also lead to expect an increase in the incineration of waste, justifying to take a closer look at the relevant legislation. In case it is adopted, this text would replace directives 89/369/EEC and 89/429/EEC.

The definition of "incineration plant" for the purpose of this proposed text is given in Table 4. However, unlike the existing directives, the proposed text also provides a specific and separate legal definition for a "co-incineration plant". According to this proposal, a co-incineration plant is "*a plant whose main purpose is the generation of energy or production of material products and which uses wastes as a regular or additional fuel. This definition covers the site and the entire plant including all incineration lines, waste reception, storage, on site pre-treatment facilities; its waste-, fuel- and air-supply systems; the boiler; facilities for the treatment or storage of the residues, exhaust gas and wastewater; the stack; devices and systems for controlling incineration operations, recording and monitoring incineration conditions*".

The proposal provides an elaborate and comprehensive set of emission limit values accompanied by a mixing rule for co-incineration. Special provisions are foreseen for cement kilns, large combustion plants and other industrial sectors (Annex II). Emission limit values for discharge wastewater from the cleaning of exhaust gases are also foreseen (Annex IV). The general emission limit values to be respected by dedicated waste incinerators are set in Annex V of the text.

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[38] FEAD, November 3, 1997, and Ciments d'Obourg, November 7, 1997, s to IPTS
[39] FEAD, to IPTS, November 3, 1997

Definition of waste:
As for the other directives related to waste, the field of application of the directives mentioned above is determined by the legal definition of waste. Materials not considered as waste will not need to be incinerated under the conditions described above.

However, considering the broad definition of waste and the inclusion of all categories of waste, some of which were previously excluded, in the forthcoming legislation, many integrated industrial chains using their own by-products as a source of energy to drive their processes may have to comply with the requirements of the proposed legislation.

Definition of energy recovery:
Considering the limitations imposed on the shipment of waste for disposal (proximity principle), the development of energy recovery in waste incinerators may lead to an increase in shipments of wastes towards the cheaper operators. The operational definition of what can be appropriately considered as a recovery operation, and not disposal or elimination, is therefore important for waste management but some regulatory uncertainties on this point remain.

In view of the different targets set for recycling and recovery by the packaging directive, the issue of determining whether feedstock recycling for plastics is material recycling or energy recovery has arisen. In the case of the feedstock recycling of plastics, basic hydrocarbons are obtained and reprocessed in standard petrochemical operations for the production of chemicals, polymers and fuels. The proportions of the various end products will change according to the refinery, the place, the time, the economic conditions of the market, and so on. The fuels will be used as any oil-based fuels. Where is then the limit between recycling and recovery? Legally, should feedstock recycling be considered as incineration "*in so far as the products of the treatment are subsequently incinerated"* to take the words of the proposed directive?

4.4.2. Other regulatory issues

Hazardous versus non-hazardous wastes:
In some cases, for example in France, while municipal solid waste can be landfilled, certain types of hazardous wastes cannot. Conversely, municipal waste incinerators are not allowed to burn hazardous wastes, even in the cases where this would be technically feasible. In fact, hazardous and non-hazardous wastes are often not incinerated in the same way because of the diversity of hazardous wastes. This creates a complementarity between the various treatment and disposal options and creates significantly different situations for hazardous and non-hazardous wastes. Some actors would like to maintain this situation and are not favourable to the merger of the two existing directives into one new one[40]. In their eyes, such a move could weaken the control on hazardous wastes. The concern here is not so much at the combustion stage but upstream, for the traceability, transport and handling of hazardous waste.

Transport of waste:
By applying the "proximity principle" and the "self-sufficiency principle", the European waste legislation (Directive 75/442/EEC) restricts the transport of waste for disposal. This creates a regulatory need to establish a clear distinction between "disposal" and "recovery", in particular for

[40] Mr. A. Heidelberger, SYPRED, France, January 21, 1999,

waste incineration with energy recovery. This need is rendered more acute by the temptation of a few national authorities to restrain the movement of wastes for recovery to fill their own existing incinerators (e.g. NL, D, DK[41]). This temptation is easy to understand because of the responsibility of the public authorities for waste management and because incinerators are expensive installations with little operational flexibility. In this respect, calls for a "European level playing field" for waste management have been formulated[42]. As a result, if the amounts of waste to be incinerated decrease significantly, not only does the incineration process experience losses of efficiency, but the cost per unit treated increases a lot due to the large fixed costs. Practical proposals have been made by the waste management industry to determine when the incineration of waste could be considered "disposal" and when it could be considered "recovery"[43]. Small, decentralized units such as made possible by non-integrated thermolysis could facilitate the implementation of the proximity principle, reduce transport costs and allow local recovery of energy, in particular in low population density areas.

The IPPC approach

The IPPC approach, by taking a global view of emissions, may lead to a re-consideration of existing emission limit values. This point was discussed in section 4.2.

Incineration and energy recovery (standards)

As we have seen, many actors involved in waste management view as unfair that a given waste may not be incinerated according to the same standards whether it is sent to an industrial facility in replacement of traditional fuels and/or raw materials or to a waste incinerator. The same holds true for a material (e.g. process residue) sometimes burnt on-site (e.g. in a paper plant) as fuel. If the same material is leaving the plant to be incinerated elsewhere, it is considered as waste and must be incinerated according to waste incineration standards. In some Member States, the material is considered as waste even inside the plant (e.g. Finland, but it is allowed to be burned as a fuel). The current proposal for a directive on the incineration of wastes excludes "clean" biomass from its scope.

Here, another potential conflict raised by the definition of waste is that between biomass used as fuel, and waste. The use of biomass as fuel is promoted by European programmes approved by the European Commission, the Council and the European Parliament such as FAIR, ALTENER or JOULE-THERMIE. However, traditional fuels such as straw, green tree cuttings, bark, olive residues, etc, are covered by the European Waste Catalogue and may be defined as wastes. When this is the case, one must make sure that such a classification does not prevent the use of the best technology to recover energy from such materials. As a result, due to the wish to encourage the use of biomass for renewable energy, "clean" biomass is not covered by the proposed directive on the incineration of waste because many installations could not afford abatement technologies. As always, the best possible option for each case should be promoted, and not necessarily incineration with energy recovery.

Regulatory work on large combustion plants:

Recently, work has started on a revision of the directive on large combustion plants (88/609/EEC, amended by 94/66/EEC for plants of more than 50 MW). This directive is applicable irrespectively of the type of fuel used. Therefore, any plant practicing the co-incineration of waste has to obey the

[41] In order to improve capacity planning, the Danish EPA wants to avoid the import of waste to avoid having to subsequently export Danish waste for lack of capacity.
[42] Mr H. Brons, VVAV, NL, , March 2, 1999
[43] Ms I. Conche, TERIS, F, January 26, 1999, .

requirements of this directive regarding nitrogen oxides and sulfur oxides emissions. It must be noted that wastes of all types (even RDF) are excluded from the European legal definition of fuel.

4.5 Technological issues

The trend towards more pre-treatment of the waste with a view to separate and recycle, leads to the removal of several fractions and may affect the calorific value of the residual waste. While the removal of the high calorific value materials such as plastics and paper from the usual waste stream may result in a decrease of the calorific value of the waste, the removal of non combustible fractions such as glass and metals have the opposite effect. The recovery of humid organic waste for composting or anaerobic fermentation may also lead to an increase in the calorific value of the residual fractions. The end result appears to be generally a reduced volume of wastes with an increased calorific value, leading to financial and technical difficulties for dedicated incinerators (e.g. in the Netherlands[44]).

An important difference between incineration and co-incineration is the fact that while the dedicated incinerator will take all the waste coming in, with a high variability, the industrial facilities practicing co-incineration usually select and pre-treat the waste they handle to reduce variability and optimize its behavior in the process.

Here the issue of process optimisation must be raised. Dedicated waste incineration processes are optimized to obtain the complete oxidation (combustion) of wastes in order to obtain non putrescible ashes that can be landfilled. Additionally, they have little choice over the nature of waste they must take. As a consequence, because flue gases from the combustion of waste are corrosive and fouling, they are limited in their ability to maximize the recovery of energy. They can only do so if they accept a faster degradation of their boilers. Cement kilns are optimized to produce cement of a given quality as efficiently as possible. Thermal electric power plants are optimized to reach a conversion efficiency as high as possible. This is generally also true for the combined heat and power plants because the electricity is always the most valued form of energy. This has implications on the choice of the best recovery route for each waste stream.

The implementation of the IPPC Directive requires the definition of “Best Available Techniques” (BAT) for every industrial sector listed in its annex I. This includes waste incinerators and cement kilns, to be handled by different technical working groups. This work will have a long-term impact on the technologies implemented in both sectors. While the work on the BAT reference document (BREF) for the cement industry is in its concluding phase, work on the incineration of hazardous waste is due to start in 2000 and work on the incineration of municipal solid waste in 2001 or 2002. Because of the far reaching consequences of this work, the waste incineration industry would like to establish a link between the BAT defined for cement production and that for the incineration of waste. The proposed directive on the incineration of waste is compatible with the IPPC directive.

Because of the large investment costs of waste incineration technology, and the need for high tech emissions control equipment, there is a trend towards the elimination of small facilities and the building of large, centralized installations instead. The UK is a good example of this trend. This influences the structure of the whole waste management chain, in particular logistics. The

[44] from A. Nijkerk, January 13, 1999

penetration of the emerging thermolysis technology, making smaller units viable, could modify this trend if commercial development brings their investment costs down[45].

4.6 Management issues

The question to be resolved on the ground everywhere in the European Union is: how to find an optimum solution for waste management in general and waste incineration in particular, given all the issues presented above?

Many elements must be taken into account simultaneously, such as those mentioned in the non-exhaustive list below:

- Waste streams are very diverse, in particular hazardous wastes.
- Some waste streams are also very variable.
- While the hazardous nature of some wastes requires special handling precautions, a good traceability and a specific management, the legal classification of waste as hazardous is not relevant for the efficiency nor the environmental soundness of incineration. The classification of a given waste as hazardous is based on intrinsic properties, and as such has no relevance for the suitability of this waste for incineration.
- The conditions of incineration of waste in the European Union are very diverse mainly because of the types of wastes, of the technology used, of the age of the installations, of different national legal requirements and of widely differing environmental demands from the public.
- Some industrial processes, and in particular cement kilns and power plants, can handle specific waste streams satisfactorily and have the potential to provide significant environmental and public health benefits to waste management provided they respect adequate standards.
- The socio-economic conditions are extremely variable across the EU.
- With few exceptions (e.g. Copenhagen), the public perception of incineration across the EU is mostly very negative and hinders the installation of waste incinerators.
- There are alternative and/or complementary options to the incineration of waste (e.g. landfilling, recycling, thermolysis, composting). Most often, the various options should be viewed as complementary; decision support tools such as life-cycle assessment can help determine in each case what is the best recovery route for each type of waste. It must be noted here that ultimately, recycling (or reuse, but not composting) does not decrease the amount of waste to be eliminated since, besides the small amount of waste produced during recycling, the recycled material will eventually come back as non-recyclable waste in a subsequent material loop. These options are not an end in themselves but should be practiced whenever life-cycle assessments show they allow a saving of resources.
- The European regulatory scene for waste management is evolving, preparing limitations for the future use of landfills and tightening environmental standards in general.
- Dedicated waste incineration requires large investments for long life-time facilities.
- Commercial competition in the area of waste management is already rife.

[45] Mr F. Martinez de Hurtado Gil, Spanish Environment Ministry, 20 January 1999,

- Installed incineration capacities in some areas suffer from over-capacity while more capacity is needed in others. It must be noted that some over-capacity may be useful as back-up resource.
- The approach to waste management planning varies widely from country to country.

The challenge for the decision maker is to come up with the best overall solution, bearing simultaneously all the elements presented above into account. The task is far from easy, and while a regulatory framework is very helpful to help taking decisions, sufficient flexiblity must be maintained in order to really be able to design the best local solutions. Some industrial[46] voices regret the fusion of the two existing directives covering the incineration of waste (one for municipal waste and the other for hazardous waste) into one new directive because they fear the relaxing of the special handling of hazardous wastes in some cases. Table 6 provides a simplified overview of the advantages and draw-backs of the main waste management options.

Table 6: Rough comparison of the relative merits of the various waste management options

Option	Advantages	Disadvantages
Prevention	• Preserves natural resources • Avoids the need for waste management • The most sustainable on the long term	• Difficult to achieve
Re-use and recycling	• Allows to maximize the benefits obtained from the use of material • Helps reduce the rate of material extraction	• In the long-term, re-used and recycled materials end up as waste • Re-use and recycling require energy and generate waste; a cost/benefit evaluation must be made to ensure the balance of benefits remains positive
Incineration with energy recovery	• Avoids the use of other fuels • Reduces the amount and volume of material to be disposed of	• Often performed with a low efficiency • May generate hazardous residues
Disposal	• If done properly, can reduce the possibility of waste to cause human and environmental harm • Easy	• No benefit for sustainable development • Has a cost

[46] Ms I. Conche, TERIS, January 21, 1999, .

5. Perspectives

5.1. The need for waste reduction

The basic need for mankind to achieve sustainable development on the long-term compels us to take an upstream view of the waste management problem, in particular in the so-called “developed” economies. Today more than ever before the need to respect our ecosystem and to reduce our resource consumption to sustainable levels is blatant. Doing so will have immediate tangible consequences on our waste management systems, decreasing their cost and reducing the environmental impact of waste. Less waste would translate in less landfills, less incinerators, less collection and transport costs, and so on.

However, waste reduction is a lot more difficult to legislate into being than prescriptions for waste management. The reason for this lies in the fact that the generation of waste starts with every human activity because 100% efficiency cannot exist. As a result, waste reduction results from a combination of attitudes such as less material demands from each of us, the implementation of more efficient processes, cleaner technologies, better economic coordination and integration, more cooperation, and so on. In this respect, concepts such as “industrial ecology” and “integration of policies” have an important role to play.

5.2 The need for the incineration of waste

Thermodynamics tells us that, whatever efforts we make, the efficiency of the processes used in all types of human activities will always be less than 100% and generate at least waste heat (second law of thermodynamics). The tendency of the natural world towards disorder means there is an unavoidable drive towards dispersion that leads to the creation of unusable material streams. Therefore, as long as mankind exists, there will be waste to manage and energy will be necessary to manage it. The aim of waste management will remain to provide in an affordable way the best protection possible of public health and the environment from the deleterious effects of waste. A good “waste manager” will therefore be judged on his ability to implement the most efficient (in all the dimensions of efficiency) waste management system for every place.

Considering the variety of wastes to be handled, it is important to keep a large variety of waste management options available in order to be able to exploit the advantages of each. No waste management option can handle all wastes, except landfilling. However, this last option would lead to a large loss of recoverable resources. It is therefore best to keep it as a last resort and send each waste streams to the option that allows an optimum level of recovery with an acceptable level of safety and cost. The incineration of waste is one of these options and, given the current techno-economic conditions, the recovery of energy is the only practical form of recovery for certain types of wastes (e.g. dispersed small combustible waste containing small plastic packaging, wood residues, soiled paper and other fractions too expensive to sort that cannot be composted; certain spent solvents and paint residues;...).

The main advantages of waste incineration are the possibility to recover energy and scrap, the rapid inertisation of waste, the strong reduction of volume and the possibility to locate incinerators near large waste generation centers if the public accepts, leading to a reduction in transport needs and to the possibility to provide district heating services. In this last case, the efficiency of energy recovery can be very high (>70%). Additionally, unlike landfills, incinerators do not produce methane and contribute less to global warming. They are also are capable of disinfecting waste containing microbial pathogens. Finally, if it reaches the right grade of industrial maturity, thermolysis promises to be able to handle a large variety of wastes and to offer flexibility and the possibility of a more decentralized management of wastes.

In the case of co-incineration, other advantages exist. Not only can waste replace non renewable fuels as in the case of incineration with energy recovery, but it can sometimes replace also other raw materials. In the case of cement kilns, there is almost no residue to dispose of because the mineral fraction (in particular iron, calcium, silicium and aluminium) is used as raw material in the cement. Co-incineration also takes advantage of investments made anyway for other purposes. Some people dispute the claim made by cement kiln operators that using wastes replaces the use of non-renewable fuels because many cement kilns burn oil refining residues. Two considerations can be made regarding this. First, these residues come entirely from non renewable resources (oil). Second, at least some of these residues may fall under the definition of waste, in which case these cement kilns already burn waste.

The main disadvantages are possibly cost, risk of atmospheric pollution and some problematic residues (e.g. fly ashes) that must be landfilled (see Table 3 in section 3.5).

Therefore, all forms of incineration of waste remain valid options for waste management and in view of their variety, constitute themselves an array of complementary options. However, one should also note that these complementary options can also compete with each other. For example, old paper can be burned in different facilities (direct combustion or co-incineration), composted, recycled or landfilled. Again, it is important that the mechisms exist to identify what the best option is and that the facilities exist to provide this best option.

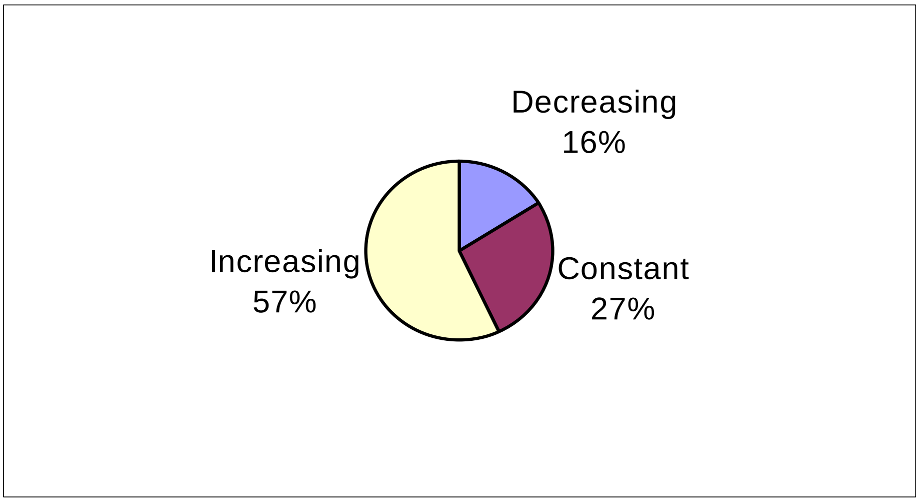
5.3 Trends

As we have seen earlier, today, landfilling is still by far the most widely used waste disposal option in the EU. However, many experts believe that the various types of incineration of waste will widely benefit from the restrictions on landfilling introduced by the new directive and from the requirements on "recovery" of packaging waste. Additionally[47], the amount of municipal solid waste incinerated in the EU is expected to increase from 31 million tonnes in 1990 to more than 56 million tonnes in 2004 and the amount of sewage sludge incinerated is also expected to increase steeply in the next few years[48]. This probably explains why, in spite of the current general reluctance of the European public for waste incineration, a majority of municipal solid waste incinerator operators in Europe appear to expect an increase in their activity over the next five years (see Figure 2).

Dedicated incineration and co-incineration are often seen as direct competitors. However, in some cases, they seem to be evolving towards a common goal. They started from very different points corresponding to their original functions. The waste incineration companies were created to eliminate waste, or at least stabilize them and reduce their volumes. The cement kilns and power producers were created to make cement and power.

[47] "EC predicts growth in incineration", Warmer Bulletin, N°64, p 3, January 1999
[48] Bontoux, L., Vega, M. and Papameletiou, D., "*Municipal wastewater treatment in Europe: what about the sludge*?", The IPTS Report, N° 23, pp 5-15, April 1998

Figure 2: Operators expectations of the utilisation of their incineration capacity for MSW: 2005 vs 1998 (Source: Juniper Consultancy Ltd, UK, 1998)



A combination of increased environmental consciousness, environmental regulations and competition for the same waste led to a range of positive developments. On the one hand, it pushed the dedicated waste incinerators to increase recovery and recycling whenever possible in order to decrease costs and increase profitability: today, all the new waste incinerators recover energy. This is most obvious for the private of semi-private operators. On the other hand, it pushed the cement kilns and the power plants to generally improve their environmental profile. As a result, since the 1970's the energy requirement per tonne of cement produced has decreased by 30% and wastes are increasingly viewed as a resource that can be fed into productive economic activities.

In Belgium for example, some waste incinerators and some cement kilns are simultaneously competitors and customers on a fairly open waste market. Today, both provide a better optimised combination of products and services (better "industrial ecology"). This can be a beneficial trend provided health and environmental safeguards are preserved. This is a sound basis to allow the flows of what may one day no longer be called "wastes" to reach their optimum treatment option. "Industrial ecology" is a concept being increasingly referred to. According to this concept, economic activities, and in particular industries must be associated so as to create a sort of symbiosis minimizing overall nuisances (e.g. the wastes from one industry can be used as raw material by a neighbouring industry). This offers interesting perspectives for the long-term.

In terms of R&D, the main drivers for waste incinerators over the last ten years appear to have been the improvement of ash management methods (stabilising, recycling), the improvement of the thermal conversion systems (resulting in more stable ashes) and to a lower extent the improvement of flue gas treatment. Factors such as inconsistent market demand, lack of agreed test methods and quality criteria and confused legal provisions are hindering the development of ash recycling.

With respect to technology choices, a recent industry survey by Juniper consultancy indicates that fluidised beds, thermolysis and gasification are likely to increase their market penetration in the next few years (see Table 7). R&D is continuing on co-incineration and co-gasification technologies with improved efficiencies.

Table 7: Technology purchasing preferences for the incineration of municipal solid waste in selected European countries for the period 1997-2006
(Source: Juniper Consultancy survey)

Country	Pyrolysis & gasification	Fluidised bed	Moving grates
Belgium	3%	10%	87%
France	9%	34%	57%
Germany	35%	10%	55%
Italy	35%	30%	35%
Scandinavia	4%	36%	60%
Spain	15%	35%	50%
The Netherlands	5%	10%	85%
United Kingdom	14%	36%	50%

6. Conclusions

First of all, it is important to take an integrated view of the whole waste generation and management chain, and not to take a merely end-of-pipe approach. Waste prevention must be an important part of the discussion as it is the preferrable option. The discussion would then focus on "material streams" handled using "generally accepted" and "environmentally safe" practices (Best Available Techniques and Best Management Practices) for recovery, recycling, treatment and disposal.

Incineration is but one group of options for the disposal and recovery of waste. In spite of its lowest priority in the official European waste management hierarchy, landfilling remains the most widely used waste disposal option across the European Union. Incineration with energy recovery and material recycling come next in increasing order of priority. Any sound waste management approach should match the various types of wastes to the various technical options available for the recovery and treatment of waste in order to find the best overall combination. No waste management option can handle all wastes, except landfilling. However, this last option would lead to a large loss of recoverable resources. It is therefore best to keep it as a last resort and send each waste streams to the option that allows the highest overall level of recovery possible with an acceptable level of safety and cost.

In the current state of know-how, incineration with energy recovery is the only practical form of recovery for certain types of wastes (e.g. dispersed small combustible waste containing small plastic packaging, wood residues, soiled paper and other fractions too expensive to sort that cannot be composted nor recycled; certain spent solvents and paint residues...). As a result, for the fraction of the wastes destined to this option, incineration should aim at delivering the highest possible efficiencies of energy recovery while preserving the optimum level of material recycling possible.

The issue of waste incineration is complex and the scientific background behind the various waste management options is far from being clear. Four main dimensions can be identified: technological, environmental, economic and social.

The incineration of waste in Europe occurs under a wide variety of technical conditions. The numerous technologies available (grate furnaces, rotary kilns, fluidized beds,…each with their sub-branches) are each best suited to handle certain types of waste. Each has its advantages and disadvantages. All the new incinerators recover energy, but many existing ones still do not and the levels of efficiency vary widely. Other forms of recovery include co-incineration, itself also performed under a variety of conditions, and thermolysis an emerging technology that appears to be promising for small scale, decentralised units. It is therefore not possible to adopt a uniform attitude vis-à-vis the incineration of waste. In order to use each technology in the best possible way, the pre-treatment of waste can be important. It is also useful in the overall optimisation of waste recovery and disposal.

A number of environmental issues are linked to the incineration of waste. The most publicly sensitive ones are related to atmospheric emissions of dioxins and heavy metals, now largely addressed by flue gas treatment. The management of ashes and slag also requires caution because of high heavy metal content. Cement kilns avoid the problems of ash and slag disposal as most minerals get trapped in the clinker and are recovered as raw material but some issues still remain on smokestack emissions. Debate continues about the potential release of heavy metals from concrete on the long-term. Slags and ashes are often used (reportedly safely) for certain civil engineering applications.

On an economic standpoint, the cost of incineration across the EU is still very variable but is in average still increasing due to the increasingly stringent emission limits requirements. For state-of-the-art facilities, costs appear to be stabilising. In some areas of Europe, a functioning market for incinerating waste in different types of facilities has emerged. Maximizing energy recovery in all the forms of incineration of waste is always desirable.

Waste management has a cost that must be borne by society. Considering the large investments necessary to have an adequate waste management system, long-term economic and legal stability are necessary.

The public image of the incineration of waste in the EU is by and large a reflection of the existing worst cases, acceptance for this option is still low. However, locally, state-of-the-art facilities have gained public acceptance. Where possible, this has provided the extra benefit of developing heat recovery for district heating because facilities could be located near populated areas (e.g. Copenhagen). In order to increase the number of these positive cases, more efforts must be made to highlight responsibilities and improve communication. More factual information about waste management must reach the public and decision-making must take public preferences into account. It is also important to develop best practices.

Today, the wide variety of materials covered by the notion of "waste" in the European Union are increasingly perceived as a resource to be used as efficiently as possible. This contributes to reducing the non-recoverable fraction of wastes. If proper regulatory safeguards are in place and reliable decision support tools such as life-cycle assessment gain in acceptance, this trend should lead to the natural optimisation of waste management. The global objective must remain to find the best possible use for wastes while minimizing adverse effects on public health and the environment.

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