PAUL SCHERRER INSTITUT

Directing Material Fluxes

Advances in Municipal Solid Waste Management and Technology

Research and Development with Respect to Technological, Ecological, Economical, and Social Aspects

Project WABO (2000 - 2001): International exchange of experience and synthesis of the knowledge gained during the Integrated Project Waste of the Priority Program Environment of the Swiss National Science Foundation (1996 - 1999)

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Integrated Project Waste
Swiss National Science Foundation

Collaborating Institutions

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CT-Environment
GEO Partner AG
Holderbank Management and Consulting
Inchema Consulting AG
Küpat AG
Rytec und Partner AG
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Directing Material Fluxes

The environmental impact of traditional waste management practice has become a central concern in industrialized countries. The past decades have seen a dramatic technology development for reducing air pollution of incineration enforced by clean air policies in industrialized countries. The prevention of air pollution has, however, changed nothing with respect to directing the flux of materials such that they would be in line with the goals of sustainable development. Toxic and/or valuable and rare elements get dispersed into the environment by current practice of disposal of treated or untreated waste materials.

Long-Term Versus Short-Term Solutions

Research and development within the Integrated Project Waste and elsewhere have therefore focused in recent years on the question which are the best ways of interfering with the material fluxes such that the ultimate goal of closed cycles may be approached. In the long-term new ways of product design and production processes will eventually lead to a material ecology which avoids wasting of important material resources as well as pollution. There is, however, no alternative to end-of-pipe technologies in the short- to medium-term.

Waste Treatment Technologies

Results of recent R&D into thermal, mechanical, and biological separation processes for achieving substantial redirection of material fluxes in waste treatment facilities show that technical solutions are feasible. At the same time it has become increasingly clear that technical feasibility alone does by no means guarantee the practicability of a proposed solution. Social and economic acceptance is ultimately decisive whether or not an ecological improvement will eventually be brought from laboratory scale into reality.

Integrated Waste Management

It seems to us that it is timely to review the technical, social, economical and ecological aspects of the problem of sustainability in material fluxes. The research carried out in the framework of the Swiss IP Waste has tried to follow this multi-criteria approach to solving the waste problems of today and the future and will be used as the basis for compiling a comprehensive review of the state of the art. The results of IP Waste are by no means complete. They need to be put into international context and complemented by knowledge and know-how which is available elsewhere.

If you are a specialist in any area of material flux management and feel you would like to contribute to an emerging integral picture of how to direct the material fluxes in the future, then please contact us at

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Preface

As a reader of this booklet you are invited to contribute to a project which aims to synthesize an emerging integral picture of how to direct material fluxes in the future.

In the framework of the *Integrated Project Waste* (IP Waste, 2nd phase 1996-1999) which was supported by the Swiss National Science Foundation 13 collaborating teams from various disciplines, including academia, consulting firms, and industry, developed new methods and technologies to solve the waste management problems of the coming century.

In a follow-up project a core team is in charge of the synthesis of the findings of the IP Waste. Together with you and other experts from an international and transdisciplinary community the results will be reflected, discussed, and put together to an integrative standard book which will be published by a noted publishing house.

This brochure contains information about the IP Waste and the most important findings obtained in the second phase of the project.

May 24, 2000 Chr.Ludwig
Villigen PSI

Introduction

Waste Management in Switzerland

The past decades have witnessed considerable changes in the sector of waste treatment and management. However, current practices still have a considerable environmental impact. As a result, the demand for new and more effective (resource oriented) solutions has greatly increased.

Waste treatment and management practices, and therefore research interests vary between different countries. Switzerland's laws are much stricter than those of other countries with respect to the release of toxic materials into the environment. This was the result of taking into account the Swiss Guidelines of Waste Management („Abfallleitbild") in legislation (TVA = „Technische Verordnung über Abfälle" or „Technical Ordinance on Waste Management"). During the past few years this fact has lead to a significant research effort in the area of waste management and technologies in our country.

The „Abfallleitbild"

The Swiss Guidelines of Waste Management were published in 1986 by the Swiss Federal Office of Environment, Forest and Landscape. The Guidelines include political, technical, and economic principles and objectives which have had a strong influence on waste management practices and legislation. From the scientific and technical point of view the following long-sighted objectives are still an issue after 15 years of discussion (quotation):

- Waste disposal systems should generate only two groups of materials from waste, namely those which can be recycled and those which are suitable for deposing on final disposal sites, i.e. sites where flows of materials into the environment (air, water, and soil) are environmentally compatible both in the short- and long-term without the need for additional treatment.
- Waste treatment methods should be designed to ensure that environmentally hazardous materials occur in their most highly concentrated form and environmentally compatible materials in their purest form (i.e. similar to earth or soil).

History of the IP Waste

SPP-Environment

Established by the Swiss Federal Parliament in 1991 the *Swiss Priority Program Environment* (SPPE) was set up by the Swiss National Science Foundation. It was designed to

- explore and help solve the urgent problems facing the environment on both, a national and global level;
- strengthen cooperation in environmental research between universities, industry and administrative authorities;
- promote the practice-oriented implementation of results in society, economy and politics.

During the second research period (1996-1999), the SPP Environment was placing emphasis on:

*Climate in Alpine Regions, Biodiversity, Society, Soil, **Waste**, Development and Environment*

All research projects aimed to help introduce and support sustainable development in the economy and society (= sustainable activity). In maintaining the SPP Environment as part of its research policy, Switzerland is contributing to the follow-up process initiated by the 1992 United Nations Conference on Environment and Development in Rio de Janeiro.

IP Waste

The *Integrated Project Waste* is an interdisciplinary framework where emphasis has been placed on the improvement of waste management systems, technologies, procedures, and waste products.

Project Partners within IP Waste

The IP Waste involved 13 collaborating projects from various disciplines, including academia, consulting firms, and industry.

A list of the projects performed in the IP Waste is given in (Table I).

Table I: Overview of Projects, IP Waste

General Waste Management Aspects, Environmental, Social, and Economic Implications

1 Social Aspects of Waste Treatment - Contributions to a Specific Technology Assessment
Walter Joos, Vicente Carabias, Herbert Winistörfer, Alex Stücheli
Technical University Wintethur, Switzerland

2 Waste Management in its Entirety: Strategies to Resource Oriented Management
Regula Winzeler, Peter Hofer, Peter Schuhmacher, Ruedi Taverna
GEO Consulting AG, Zürich and Basel, Switzerland
2a: Sub-project: Influence of Recycling Processes on the Dynamics of Waste Management (GEO - Tenum)
2b: Sub-project: Consequences of Ecological Tax Reform on Waste Management (GEO - econcept)
2c: Sub-project: Exchange of Information and Results Obtained from Projects within IP Waste and the Netherlands (GEO - Hafkamp)
2d: Sub-project: Material flux analysis as a basis for resource-oriented waste management (GEO - TU-Wien)

3 Environmental Assessment of Thermal Waste Treatment Processes
Stefanie Hellweg, Konrad Hungerbühler
Swiss Federal Institute of Technology ETH, Zürich, Switzerland

4 System Dynamics of Waste Management Including Introduction of New Technologies
Heinrich Widmer, Stephan Textor, Peter Steiner, Walter Ryser, Patrick Wäger, Paul W. Gilgen**
Rytec AG, Münsingen, Switzerland, *Swiss Federal Laboratories for Materials EMPA, St. Gallen, Switzerland
4a: Sub-project: Consequences of Separate Thermal and Material Valuation of Plastics Wastes on the Swiss Waste Management System (Rytec - SSK)

Waste Treatment Technologies

5 Thermal Treatment of Residues Containing Heavy Metals with Regard to Further Processing of the Metallic Fractions, with Special Reference to Non-Metallic Automobile Shredder Residues (ASR)
Charles Keller
INCHEMA Consulting AG, Zürich, Switzerland

6 From Waste to Resource: Microbial Metal Recovery from Waste Incineration Residues
Helmut Brandl, Christoph Brombacher, Walter Krebs
University of Zürich, Switzerland

7 Thermal Separation of Heavy Metals from Waste Incineration Residues Below Melting Temperature
Aldo Jakob, Rudolf Mörgeli
CT-Environment AG, Winterthur, Switzerland

8 Engineering-Scientific Proof of Large Scale Experiments Regarding Integrated Melting of Slag in an Existing Municipal Solid Waste (MSW) Incinerator
*Serge Biollaz, Hans Künstler**
Paul Scherrer Institute PSI, Villigen PSI, Switzerland, *Küpat AG, Uitikon, Switzerland
8a: Sub-project: Validation Experiments for Heavy Metal Evaporation in MSW Incineration (Küpat - PSI - CUTEC -FhG)

9 Product Utilization and Separation of Harmful Elements in the InRec-Process
Verena Schmidt, Christian Wieckert, Adrian Selinger, Hans Rüegg*
*ABB Alstom Power, Baden-Dättwil and Winterthur, Switzerland

10 Fundamental Aspects of Heavy Metal Behavior During Thermal Treatment of Waste and their Residues
Jörg Wochele, Christian Ludwig, Samuel Stucki, Patrick O. Auer, Albert J. Schuler
Paul Scherrer Institut PSI, Villigen PSI, Switzerland
10a: Sub-project: see 8a

11 The Behavior of Chlorine and its Species in Molten Incineration Residues under Different Redox Conditions
Andreas Gössnitzer, Markus Tschudin
Holderbank, Management and Consulting AG, Holderbank, Switzerland

Assessment of Long-Term Stability of Residues

12 Characterization and Utilization of Thermally Treated Municipal Solid Waste and their Long-Term Stability with Respect to Environmental Impact
Daniel Traber, Urs Mäder, Urs Eggenberger, Tjerk Peters
University of Berne, Berne, Switzerland
12a: Sub-project: Evaluation of applications for thermally treated ashes - expertise and professional assistance (UniBe - TFB)

13 Evaluation of TVA-limiting Values with the Method of Mass Transfer in a Waste Dump
*Bruno Covelli, Werner Baumann**
Tecova AG, Wohlen, Switzerland, *Dept. of Environmental Protection, Kt. Aargau, Aarau, Switzerland

„WABO“

Introduction

IP Waste has focused on the difficult task of transferring knowledge to industry and the authorities. Due to the pressure of economic problems in the past years, environmental concerns are no longer top priority in our society. New ecological technologies that looked commercially interesting and technologically feasible five years ago have not entered the market for economic reasons.

In the long-term, finding the difficult path to sustainability is the only choice for mankind. However, there are controversial opinions of what a „sustainable world“ could look like, and it is even more unclear how to get there. The eco-efficient use of energy and materials is a promising approach towards achieving such an ambitious goal. IP Waste has been a first step into this direction. However, in the past, too little effort has been made to harmonize the different views and opinions held in Switzerland, Europe, and other countries. This gap is due to the local character of waste problems (each country has its own approach to solve them) and the difficulties in exchanging information between many different disciplines (business and academia).

In contrast to climate problems, waste problems have erroneously never been discussed on a global scale. An exchange of ideas between countries is almost not existent. Experts are often amazed about the variety of guidelines and legislation in different countries. Nevertheless, an exchange of information, free of any local restrictions, seems to be the first step in the right direction.

A core group of the IP Waste team consisting of people from industry, consulting firms and researchers from various fields has successfully cooperated in the past. Related research and the results of other projects have not been considered yet in an integrative way and there is no agreement on many issues related to waste treatment and management. A synthesis leading to a comprehensive „standard book“ is expected to be a considerable contribution towards the implementation of future waste management practices.

Most projects have published their findings in scientific articles and conference contributions and in an adressee-oriented final report.

IP Waste has made efforts to transfer the results to industry and authorities. IP Waste has organized several symposia and workshops with themes such as:

- „Paths Towards Sustainability in the Field of Waste Treatment and Management - Re-search and Development for Application“
- „Waste Management in the 21st Century: Bio- and Geo-compatible Products“
- Optimal Residue Quality: „Melting or Sorting?“
- Products from Waste Treatment: „How Good is Good Enough?“

A Standard Waste Book: Goals and Visions

The above activities have had a most valuable influence on the integration of the IP Waste results, however, a comprehensive synthesis and a critical analysis in an international context is still missing. In the project „WABO“ („Waste Book“) we propose to fill this gap by publishing an integrative „standard book“ entitled: „Directing Material Fluxes“.

Many books on waste treatment and management have been published, however, in most cases interdisciplinary views are rare, and practicable visions are missing. There is a lack of comprehensive standard books which are orientated towards the future and identify future research needs.

Therefore, the synthesis of the results of the IP Waste projects along with contributions from the international community should be presented in a book which aims to have a formative influence in the field.

The synthesis will consider the „integrated view“. The focus on „Directing Material Fluxes“ takes into account that waste management will no longer be limited to end-of pipe solutions but is part of the management of material cycles.

Who is the Intended Audience?

We address the book to readers of different professional backgrounds. The readers will be updated with the interdisciplinary content in such a way that they can comprehend without being „professionals in waste and material fluxes“ themselves. On the other hand detailed research will be presented.

- Teachers and students get a basic introduction to an interdisciplinary overview about the subjects waste management and waste treatment technologies. Moreover, they get access to selected research areas.

- Researchers learn about research and development in Switzerland in comparison with international research activities. Evaluated research results are presented in more detail, scientifically correct, and yet easily understandable. The book stimulates future research.
- Waste managers will see how applications of various disciplines can be combined to find waste treatment options which are environmentally sound, economically feasible, and socially acceptable. They find a guide to new technologies and their comparison to old ones under environmental and economic criteria.
- Policy makers and politicians find an overview of various strategies in management of waste and material fluxes and their possible implications. Furthermore they are informed about the state of the art in technological developments which can he1p them in designing laws, taxes, and other steering instruments.
- Concerned citizens will be informed on current and possible future developments and their risks. They will find proposa1s of how they can contribute to sustainable waste and resource management, and how they can take part in decision-making processes.
- Private companies find information of what happens or could happen to their waste, and how they can influence the system.

Formal Structures and Layout

We are aware that it is very ambitious to write a book for different audiences. Therefore, it will be paramount to properly structure the information presented in the book. The layout should help readers having different backgrounds to individually navigate their way through the book.

Possible book layout:

- In the main text (the synthesis) the reader will be introduced to the different views of the research disciplines considered. This text is easy to follow.
- In case studies the results of selected IP Waste projects and other contributions will be presented. This presentation will take into account the complexity of the particular matter, but will be kept as straightforward as possible.
- Some information will be especially interesting for certain addressees. In the book special graphical elements (such as boxes, frames, signs etc.) could call their attention.

Other suggestions are welcome.

Goals of the Synthesis Book

The proposed synthesis book provides a broad review of the state-of-the art in different aspects of waste management and puts this knowledge into a more general context of directing material fluxes. It will be useful as a reference for the international scientific community in fields such as inorganic chemistry, process engineering, environmental science, technology and economy, geo-chemistry, social science etc.. The synthesis process and the condensation in the book will add value to the individual results obtained in research projects within the IP Waste.

We expect the product to become an important source for the formulation of the relevant scientific questions regarding resource and waste management in the time span of the next ten years.

The waste book also aims to be useful for teachers of university level courses on waste and related themes.

The Integrated Project Waste (1996 -1999)

Problems with the Acceptance of Technical Solutions

The past years have shown that new technologies which diverge fundamentally from incineration in the grate furnace and include expensive melt-metallurgical processes have not managed to find market acceptance. There are several reasons for the lack of transfer into practical application. On one hand the high temperature processes still have unsolved technical problems, on the other hand the obvious ecological advantages cannot be exploited economically as long as there is no market for the recycled products. Large investments into little proven technologies are a risk which today no plant operator will take. Furthermore there is scepticism in the public towards the erection of new large plants. The lacking public acceptance of a new type of incinerator in the town of Thun (Switzerland) has been studied by the social science team of IP Waste as a case study.

Technology Transfer and Social Aspects

Switzerland has reached a high level of environmental standards and waste management has mainly been discussed as an environmental issue. The social component of a waste management system which would comply with the goals of sustainable development has, however, been neglected.

During the planning and decision making for new waste management options (treatment plants, new legislative measures, etc.) the concerned citizens and environmental organizations should increasingly be included in what has been referred to as participative process (e.g. acceptance dialogue, mediation, „round table“, cooperative discourse).

A formal system of social compatibility analysis was elaborated. The approach chosen elaborates a list of social acceptance criteria which are tested semi-quantitatively to obtain an objective description of the social compatibility of a given waste management project.

An example for implementing the elaborated concepts of social compatibility is the participative acceptance dialogue with accompanying groups. Such dialogues may play an important role during the realization of new incineration plants or when looking for other alternatives.

The registration and valuation of social aspects is important in all cases which are of public interest. Public and private authorities should introduce social compatibility analysis in their own responsibility, following governmental guidelines. One area of application of this instrument is in the consensus-oriented process for conflict management, where, e.g., the social dimension of an object to be assessed needs to be structured, diverging judgements reached by different groups need to be elaborated and possible solutions discussed.

Technology for Flexible Solutions

Radically new technologies have a difficult position in the market of large scale plants. The developments which were carried out in the mostly industrial R&D departments of the IP Waste's technical projects have therefore concentrated on processes which are either based on existing equipment like e.g. the combination of grate furnace and rotating kiln in the VS process (Küpat), or which can be integrated into existing plants as additional plants such as the Fluapur process (CT Environment) or like the choice of processes developed by ABB Alstom Power (the cited technologies are presented below). The concentration of the efforts on integrable add-on plants might be the technological answer of the IP Waste developments to the acceptance problems encountered with the operators as well as with the general public.

Purification of Fly Ash by Heavy Metal Evaporation: FLUAPUR

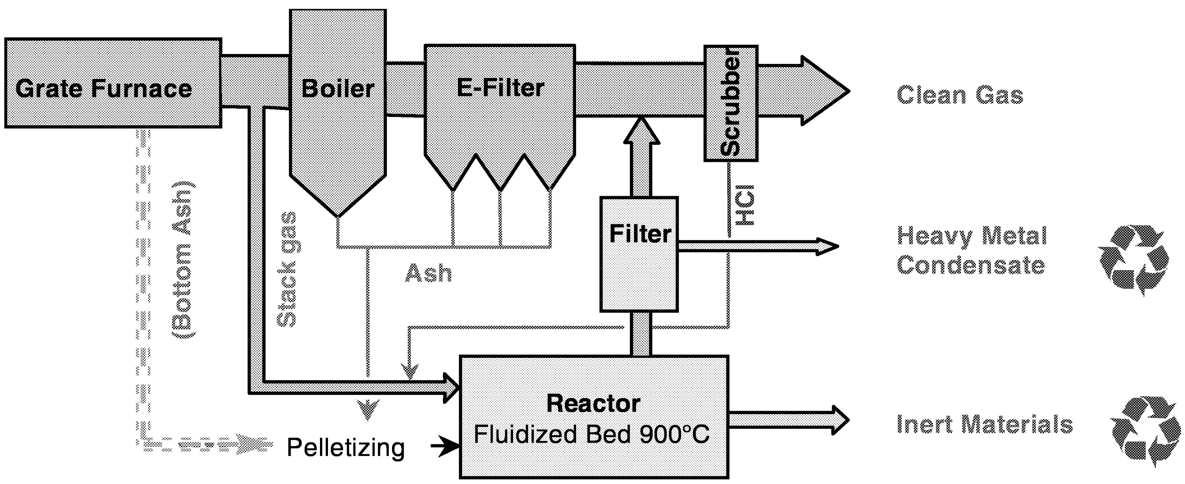

Fig. 1: CT-FLUAPUR process for thermal treatment of MSW incineration residues.

Fig. 1 shows the CT-FLUAPUR process for the thermal treatment of MSW incineration residues. The residues have to be conditioned before thermal treatment, i.e. fly ash has to be granulated. As an option, bottom ash can be treated as well after breaking, iron removal, and granulation. The thermal detoxification of these residues is performed in a fluidized bed reactor at 900 °C. A part of the incineration gas which is enriched with about 10% HCl, is used as a reaction gas and simultaneously as a thermal source for the reactor. A natural gas burner can supply additional heat. HCl for the process is obtained from the wet flue gas scrubber.

The residues leave the reactor as mineral products poor in heavy metals. The heavy metals that are volatilized in the reactor are collected, after quenching, as pulverized condensate. The off-gas is fed back into the incinerator‘s flue gas treatment system.

The most important requirements for the success of a fly ash treatment process, i.e. the possiblity to achieve a good product quality at reasonable costs, have been demonstrated.

Incineration of MSW by the VS-Process

In contrast to the conventional MSW incineration process the VS-process treats municipal solid waste in two consecutive steps. VS stands for „Vergasen“ (to gasify) and „Schmelzen“ (to melt). In the first step waste is gasified with primary air on a grate (air ratio: λ = 0.7). In the second step the products (low BTU gas and coke) are burnt in a rotary kiln with combustion air. To ensure complete combustion, the exhaust gases are mixed in a secondary combustion chamber.

By adjusting the mass flows of waste, primary and combustion air, the intended slagging operation in the rotary kiln is achievable. With heating values of waste at about 12 MJ/kg, gas temperatures of up to 1400°C have been reached without using auxiliary fuels such as oil.

Field experiments on a full scale plant demonstrated the feasibility of the VS-process. The process allows to improve the bottom ash quality with respect to heavy metals, such as Cd, Zn, and Pb.

A New Eco-efficient Low Cost Technology for the Treatment of MSW: PECK

The thermal separation efficiencies for heavy metals in the VS- and FLUAPUR-processes have been combined with those known for mechanical separation technologies. Fig. 2 shows the concept we have elaborated and which allows to reach our goals i.e. to achieve better bottom ash qualities at comparably low treatment costs.

The concept of PECK is the result of the intense exchanges between the involved partners within IP Waste. The integrated process is an important step towards sustainable waste management and resource recovery from MSW. The proposed process is ecologically sensible, technically feasible and economically acceptable.

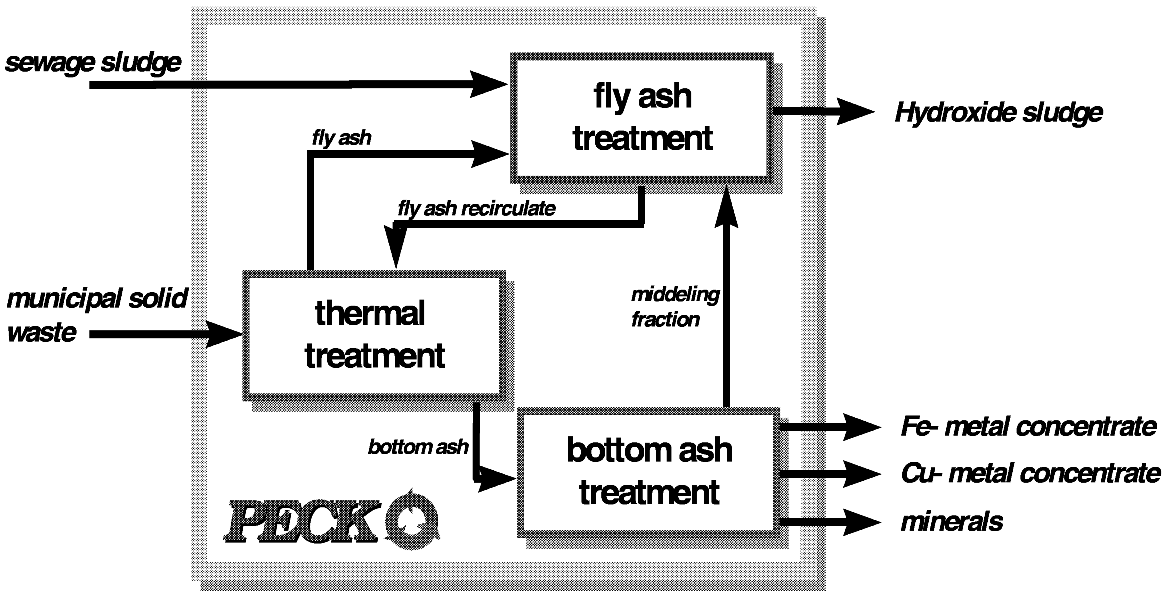

Fig. 2: Substantial metal fluxes in the PECK technology which is patented by a consortium of three firms (Küpat, CT Environment, Eberhard Recycling) and the Paul Scherrer Institute.

Melting and Dry Separation: InRec^{plus}

In conventional incinerator plants, bottom ash is dumped into a water sealed discharger. In the InRec-concept a dry removal system is used. Different discharge systems have been developed depending on the subsequent ash sorting system. A possible combination of process steps and aggregates in the InRec-process for the treatment of incineration residues is shown in Fig. 3. Dry sorting combined with optional vitrification and foam slag production allows to obtain a high degree of metal recovery, a customized generation of gravel, selected vitrification for fractions of concern, low vitrification costs due to an improved rotary kiln technology, and a decrease of treatment costs from foam slag revenues.

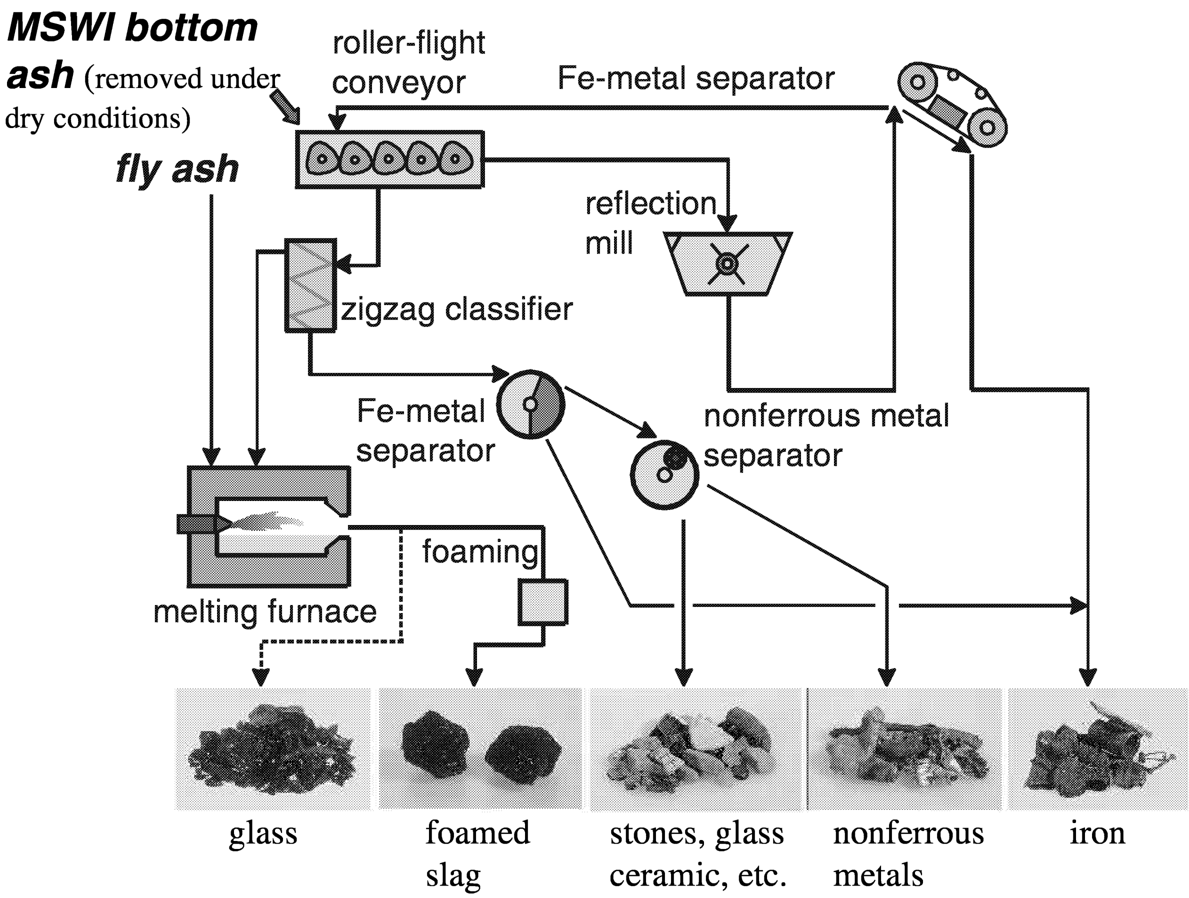

Fig. 3: InRec-process for the treatment of MSW incineration residues.

Treatment of Automobile Shredder Residues (ASR)

As an example of an integrated process for optimized treatment of a special waste fraction, a hierarchy of treatment options for Automobile Shredder Residues (ASR) is shown in Fig. 2. The recommended staged procedure with co-ordination between all the stakeholders was developed within a project dealing with ASR disposal.

In the whole process of ASR treatment at least one thermal processing step is necessary for destroying the toxic organic components in the material and for utilizing the high calorific value of ASR. Pyrolysis is best suited for this as it avoids the oxidation of the recoverable metals such as Cu and Fe. Pyrolysis is best carried out using a fluidized bed reactor if the largest particles of plastics and metal are separated out before. This mechanical separation previous to the pyrolysis has to be optimized to achieve higher efficiency than state of the art. Organic parts such as large pieces of foamed rubber which are not heavily contaminated should be separated out and incinerated more effectively in a MSWI grate furnace. The separation of organic parts must be optimized with respect to energy content (the pyrolysis reactor should be run without external energy input) and reactor size (avoid high loads of material which do not necessarily need to be pyrolysed).

An optional high temperature treatment step for melting non recyclable residues should only be considered after all the previous process steps have been implemented. The advantage of this strategy is that the composition of the residues is better predictable and the process can hence be designed with less uncertainties.

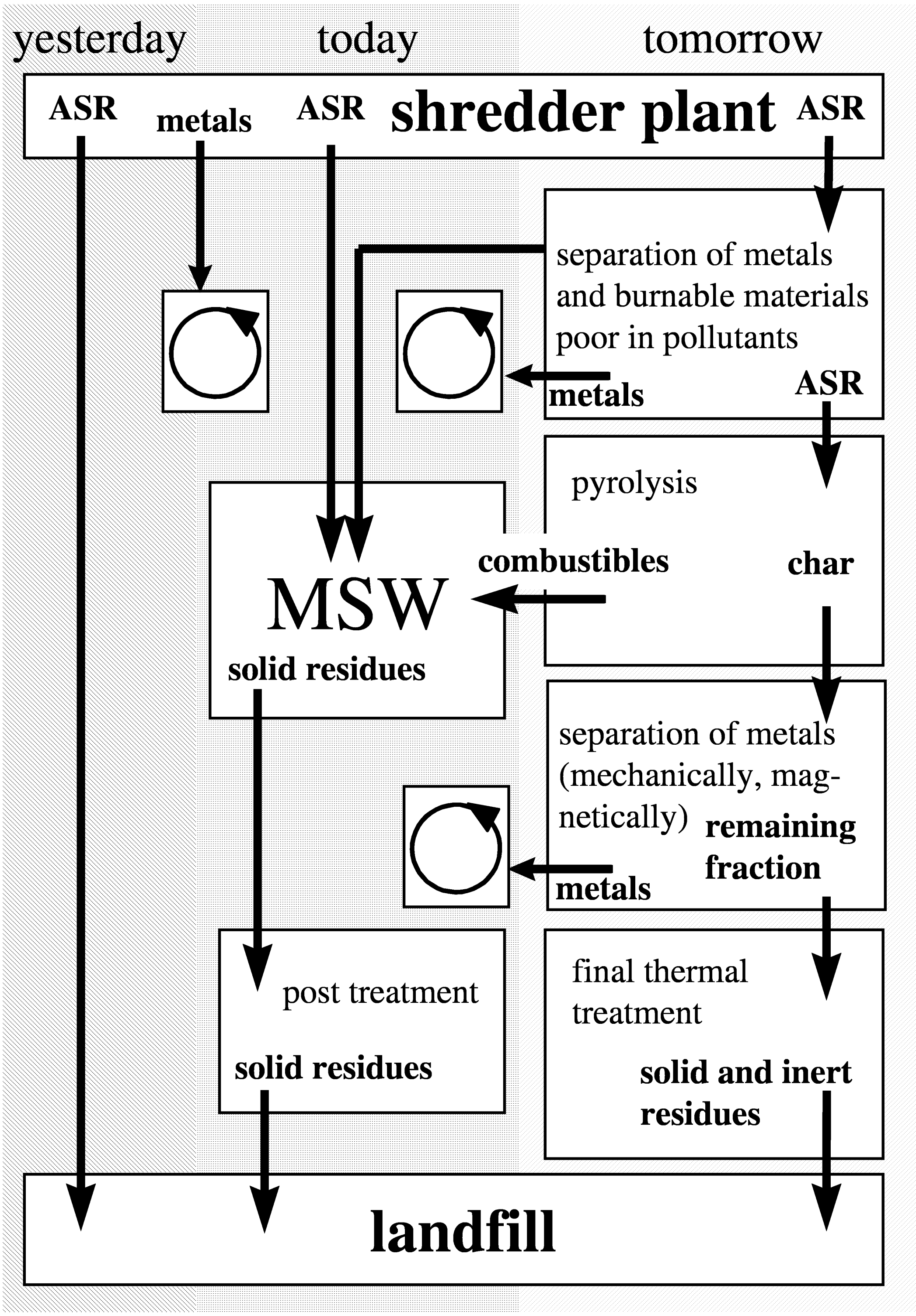

Fig. 4: ASR disposal in Switzerland: yesterday, today, and tomorrow.

The outlined procedure allows to tackle the ASR problem in stages and to introduce significant improvements to the present situation by integrating it into the Swiss waste management infrastructure. The whole existing waste treatment infrastructure could be used more efficiently with advantages for all those involved (the organization of car importers responsible for finding and financing acceptable solutions, the car shredder operators and the operators of MSW incinerators) – and without negative impact on the environment and on other public interests.

Managing Flows of Materials, Energy, and Costs using Dynamic System Modeling

The modularity of processes and the inter-regional co-ordination become the more important, the more the economic constraints become dominant in waste management. The system-dynamic modelling of the regional management of incinerable waste is suited to analyse the parameters relevant to an integral optimisation of the costs, material fluxes and energy management. The developed model can be used for strategic decisionmaking regarding future investments.

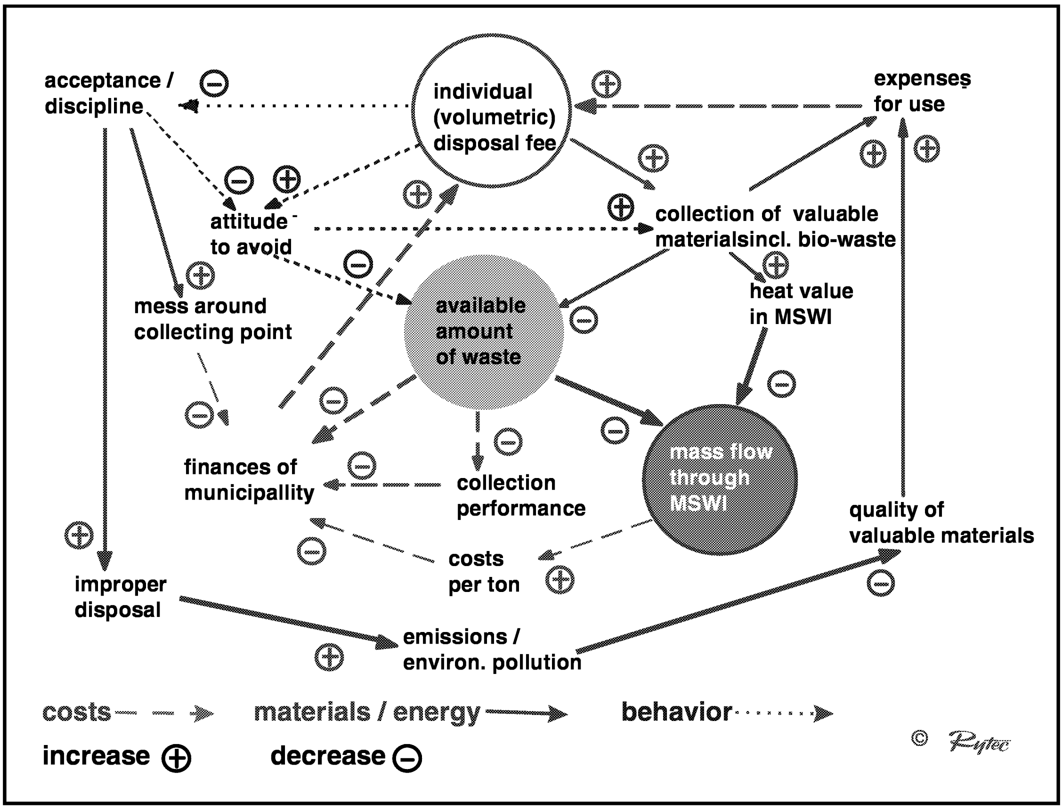

Fig. 5: Parameters having an influence on the amount of municipal solid waste which is delivered to the MSW incinerators. Causal loop diagram.

System Model

Fig. 5 shows the complex systems aspects of a regional waste management system with arrows symbolizing positive or negative feedback between important parameters. Computer programs taking into account these dependencies have been developed for system dynamic modeling. The planning in waste management normally follows regional concepts and decisions. Therefore, the application of bottom-up models proceeding from a municipal solid waste incineration plant to a larger region makes sense.

Three types of models were accordingly developed which allow to study complex, dynamic, process- and development-oriented aspects of costs, energy, and material fluxes of regional waste treatment:

ECOSOLVER MVA-1 is a program that allows to optimize the operation of an incinerator plant, WASTEMANAGER is oriented towards regional waste management and planning. It models consequences of management decisions on investment and allocation of incineration capacities in a regional context. EcoSolver IP-SSK is a tool which has been developed specifically to model scenarios of increased plastics recycling on the operation of existing incineration infrastructure.

One important conclusion from this work is that the optimized operating of local treatment plants does not guarantee an optimized waste management on a inter-regional or national level. It is still open, how the development is going to be on a national level. Long-term goals will have to be reconciled with short-term economic constraints. The optimization of single solutions locally can lead to bad investment decisions with economic consequences. Only by intensive and suitable co-ordination can the local waste management organizations be integrated into an optimum for the entire waste treatment in Switzerland.

Ecological Aspects

The ecological assessment of different incineration technologies shows clearly that the direct and indirect atmospheric emissions of a plant with modern air pollution control equipment are negligible. If the energy produced in the incineration plant is taken as a bonus, the greenhouse gas emissions of the incinerator are cancelling out. The environ-mental impact of modern waste incinerators is limited to the dispersion of pollutants from the residues, i.e. basically to the toxic heavy metals which can be released from the ash landfills via aqueous leaching.

Ecoefficiency of Different Waste Treatment Processes

An LCA analysis considering all operations from waste collection and transport to incineration and landfill of ashes was performed to compare different waste treatment technologies. It was of special interest to asses the impact of future waste treatment processes which lead to vitrified products.

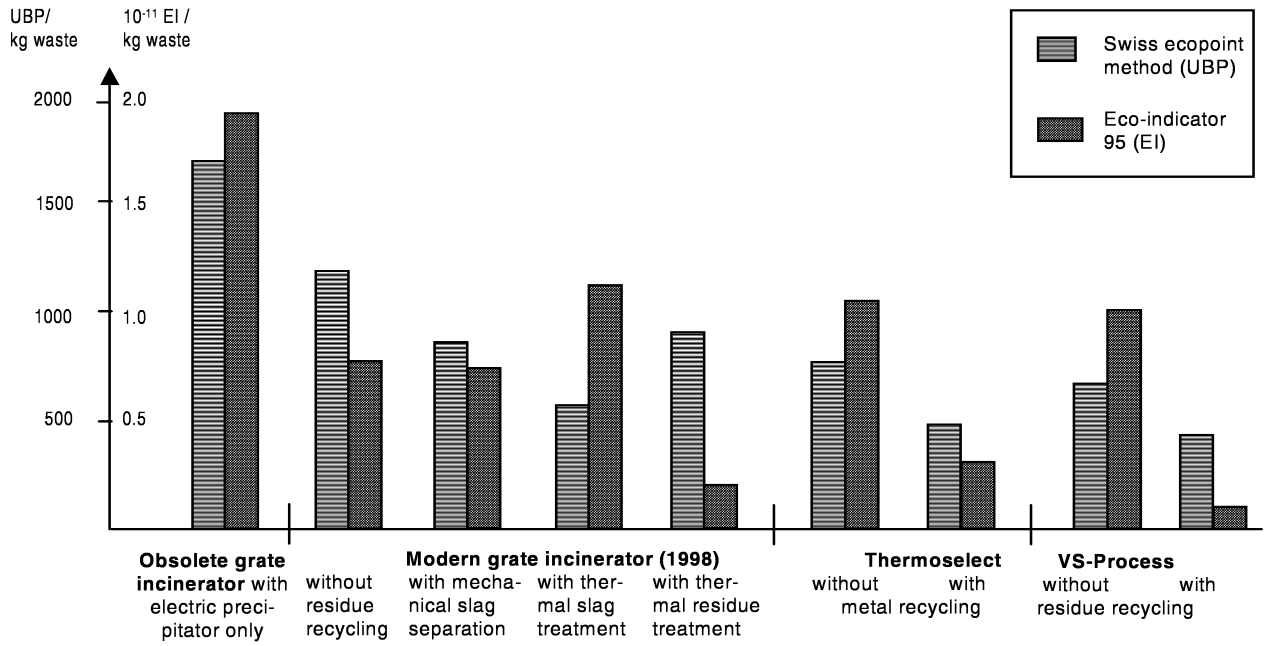

Fig. 6: Impact assessment results with Eco-indicator 95 (EI) and Swiss Ecopoint Method (UBP) (credit was granted for energy, reference systems: Swiss electricity and heat production with gas).

The results of the LCA lead to the following conclusions:

- The implementation of modern air pollution control measures has led to the situation that the incineration process itself does not contribute any longer significantly to the environmental assessment categories photosmog, acidification, ozone destruction, terrestrial ecotoxicology, human toxicology.
- Heavy metal emissions to water from the landfill and the connected toxicological impact categories are ecologically relevant with respect to all technologies.
- The incineration and the landfills cause more than 90% of all potential impacts. Road transport is negligible (~1%) over the typical average distances of 10 km in Switzerland.
- New technologies have a better environmental performance than conventional technologies (assuming that the results of pilot plants are representative).
- The thermal treatment of fly ash is ecologically beneficial. This technology can be added to conventional or advanced technologies as a separate module, or it is already integrated in the overall technology (e.g. Thermoselect).
- The bottom ash treatment reduces potential damages considerably according to the Swiss ecopoint method. On the contrary, the mechanical treatment is judged to be indifferent with Eco-indicator 95. The thermal treatment even seems to contribute negatively to the ecological performance. However, the Eco-indicator 95 method is obsolete with respect to the assessment of toxic releases, which is the reason for these strange results.
- A combination of the thermal treatment of bottom ash and fly ash seems to perform better than the other technologies (optimal results with both impact assessment methods). However, a further ranking of new technologies cannot be performed by the present LCA.
- Landfilling of vitrified slag would have fewer impacts than shown in the present LCA considering the predictions of the models developed to assess the stability of vitrified residues in landfills (see below). On the other hand, the risk of future emissions cannot be ruled out completely. Separation technologies with the goal of recycling do not have this disadvantage.

The considered technologies try to solve the main problem of waste incineration, the heavy metal emissions. Two strategies are applied: the separation of heavy metals from the incineration residues for recycling purposes and stabilization/homogenization of the residues. Both approaches have ecological advantages. However, a sound ecological comparison of these two basic approaches needs further research on landfill models and on methodological issues of LCA with respect to temporal differentiation.

Thermal, Mechanical, and Biological Treatments

The combination of mechanical and thermal processing promises cost-effective solutions with little risk and high flexibility for the separation of metals from bottom ash. Process integrated sintering or melting are important in designing homogeneous and inert products from the mineral fraction of the residues. High temperature melting-metallurgical processes which melt the whole mass of the non-combustible fraction of waste to extract the metals seem less favourable, as they imply expensive equipment (high temperature lining of furnaces) and high energy consumption. In addition the non-volatile metals are recovered in a form which is not suited for recycling (e.g. Cu/Fe alloys which are problematic in the processing of iron scrap as well as in the Cu refining processes).

The average heavy metal content in MSW is about one to two orders of magnitude above the natural background ("earth crust", uncontaminated biomass and corresponding waste fractions). The process goals for the production of reusable or finally depositable products from the ashes of MSW can be deduced from available literature data regarding average waste compositions. A depletion efficiency of about 90% for most relevant heavy metals is necessary for bottom ash, and of more than 99% for the fly ash which is enriched with heavy metals. The process goals can be achieved by thermal treatment of fly ash in HCl atmosphere. The addition of HCl is, however, not feasible in the incineration process and therefore the process goals for bottom ash cannot be reached by primary measures in the incineration process, as has been revealed by laboratory and pilot plant experiments. Especially for Cu and Fe the most cost effective separation technology is not thermal, but appropriate mechanical processing.

Generally the research in the IP Waste has produced the following guidelines for separating metals from ashes:

1. Thermal volatilization of heavy metals is best carried out in reducing and/or HCl-enriched atmospheres at temperatures below the ash melting point.
2. Non-volatile metals and metal scrap of large dimensions are best removed from ash or pyrolysis coke by mechanical processing.
3. Fly ash can be decontaminated and metal salts recovered to the extent that it can be recycled or deposited.

Recovery and Recycling of Heavy Metals

Thermal Treatment

Thermal Separation of Heavy Metals

Experiments were performed on laboratory, pilot, and on full scale.

A positive influence on the volatilization of heavy metals during incineration and thermal treatment of incineration residues was found for increased temperature, a reducing atmosphere, a long residence time and especially for the chlorine content.

Examples

Laboratory scale and pilot plant experiments have shown that Zn and Pb can be separated during the incineration to produce a better quality bottom ash by applying a reducing atmosphere or adding chlorine. The element Cu cannot be removed from the bottom ash without the use of chlorine.

Laboratory tests have shown that heavy metals, such as Cd, Cu, Pb, and Zn can be removed from fly ash in a fluidized bed reactor with the assistance of HCl gas and at temperatures below the melting point of the fly ash (see FLUAPUR-process above). The typical evaporation behavior and quality obtained during the thermal treatment of fly ash is shown in Fig. 7.

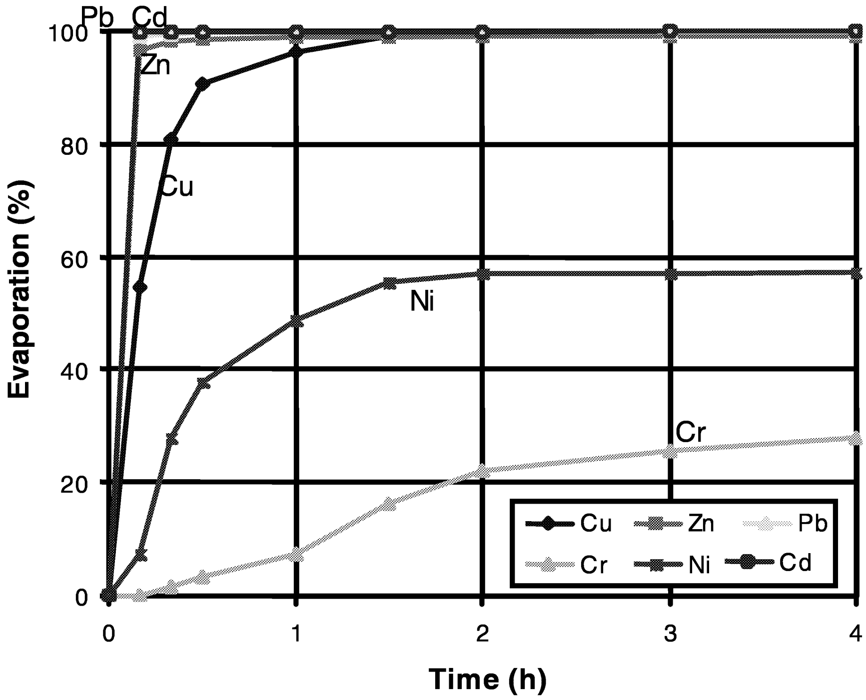

Fig. 7: Evaporation of Cd, Cr, Cu, Pb, Zn, and Ni from a mixture containing MSW incineration fly ash and 10% coal. The temperature was kept constant at 900°C and the atmosphere was enriched with 10% HCl.

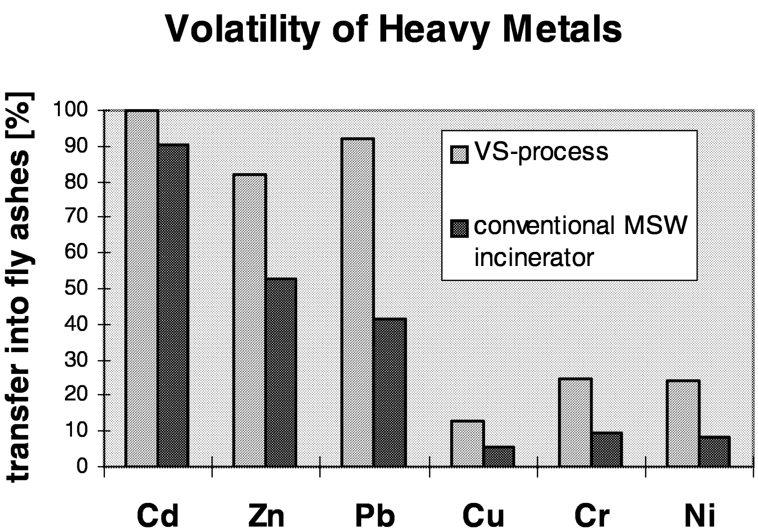

Fig. 8: Comparison of transfer coefficients obtained by the VS-process and conventional MSW incineration.

Laboratory experiments (ABB Alstom Power) have also been performed in absence of HCl using a rotary kiln. The thermal treatment below the melting point of the ashes (fly and/or bottom ashes) lead to a good separation, i.e. better than mechanical, of heavy metals. Zn, Pb, and Cd concentrations could be reduced to levels below the TVA (Technical Ordinance on Waste Management) limits.

The metals remaining in the residues are stabilized in mineral phases such as silicates, i.e. these products show a much better leaching behavior than untreated incineration residues.

Different melting processes (e.g. InRec, Deglor, AshRec) for treating dry ash developed by ABB Alstom Power were investigated at pilot and/or industrial plant scale. In an oxidizing melting process (such as Deglor) it is possible to produce a highly inert and homogeneous glassy material. The Zn content of this glass, however, lies above the limits of the Swiss TVA. To achieve the TVA limits for inert materials, especially the limits for Zn in fly ash and Cu in bottom ash, it is necessary to apply a reductive process. In such a process the Cu in bottom ash can be separated out of a liquid metal phase. Using a rotary kiln as the melting aggregate it is possible to reach the TVA limits within a residence time of 1-2 hours.

Fig. 8 illustrates the advantages of the reducing conditions in the VS-process. By changing the operation conditions in the VS-combi-reactor from conventional incineration to VS-process conditions the transfer coefficients of the heavy metals, such as Cd, Zn, and Pb, were significantly increased.

Investigations on the Volatility Behavior of Heavy Metals

New methods have been developed which allow a) to simulate the incineration of municipal solid waste on laboratory scale, b) to perform on-line evaporation measurements of heavy metals from solid samples, such as fly ashes, and c) to separate heavy metals via fractionated condensation.

With a tube furnace, using small amounts of synthetic waste, and considering similarity conditions the processes of an industrial furnace can be partly reproduced (Fig. 9). With a simple experiment we have an inexpensive instrument for testing the influence of various operation modes and different combinations of materials on the volatility coefficients (transfer coefficients, Fig. 10) of heavy metals.

The new measuring techniques for the on-line measurement of heavy metals in hot gases is very helpful for the development of new thermal processes on laboratory scale. The method has the potential to be adapted for the monitoring on industrial scale.

Mechanical Treatment

The dry removal of bottom ashes from incineration allows a better separation of heavy metals from this residue. Salts and unburned carbon can be mechanically separated to a large extent by air sifting. In dry bottom ashes metals, such as Al and Fe, do not oxidize and can therefore be recycled. By previously crushing the ashes it is possible to separate 75% and 60% of the Cu and Zn, respectively, as elemental fractions.

Although, biological and thermal treatment allow to achieve a more efficient separation. Cu, however, is difficult to separate during incineration. It was shown that a mechanical post treatment of such residues makes sense and is technologically and economically feasible.

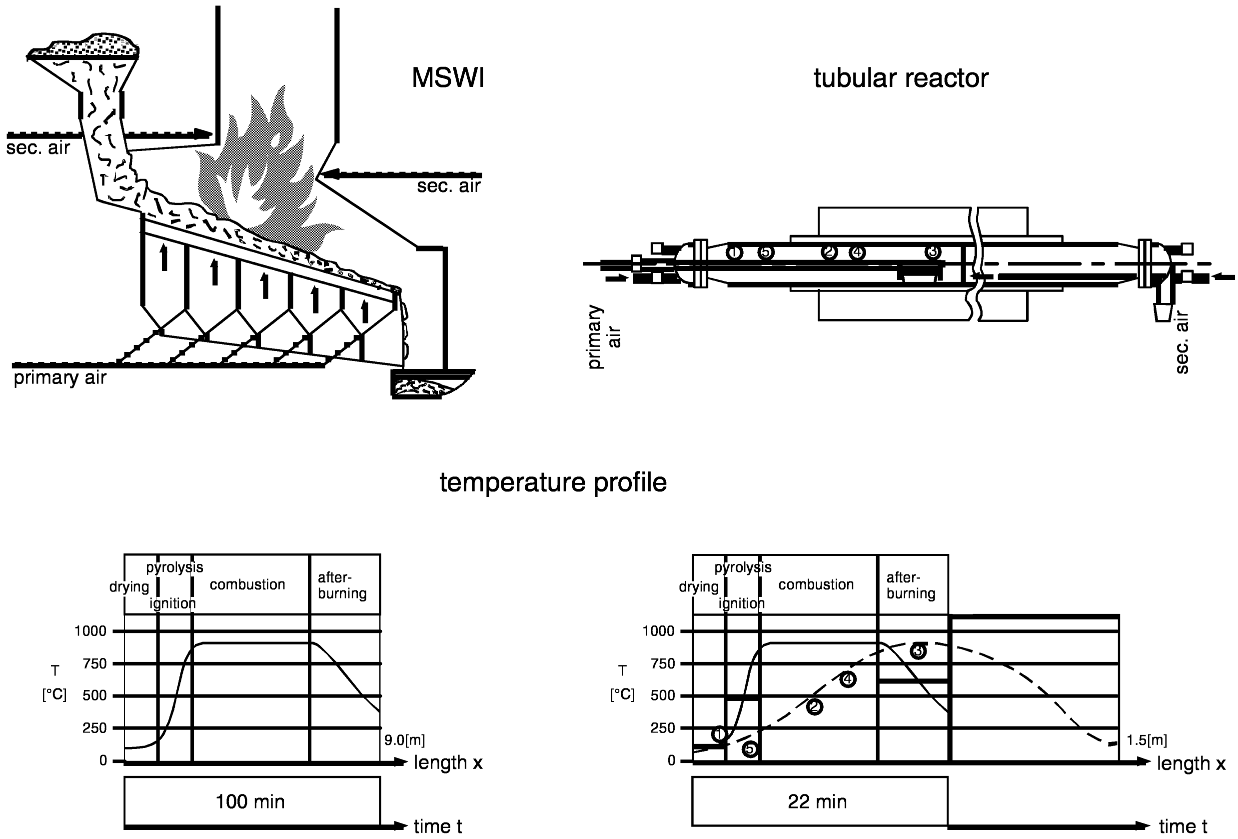

Fig. 9: Simulation of the incineration process on a grate furnace in the laboratory using a quartz glass tube reactor. The probe is placed in an Al_2O_3-crucible which is moved along the reactor tube (positions 1-5) to simulate a given temperature-time profile. Residence time, redox-conditions, chemical composition and grain size have been considered.

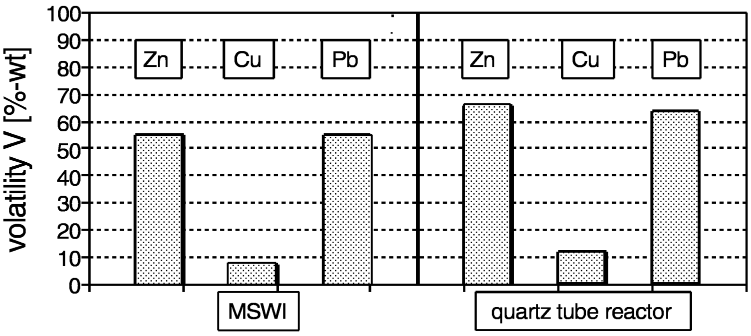

Fig. 10: Comparison of the volatility of Cu, Pb, and Zn during MSW incineration (Belevi, 1993) with results from laboratory simulation.

Biological Treatment

Generally one can state that bio-leaching processes are, besides their ecological advantages, economically attractive.

Bio-leaching has already been used for mining purposes (e.g. recovery of Au or Cu) or tested for soil remediation. Our results show that biological methods are also potentially useful for the efficient extraction of heavy metals from MSW incineration fly ashes using different microbes (Fig. 11).

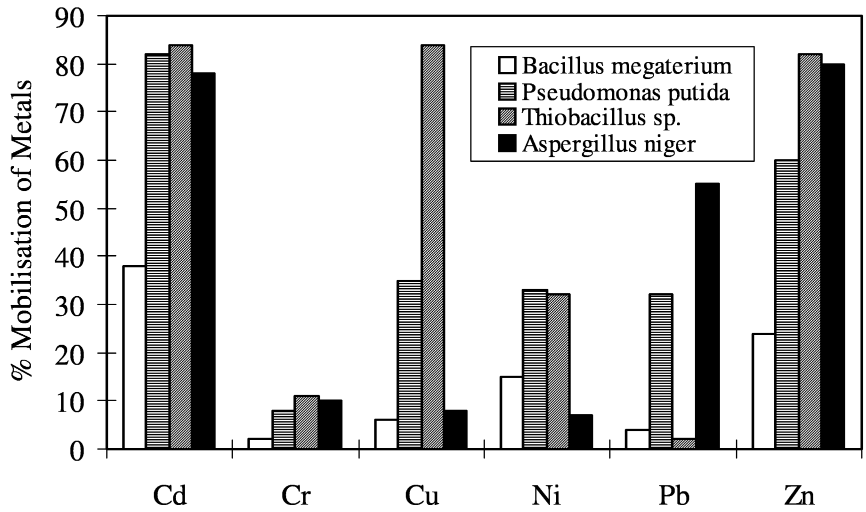

Fig. 11: Metal mobilization from MSW incineration fly ash in a 2% suspension of different microorganisms.

From the results the following conclusions can be drawn:

1 Biological treatment (bio-leaching) of fly ash from incinerators as well as other metal containing solids is feasible.

2 Bio-leaching is as efficient in mobilizing metals as chemical leaching. In some cases enhanced mobilization by bio-leaching has been observed.

3 The efficiency of mobilization of a given metal varies with the material to be treated, the organisms used, and the conditions of cultivation.

4 A two-stage process in which the function of growing the biomass and the leaching agent is separated from the proper leaching process, is better suited for treatment.

5 Metal recovery from the leachate solution can be achieved by precipitation or electrolytic reduction.

6 The extraction process can be scaled up to pilot scale. The process needs to be optimized in a pilot plant, which will produce the data necessary for a full evaluation (including life cycle analysis) of the process compared to alternative treatment technologies.

The economy of bio-hydro-metallurgical processes has to be assessed with respect to conventional techniques, such as pyrometallurgical or hydro-metallurgical processing. From the scarce data in the open literature for classical processes one obtains that processing costs are in the same order as for bio-leaching processes.

Conclusions

Heavy metals such as Cd, Pb, and Zn can be recycled from municipal solid waste by a) optimizing the incineration process and b) a subsequent treatment of the filter ashes.

The thermal recovery of Cu seems difficult but the performance of today‘s mechanical separation systems is already high and allows to treat large volumes which is necessary for the treatment of bottom ashes.

Clean residues will not have to be landfilled in the future and could be used as secondary raw materials, e.g. in the construction industry.

In the proposed processes the heavy metals result as concentrates. For the optimum recycling the heavy metals should be separated into different fractions. First attempts have shown that the method of fractionated condensation, thermal desorption (principle of distillation) or a combination of both techniques could improve the quality of the recycled heavy metals.

Economic Aspects

Whether the processes which are based on largely existing technology will find market acceptance will to a large extent depend on the achievable cost reductions for the landfilling, i.e. whether the cost savings for the deposition can pay the additional processing costs. There are of course only cost savings to be made in the landfilling if a market can be found (at least at zero price) for the products. For that to occur the legal boundary conditions will need to be adapted such that a clear classification can be applied to the products which reflect their ecological quality. For this it is important to elaborate clear assessment criteria.

The Value of Secondary Raw Materials?

The costs for melting processes are very high. Therefore, considering today's landfill costs in Europe the production of high quality products is imperative. An appropriate process for the direct production of foamed slag from molten residues (see InRec^{plus}-process), is in the final stage of development.

The question of reusing „inert" or even heavy metal free products is a very complex one and cannot be answered only considering the leaching behavior. E.g. currently the cement industry does not have a demand for secondary raw materials, because enough primary resources are available and the first results also show no advantage to increase the cement technical properties. However, the opportunities for the use of secondary raw materials have not been tested extensively enough so far.

The purification of ashes using less expensive and energy intensive technologies may be more practicable than melting procedures. The realization of new technologies is more likely if the new processes reduce today's disposal expenses by avoiding expensive landfill costs. The treated fly ash as obtained in the FLUAPUR-process can be used as inert additive (up to 10%) to concrete. For a plant treating 500 kg of fly ash per hour the costs are 500 to 600 CHF per ton, which is comparable to the current disposal costs for fly ash. About 60% of the costs are investment costs.

Closing Material Cycles

A comprehensive view of resource management includes waste management / disposal and the use of primary resources. A high standard in sustainable waste management can only be achieved if material cycles can be meaningfully closed, considering ecological, economical and social aspects. From this perspective the thermal treatment of incineration residues makes sense. The separation of heavy metals allows a reuse of them in metallurgical processes and produces silicate glasses for construction materials which may substitute primary thermally pretreated resources and therefore allows to reuse the invested energy.

Assessment of Residues from New Processes

The central question as to what material properties the products from waste incineration have to have in order to be recyclable or to be suited for long term deposits was discussed at length within IP Waste workshops. The answer to this question implies that the scientific fundamentals of the behavior of these materials in a landfill or as a construction material can be predicted. The characterization and the modelling of the behavior of vitrified materials in landfills which were carried out within the IP Waste framework have contributed new insights to this question. The results of this work suggests, that compared with state-of-the-art ashes, vitrified residues show a stability which reduces the rate of dissipation of toxic materials by a multiple. The quality standards which need to be fixed for a material which is expected to be around for centuries must be negotiated in a political consensus process. In addition to the environmental pollution potential of a deposit a sustainable assessment of quality criteria needs as well to address the resource aspects of conserving rare elements. Robust strategies are asked for, i.e. measures need to be taken today which do not impede future improvements. With respect to the heavy metals in residues this means that, unless the costs are prohibitive, separation, concentration and recovery is to be preferred to melting and inertisation which in many cases is as cost and energy intensive.

Characteristics of the New Thermal Products

Inertisation and Leachability

The products of the new thermal treatment processes have been characterized by studying their chemical and mineral composition and by performing column leaching tests.

The inertisation was mostly excellent for glass matrices, silicates and in refractive oxides but less good in sulfides and alloys which, however, are only present in low quantities. The sample matrix is a homogeneous glass or silicate. Therefore the good leaching behavior is not at all astonishing. The measured dissolution rates of the solids is overlapping which the rates known from feldspar (earth crust) dissolution but tend to be higher than expected. Applying these results to a real landfill situation we expect that the landfill dissolves at similar rates as its mineral underground (for similar flow conditions). The release of the heavy metals cannot be significantly faster than the dissolution of the solid matrix. However, the heavy metal concentrations in the eluates of column experiments are still under investigation to close open questions. For using the experimental rates to quantify the release of toxic substances from landfills it is necessary to adapt the field conditions. It is common knowledge that weathering rates determined in field studies are about one to two orders of magnitude smaller than those determined in the laboratory. This means that the dissolution rates determined in the laboratory experiments are most probably much higher than those expected in the real landfill.

Long-term Safety of High-Temperature Bottom Ash Landfills

The long-term safety of a landfill containing bottom ash from conventional municipal solid waste incinerators need care over a long time scale resulting in high costs. This mortgage will be left to future generations. With the danger that in a few hundred years we will have incidents in which ground water will be heavily contaminated.

Technically it is possible to incinerate municipal solid waste at higher temperatures (e.g. VS-process), so that the resulting bottom ash consists of a glassy matrix. It has been shown that with high-temperature bottom ash from an industrial plant it is possible to construct a landfill which releases a leachate having concentrations below the limits for drinking water. New analytical methods were provided to assess the long-term security of such new landfill bodies.

It is necessary to improve the processes for the production of high-temperature bottom ash to have a constant quality of the glass matrix and a given grain size can be guaranteed.

The results of a probabilistic risk analysis for conventional landfills have shown:

- The maintenance of a landfill in agreement with the Swiss TVA is extensive. Moreover, such landfills have to be maintained for hundreds of years.
- The leachates have to be collected and treated for hundreds of years. After 400 to 800 years the technical barriers will fail. Synthetic materials commonly used as coverages may fail even earlier (i.e. after 50 to 100 years). Depending on the release path very expensive redevelopments will be necessary. A landfill containing high-temperature bottom ash does not need any technical barriers. With an optimized glass matrix the pollutants in the leachate do not exceed the concentration limits for drinking water.
- In an extraordinary event the concentrations of harmful substances in the leachate could increase if the grains of the bottom ash are too small. However, under conditions similar to that of a normal landfill, we expect to have such an extraordinary event in the time range of 800 to 9000 years.

Legislation

By the Swiss TVA inert solid materials are characterized firstly by the leaching behavior and secondly by a given maximum total concentration of certain toxic substances (mostly heavy metals). However, it has to be discussed if the TVA limits are appropriate for products obtained from the new thermal processes. The glasses and crystalline products from the high temperature processes pass the standard leaching tests, even if the concentration limits are much higher than allowed in inert solids. Even on a long-term-scale the limits given by the TVA are therefore not related to the material fluxes into the environment. The TVA limits cannot be derived from leaching tests only. New instruments have therefore to be developed to define such „inert solids“. We suggest to include a) a possible reuse of metals, b) bio-compatibility and c) a comparison of natural and antropogenic heavy metal fluxes.

Sustainability in Waste Management

Sustainable solutions always require choosing and prioritising between different, often contradictory options. The problem of defining reasonable goals for a sustainable waste management system and of finding ways to get there have been discussed within IP Waste. In a series of workshops and discussion rounds the theses were elaborated by the research team together with actors from waste management. The comparison of the sum of the goals for a sustainable waste management system with the existing goals set forth in the Swiss Guidelines for Waste management reveals that while the ecological goals are well taken care of, there is a lack of clear-cut goals with respect to social and eco-nomic aspects. This view was largely confirmed by a Delphi-opinion poll among Swiss waste management specialists on the future of the waste management system in Switzerland which was carried out in parallel.

In a broad approach it was tried to describe the present waste management system of Switzerland and to deduce goals for future developments taking into account the goals in line with sustainable development. With the ultimate objective to provide policy-makers with tools and suggestions towards a sustainable integrated waste management the project started with an analysis of the waste management policies which over the past 50 years had an influence on the material flux in the waste sector. This analysis provided a set of policies which have proved to be successful in implementing ecological goals. The second step was to define the goals for sustainable waste management. The resulting goal system is, in a simplified diagram, shown in Fig. 12. Different goals were placed in this diagram with respect to the three dimensions of sustainability. Based on past experience and the generalized system of objectives the next step was the formulation of scenarios for future developments. These scenarios were discussed independent of actual constraints and were then used to investigate which future developments might be most in line with the goals for sustainable development. This process of designing and validating scenarios was carried out in workshops with participants from the research team and with actors in waste management operations.

Based on the analysis of the past and the possible future developments the team elaborated a set of recommendations for future policies to be adopted for reaching sustainable solutions in the management of material fluxes.

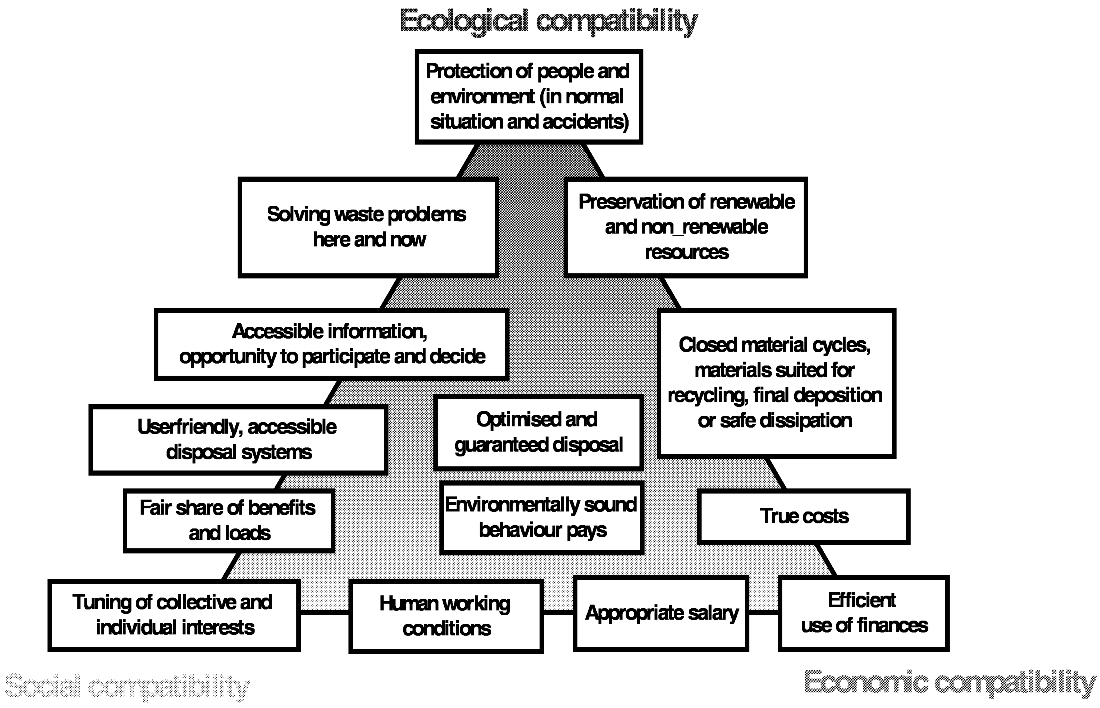

Fig. 12: Aim system for sustainable waste management.

The following requirements must be fulfilled for the implementation of a sustainable waste management system:

1 Equal assessment of the present and of the future (long-term is more important than short-term)

2 Focussing on the complete system rather than on parts. Waste management should be viewed as a part of the political economy.

3 Goals should be discussed at all levels of the federalistc structure, aim conflicts should be eliminated and priorities for implementation set. Aims should be tackled even if they can not be solved in a short-term.

4 The aims and strategic principles have to be communicated broadly to all.

5 The legal boundary conditions have to be well defined to guarantee a consequent enforcement and to give clear boundary conditions for the actors of waste management operation. This is the basis for predictable and calculable conditions and therefore for a fair situation for the authorities, companies and privates.

6 Economic instruments have to be considered. Especially the instrument of the so called ecological tax reform has been investigated. The results have shown that charging energy and relieving „work-effective“ taxes causes a change to less energy intensive wastes, but does not solve any other problems relevant to waste management. It was shown that using these instruments for directing material fluxes is more effective for promoting ecologically optimized products (e.g. replacement of toxic with environmentally compatible materials).

Strategic Principles and Instructions

With these boundary conditions in mind the following strategic principles and instructions for action were formulated:

- Liberalization with clear boundary conditions. E.g. Coordination in those fields which entail high investment costs and for which safety is of concern on one hand, liberalization in the fields of logistics and recycling on the other.
- Optimum equilibrium between avoiding, re-

cycling, and disposing of materials, taking into account all aspects of the goal system for sustainability.

- Materials should only be landfilled if they are suitable for an ultimate disposal (many centuries).
- Increased producer responsibility. This means energetic and material optimization for the whole product cycle to reduce pollution; analysis of material fluxes in companies, and transparency in product declarations.
- Increased consumer responsibility. Initiate a change in attitude towards more cooperative, environmentally adequate and modest behavior is an option that should be aimed for in the long-term but which, in a short-term will cause economic pressure.
- High transparency and userfriendliness of the waste disposal infrastructure. E.g. disposal systems should be simple, product specifications should be declared, and sustainable behavior should be honored.

The applicability of the above recommendations and principles has to be proved in the real world, and discussed with all stakeholders concerned with practical waste management decisions. The Guidelines for Waste Management have to be complemented with social and economic aspects.

Project Abstracts

In the following chapter we have composed abstracts which give briefly information about the single projects. For more information please contact the research groups via the provided e-mail address.

Social Aspects of Waste Treatment - Contributions to a Specific Technology Assessment

Walter Joos, Vicente Carabias, Herbert Winistörfer, Alex Stücheli

It is becoming increasingly evident that a waste management program, and especially a waste treatment technique, which ignores social aspects, is doomed to failure. Aspects concerning the problems of public acceptance, consumer behavior and changing value systems are no less important than the technical or economic aspects in waste management research and decision-making. Results of the three-round written Delphi-Expertquestioning „Contributions to the development of waste management in Switzerland" show that decision transparency, interregional cooperation, information policy and public participation are important factors with regard to the public acceptance of waste management in Switzerland. The results and recommendations of the Delphi-Questioning should be utilized in order to improve the social compatibility of waste management. Therefore, to include social compatibility in planning processes, a tool is being developed: the Social Compatibility Analysis. An example of putting social compatibility into operation is the participation orientated acceptance dialogue.

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Waste Management in its Entirety: Strategies to Resource Oriented Management

Regula Winzeler, Peter Hofer, Peter Schuhmacher, Ruedi Taverna

The development of waste management in Switzerland in the period of 1950-1970 was analyzed. The goals for sustainable waste management are defined in hierarchical order. Starting with scenarios for a sustainable future for the Swiss waste management and subsequent valuation regarding sustainability criteria, recommendations for the future have been deduced. A sustainable waste management system („waste management in its entirety") considers the entire life cycle of products (resources, raw materials, consumer products, waste products) as well as the processes of production, consumption, recycling and waste treatment/disposal. In a sustainable waste management system it will be essential to find an optimum balance between waste reduction, recycling and waste treatment. The Swiss guidelines of waste management of 1986 comprise most of the ecological aspects of a sustainable waste management, but economical and social aspects need to be included in more detail.

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Environmental Assessment of Thermal Waste Treatment Processes

Stefanie Hellweg, Konrad Hungerbühler

Gas purification systems caused a significant reduction of harmful air emissions of waste incinerators in the past. However, the potential emissions from landfilled incineration residues remain to be a threatening risk. New separation and high temperature technologies (producing a glassy slag) cause less potential damages than conventional grate incinerators. In this context, it is of minor importance whether integrated technologies are implemented or whether complementary modules are added to the conventional plants. A sensitivity analysis shows that the results do not vary much with a change in the waste composition. However, the way of valuing long-term emissions can have a major influence on the results. Transport is not very relevant regarding Swiss distances, but becomes a major ecological problem when waste is transported more than 1000 km.

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System Dynamics of Waste Management Including Introduction of New Technologies

Heinrich Widmer, Stephan Textor, Peter Steiner, Walter Ryser, Patrick Wäger, Paul W. Gilgen

Development of Swiss waste management and technology in the last years was governed by conceptual and legal prescriptions. They mainly concerned reduction of emissions from waste incineration and improvement of the quality of residues to be landfilled. Local operational and regional waste management interests were predominant. Optimizing operational or regional units does not effectively lead to optimal material-, energy- and cost flows in the national waste management system. In the present project, system dynamic software tools were developed for operational and strategic planning of regional waste management and applied in a first example.

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Thermal Treatment of Residues Containing Heavy Metals with Regard to Further Processing of the Metallic Fractions, with Special Reference to Non-Metallic Automobile Shredder Residues (ASR)

Charles Keller

The project was concerned with disposal of the light-density fraction of non-metallic auto-motive shredder residues (ASR). With a view to improved disposal solutions in the future, more detailed ASR composition analyses than hitherto were carried out. Also, industrial-scale material flux analyses were performed with the aid of the pyrolysis kiln at BATREC Ltd. and systematic studies of thermal ASR treatment were undertaken using a bench-scale reactor and screen analyses of pyrolytically treated ASR. These showed that pyrolysis is well suited as the central thermal process step in future ASR disposal in accordance with the medium–term objective of the Swiss end-of-life vehicle disposal concept (IGEA concept) with the construction and operation of special thermal ASR treatment plants. With fuller separation of recoverable metals, such as iron and copper, before and after pyrolysis by mechanical and electro-magnetic methods, the result is a strategy for realization of this disposal objective which can be implemented in stages, considers the interests of ASR suppliers, plant operators and the public alike, and can therefore be quickly translated into reality. In environmental, economic and political terms, the integration of these new systems into existing municipal solid waste incineration plants is the most beneficial option.

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From Waste to Resource: Microbial Metal Recovery from Waste Incineration Residues

Helmut Brandl, Christoph Brombacher, Walter Krebs

The objective of the project was to apply a microbial leaching process („bio-leaching") for the mobilization and recovery of metals from solid materials such as e.g. incineration residues, galvanic sludge, or electronic scrap as well as metal-contaminated soils. These materials represent a valuable secondary resource due to their high heavy metal contents. Bioleaching allows the cycling of metals by a process close to natural biogeochemical cycles reducing the demand for resources such as ores, energy, or landfill space. Different solids have been microbiologically treated. several metals were completely mobilized depending on cultivation conditions and organisms applied. Metals were recovered by precipitation or electrolysis. A pre-industrial pilot plant was developed and a first run has been conducted. Bio-leaching represents a biological technique which fit well with the overall „green" movement of maintaining nature's harmony that dominates environmental awareness and much of public policy today. Government regulations and (research) policies that favor green technologies are a key incentive for developing such technologies. These find a wide acceptance in public and in politics. It is a matter of innovative technologies with a proved market gap.

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Thermal Separation of Heavy Metals from Waste Incineration Residues Below Melting Temperature

Aldo Jakob, Rudolf Mörgeli

The CT-Fluapur process, developed by CT Environmental Technology Ltd., transforms toxic fly ash (and slag) from municipal solid waste incinerators (MSWI) into a harmless inert material, which can be reused. Up to now, particularly fly ash has to be treated as hazardous waste and has to be deposited in strictly controlled landfills because of its high content of leachable heavy metals and enhanced contents of dioxins and furans. However, in view of a sustainable waste management it is not wise to install landfills. They always involve a potential pollution risk over long-term periods. The MSWI residues should rather be considered as raw materials which can be recycled. For example by separating the heavy metals from the inert residue matrix and by destroying the dioxins/furans. CT Environmental Technology Ltd. has reached this goal in the laboratory. The heavy metals could be separated from the MSWI residues nearly completely by a thermal treatment and the dioxins/furans could be destroyed. Optimum process parameters were a temperature of ca. 900°C, i.e. below the melting point of the residue, an addition of ca. 10% of coke, and an atmosphere of flue gas enriched by hydrochloric acid. The very promising results from the laboratory scale investigations and the calculated reasonable costs of the process will be verified during the next years in a pilot plant in the MSW incinerator in Lucerne.

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Engineering-Scientific Proof of Large Scale Experiments Regarding Integrated Melting of Slag in an Existing Municipal Solid Waste (MSW) Incinerator

Serge Biollaz, Hans Künstler

With the incineration of municipal solid waste (MSW) in the VS-process disposable residues or reusable products are to be produced (VS: „Vergasen“ (to gasify), „Schmelzen“ (to melt)). For the immobilisation of the heavy metals the vitrification of the bottom ash is integrated in the incineration process. In field experiments the VS-process was successfully simulated experimentally on a full scale incinerator. The observed heavy metal separation of the VS-process have been confirmed scientifically. Suggestions for improvement of the VS-process are available (operation, integration) and have resulted in the concept suggestion PECK. This is based on a modular combination of technologies with thermal and mechanical separation steps for the of heavy metal separation. The concept has been elaborated by the partners PSI, Eberhard Recycling, CT Environment and Küpat (PECK). With the new integrated process a substantial step towards sustainable waste management and recovery of raw materials from municipal solid waste has been made. The PECK-concept is ecologically sound, technically feasible and economically viable.

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Product Utilization and Separation of Harmful Elements in the InRec-Process

Verena Schmidt, Christian Wieckert, Adrian Selinger, Hans Rüegg

The InRec-process of ABB Alstom Power has been developed with the goal to improve the quality of waste incineration residues (fly ash, bottom ash) with reasonable effort and to produce recyclable end-products. Based on modern grate combustion technology, this process allows the separation of ferrous and non-ferrous metals from bottom ash in good quality (due to a dry extraction system). For the treatment of fly ashes, vitrification processes are employed. The commercially operating oxidative process Deglor produces a very homogenous, leaching resistant glass product, though with relatively high concentrations of zinc. If a reduction of heavy metal content is desired for fly ash or bottom ash fractions reductive melting processes are required. The newly developed InRec^{plus} melting process produces glass ac-cording to the Swiss TVA inert material category with treatment times of 1-2 h. The economic viability of the different process combinations depends mainly on the possibility for recycling of the glass products. A new process module has been developed which allows the production of a foam slag product with a variety of reuse applications.

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Fundamental Aspects of Heavy Metal Behavior During Thermal Treatment of Waste and their Residues

Jörg Wochele, Christian Ludwig, Samuel Stucki, Patrick O. Auer, Albert J. Schuler

The fundamental aspects of heavy metal behavior during thermal treatment of waste and their residues are not well known today. With respect to a possible thermal separation of heavy metals, different process parameters that influence the volatility of metals were investigated. For laboratory investigations new methods have been developed for on-line measurements of heavy metals during evaporation and to simulate the incineration process of a municipal solid waste incineration plant. It was shown that cadmium, lead, and zinc could be thermally recycled from municipal waste. However, copper can not be volatilized at common incineration temperatures and the thermal separation is unlikely without gaseous hydrochloric acid.

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The Behavior of Chlorine and its Species in Molten Incineration Residues under Different Redox Conditions

Andreas Gössnitzer, Markus Tschudin

Municipal waste incinerator residues have to be treated to be suitable in the building materials industry. The present paper pays special attention to the element chlorine during the refining process in the liquid state (temperature above 1300 °C). Conditions for a high degree of separation were defined. The results confirm developments already applied successfully within different industries.

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Characterization and Utilization of Thermally Treated Municipal Solid Waste and their Long-Term Stability with Respect to Environmental Impact

Daniel Traber, Urs Mäder, Urs Eggenberger, Tjerk Peters

Novel thermal processes for the treatment of residues from MSWI offer potential for separation of heavy metals and further use of its products. Concerns regarding long-term stability make a valuation and use of such products difficult. This project strives at filling important knowledge gaps.

Speciation of heavy metals between matrix, silicates and minor components is quantitatively shown in products from high-temperature processes. Flow-through column experiments of 3-12 months yield bulk dissolution rates for glassy products of about 10-11 kg/m2/s, only marginally faster than those measured in the laboratory for feldspar. Such products are chemically stable over long periods of time and fulfill leaching criteria stipulated for inert materials, but partially exceed the regulatory limits (TVA) set for heavy metals in the solid. The rational for such limits requires additional arguments derived from sustainability, avoidance, or from the comparison to natural and man-induced heavy metal fluxes.

All examined products demonstrate some degree of puzzolan properties. Limited use in concrete to substitute binder or additive may be possible but requires in-depth examinations. Aspects of product design have been only marginally explored to access alternate possibilities for further use of products from waste processing.

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Evaluation of TVA-limiting Values with the Method of Mass Transfer in a Waste Dump

Bruno Covelli, Werner Baumann

A simulation program was developed to calculate the emissions from a high-temperature bottom ash landfill and the quality of leaching water. Probabilistic methods were used to evaluate the long-term safety of actual landfills (fulfilling the Swiss Technical Guidelines TVA) and of landfills for new high-temperature slag. These tools were tested in realistic case studies. As a result, it is possible to define the quality requirements, which should be imposed on bottom ash, and to evaluate the long-term safety of a landfill with vitrified slag.

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Directing Material Fluxes

The environmental impact of traditional waste management practice has become a central concern in industrialized countries. The past decades have seen a dramatic technology development for reducing air pollution of incineration, enforced by clean air policies in industrialized countries. The prevention of air pollution has, however, changed nothing with respect to directing the flux of materials such that they would be in line with the goals of sustainable development. Toxic and/or valuable and rare elements get dispersed into the environment by current practice of disposal of treated or untreated waste materials.

Long-Term Versus Short-Term Solutions

Research and development within the Integrated Project Waste and elsewhere have therefore focused in recent years on the question which are the best ways of interfering with the material fluxes such that the ultimate goal of closed cycles may be approached. In the long-term new ways of product design and production processes will eventually lead to a material ecology which avoids wasting of important material resources as well as pollution. There is, however, no alternative to end-of-pipe technologies in the short- to medium-term.

Waste Treatment Technologies

Results of recent R&D into thermal, mechanical, and biological separation processes for achieving substantial redirection of material fluxes in waste treatment facilities show that technical solutions are feasible. At the same time it has become increasingly clear that technical feasibility alone does by no means guarantee the practicability of a proposed solution. Social and economic acceptance is ultimately decisive whether or not an ecological improvement will eventually be brought from laboratory scale into reality.

Integrated Waste Management

It seems to us that it is timely to review the technical, social, economical and ecological aspects of the problem of sustainability in material fluxes. The research carried out in the framework of the Swiss IP Waste has tried to follow this multi-criteria approach to solving the waste problems of today and the future and will be used as the basis for compiling a comprehensive review of the state of the art. The results of IP Waste are by no means complete. They need to be put into international context and complemented by knowledge and know-how which is available elsewhere.

If you are a specialist in any area of material flux management and feel you would like to contribute to an emerging integral picture of how to direct the material fluxes in the future, then please contact us at

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