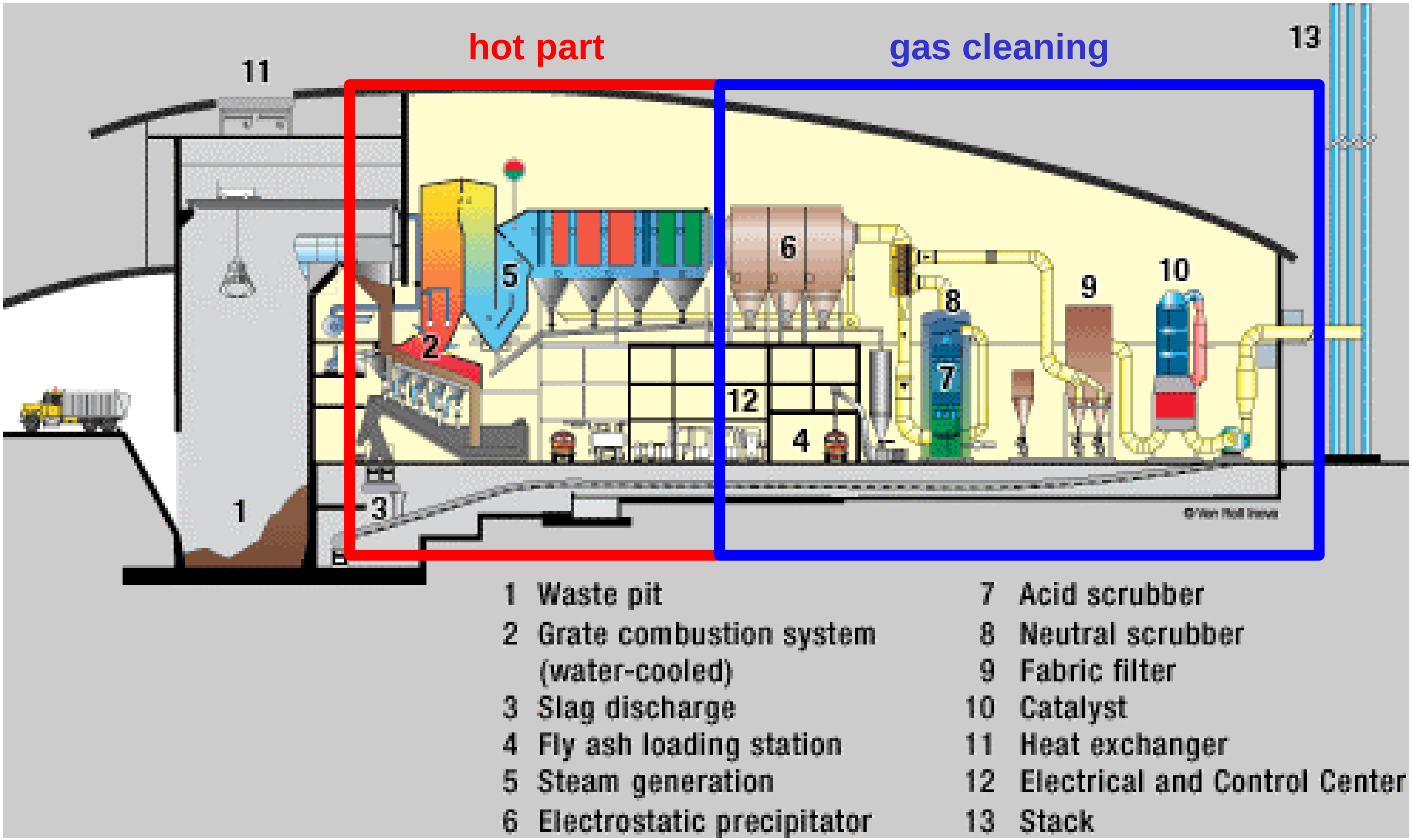
UPSWING
– a novel concept to reduce costs without changing the environmental standards of waste combustion

presented at

Operating Experience and Techno-economic Benefits and Environmental Benefits of Energy Recovery from Renewable Waste Materials

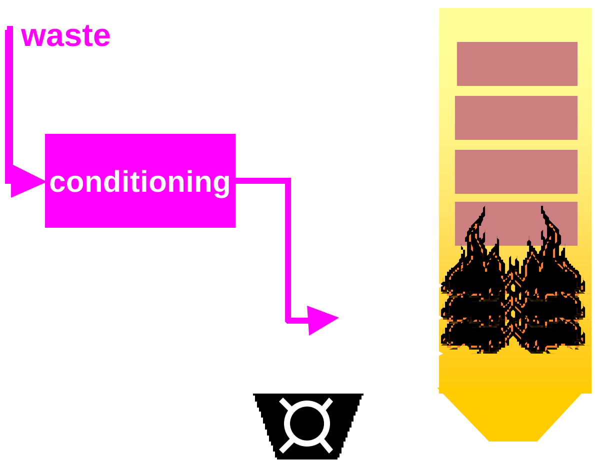
Tokyo, October 27, 2003

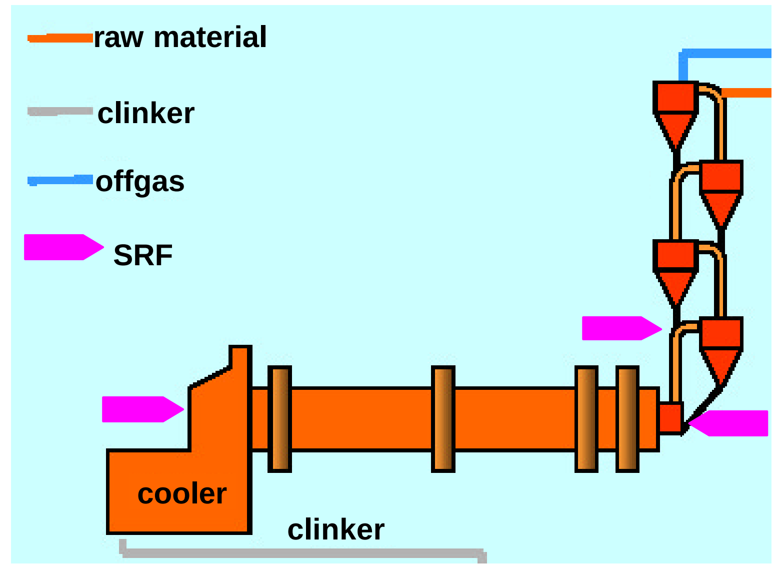
J. Vehlow, H. Hunsinger, S. Kreisz, H. Seifert
Institut für Technische Chemie – Bereich Thermische Abfallbehandlung



municipal solid waste incineration plant Nürnberg

➊ combustion or co-combustion in other thermal processes (power plant, cement kiln ...)

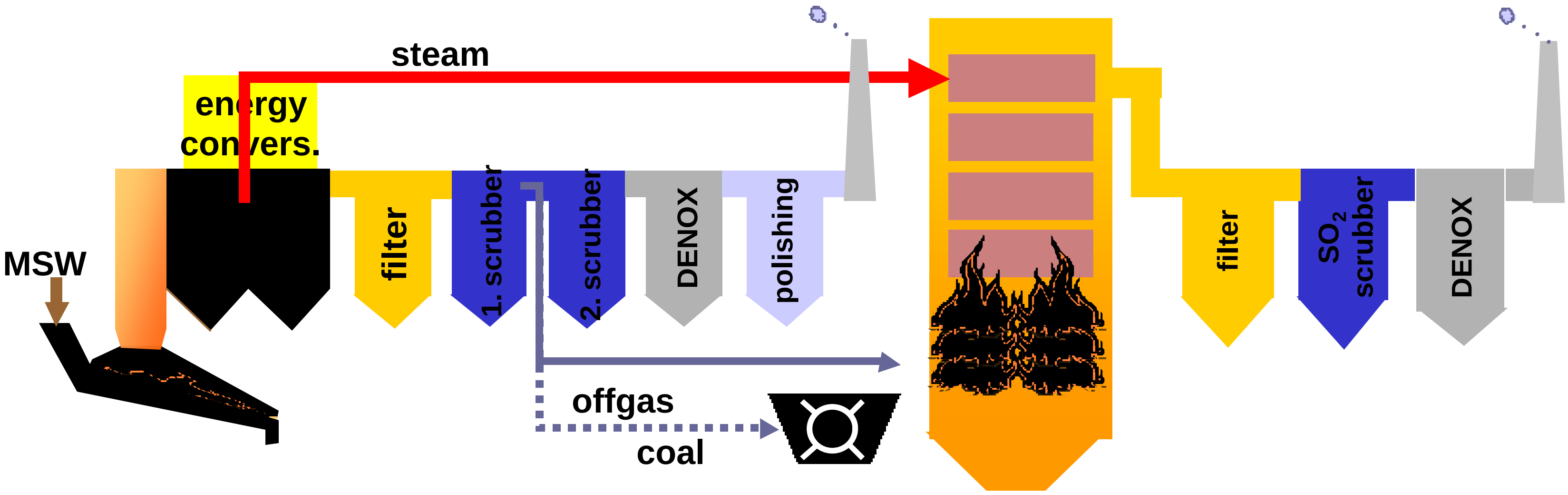




➋ combination of waste combustion and other thermal processes

options for cost reduction

Konzepte



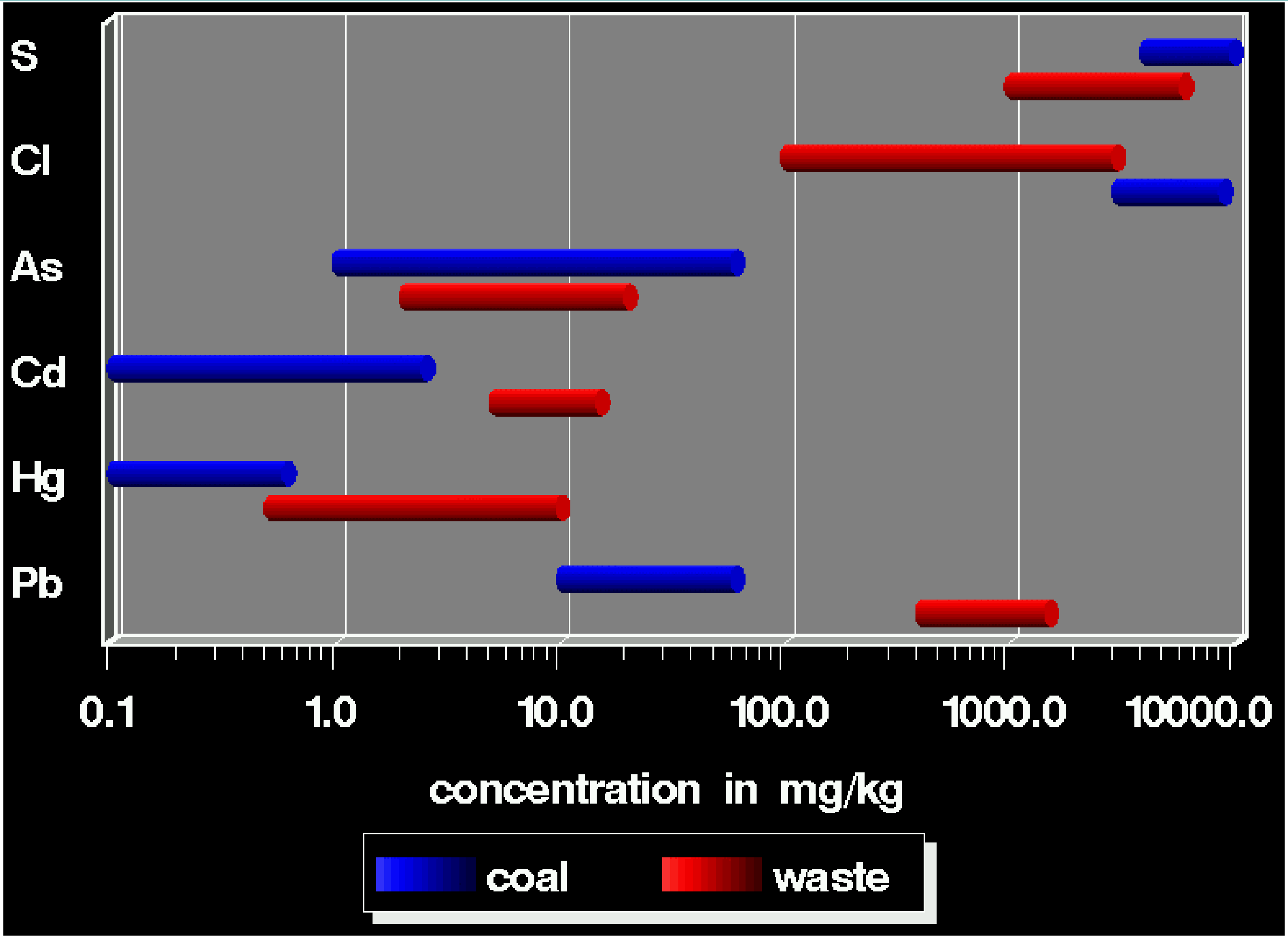
UPSWING-Prozess

(Unification of **P**ower Plant and **S**olid **W**aste **IN**cineration on the **G**rate**)**

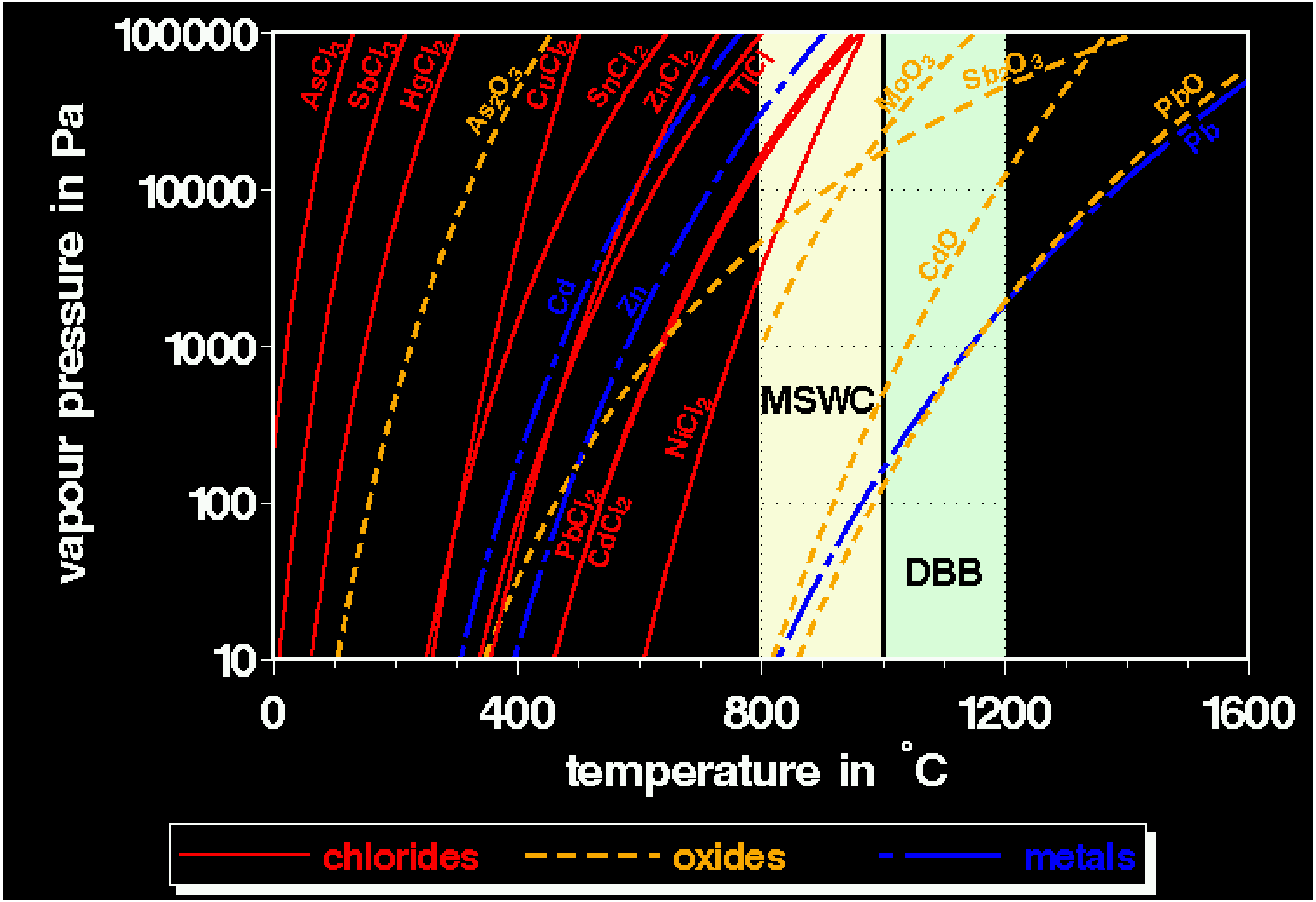
to be clarified

- **fate of waste born pollutants**
  - **volatile heavy metals (Hg, Cd, Pb, ...)**
  - **acid gases (HCl, SO_2, ...)**
  - **NO_X**
  - **organic pollutants (PCDD/F, ...)**

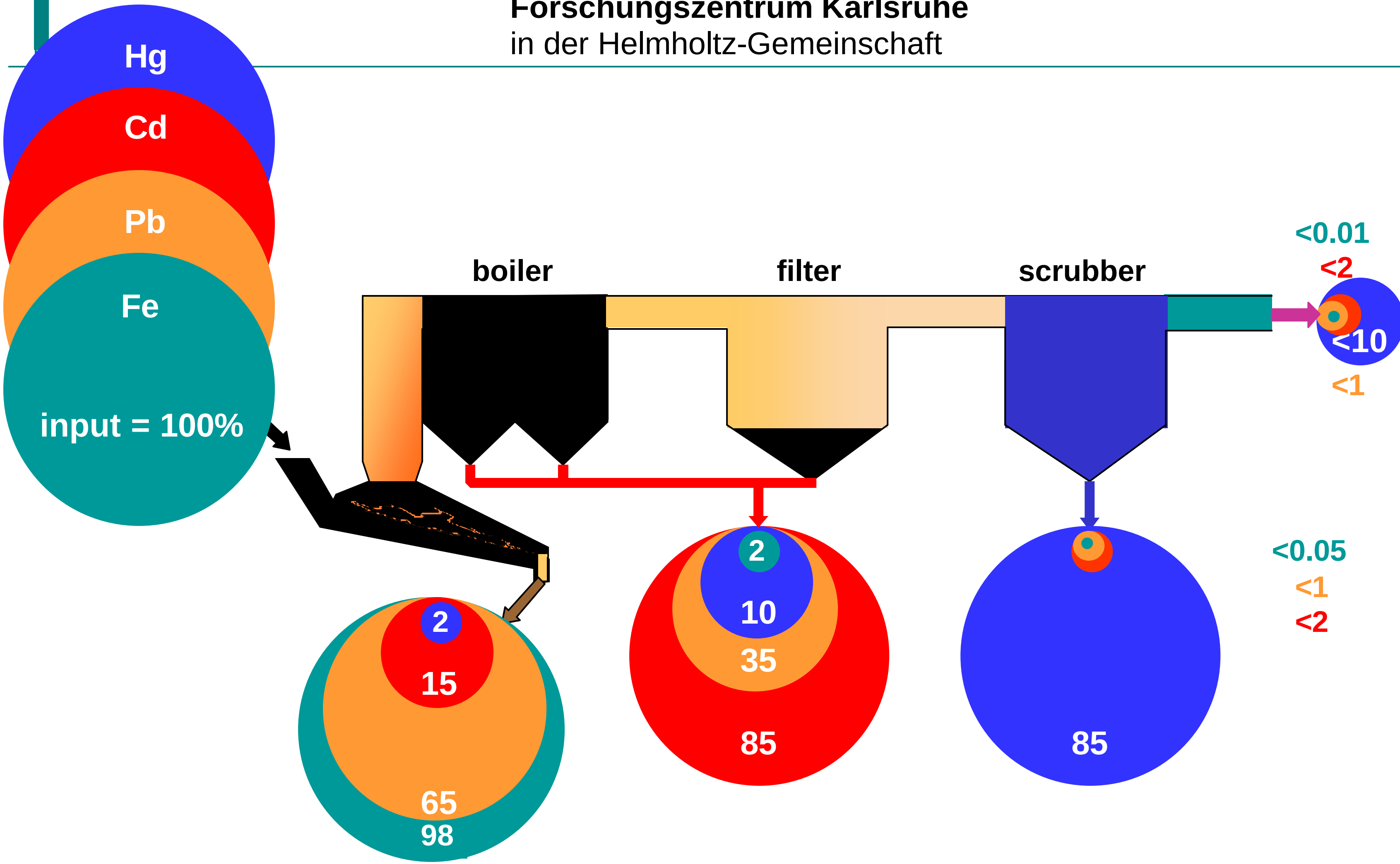
- **effects in the power plant**
  - **coupling of offgases from waste incineration**
  - **burner stability**
  - **failure of single components**
  - **quality of power plant residues**



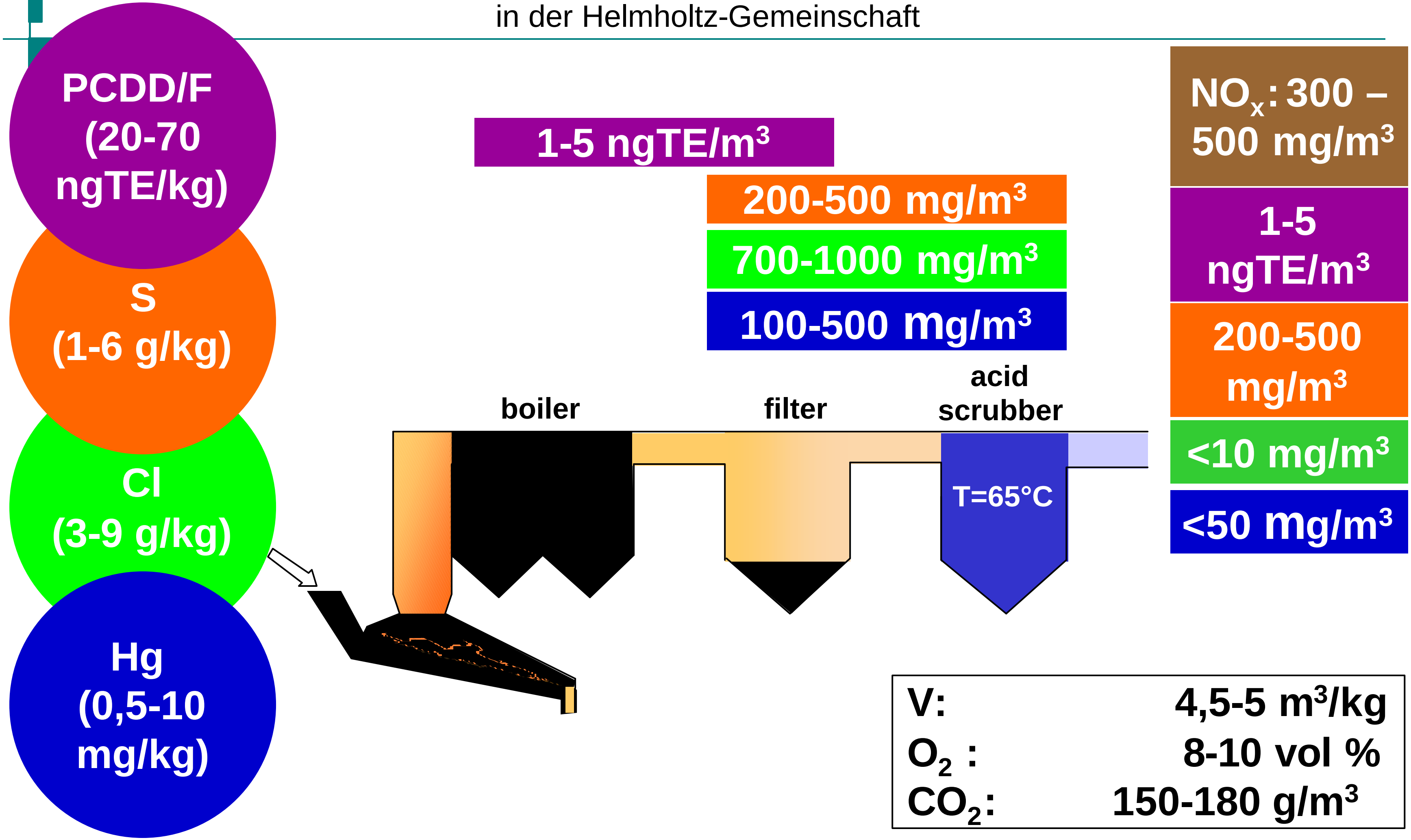
element concentration in hard coal and MSW



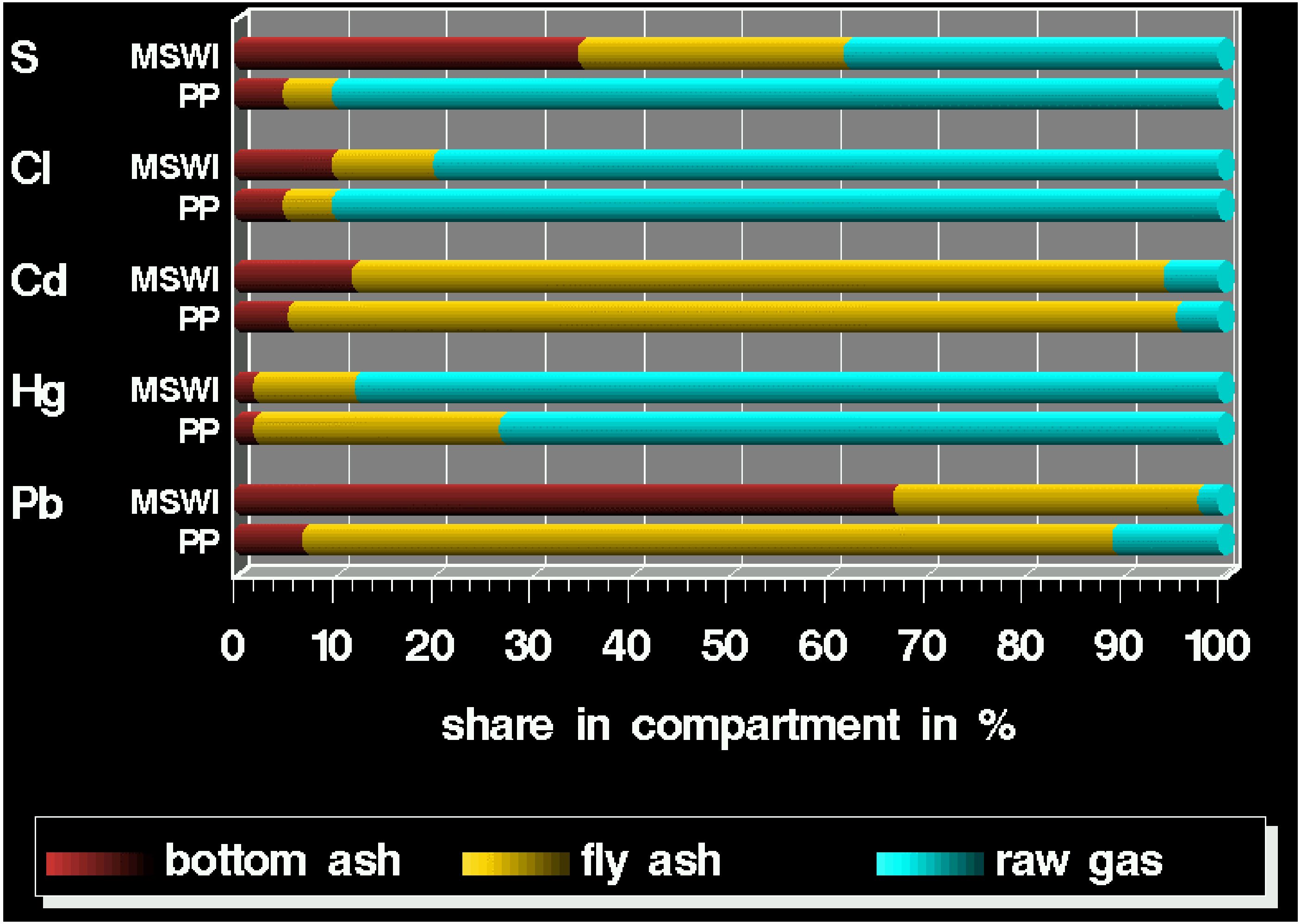
vapour pressure curves of heavy metal species



percent partitioning of metals in waste incineration



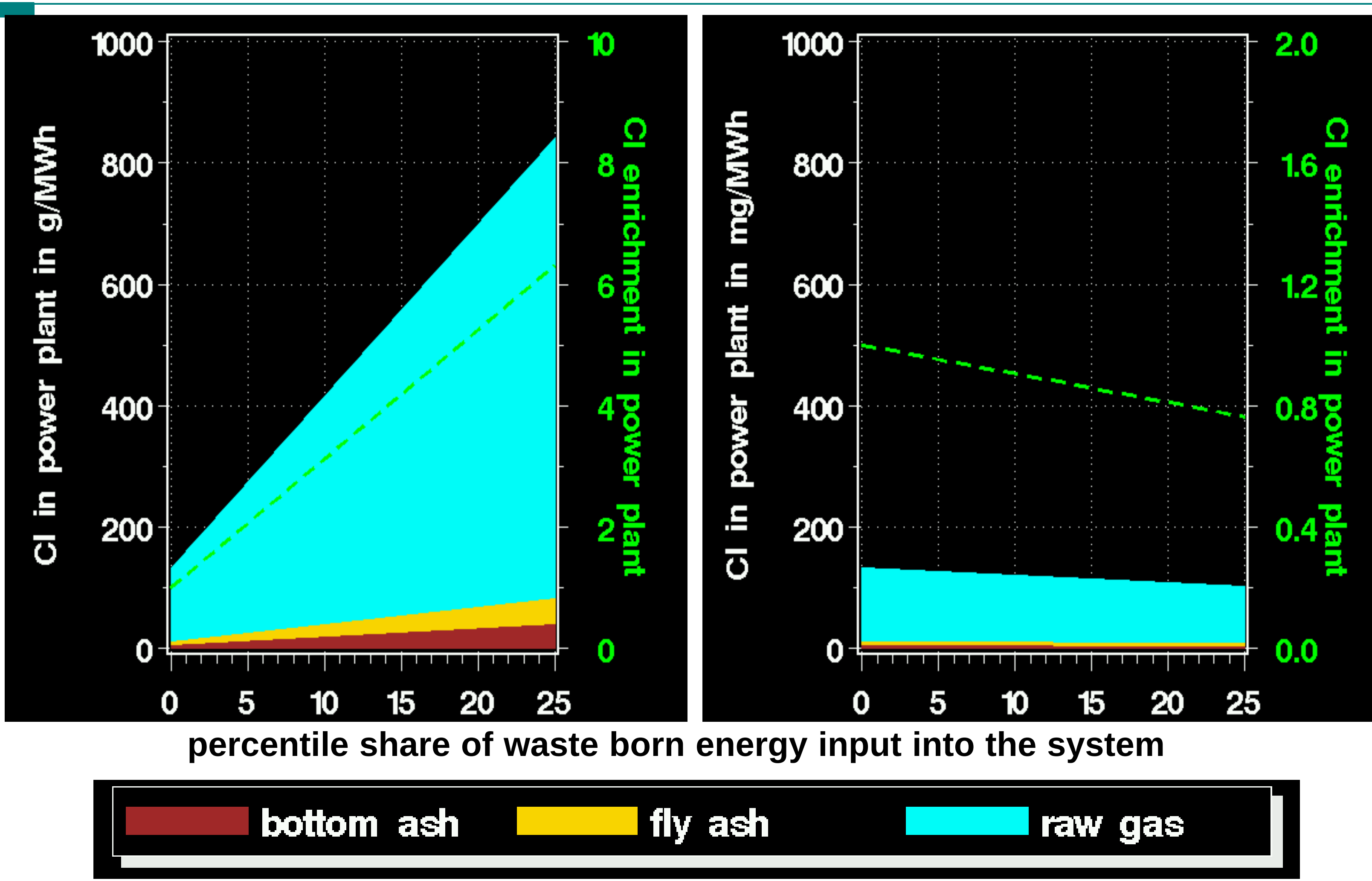
components of concern in waste incineration fluegas



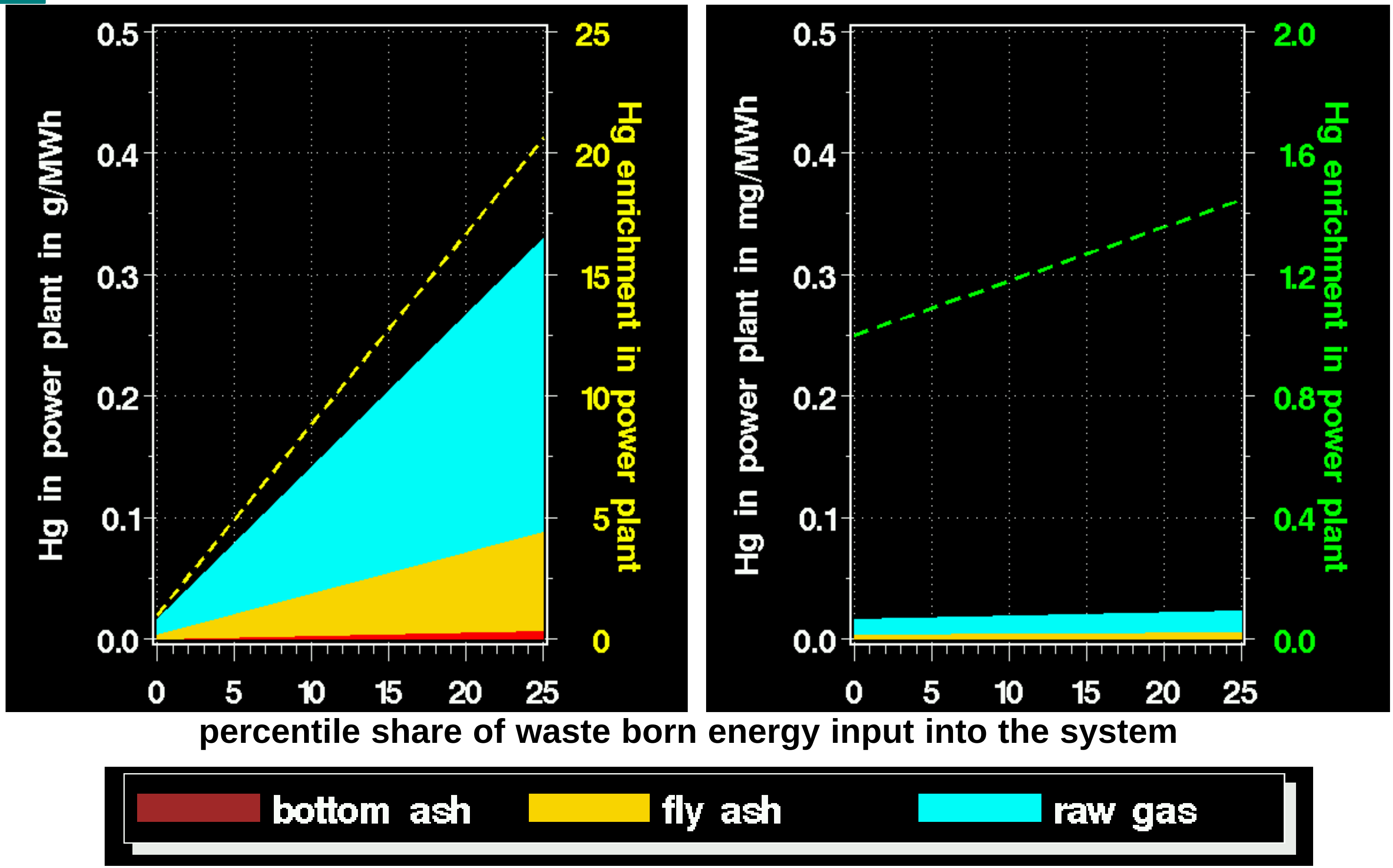
partitioning in waste incineration and power plant

	H_u	V	grate ash	boiler ash	fly ash
	MJ/Kg	m^3	%	%	%
MSWI	10	5	25	0.3	1.5
PP	30	9.6	0.35		4.6

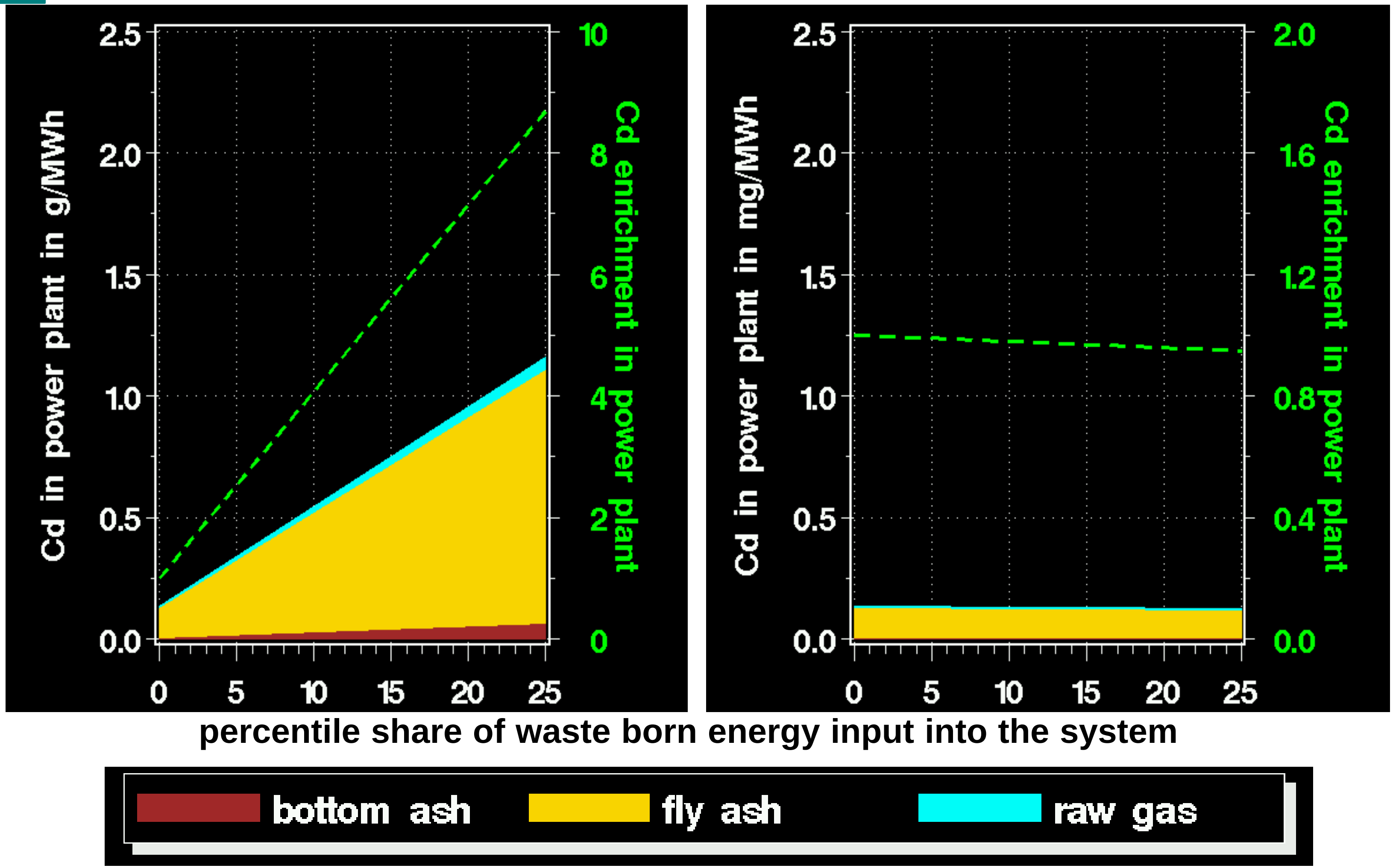
basic data for calculation of partitioning



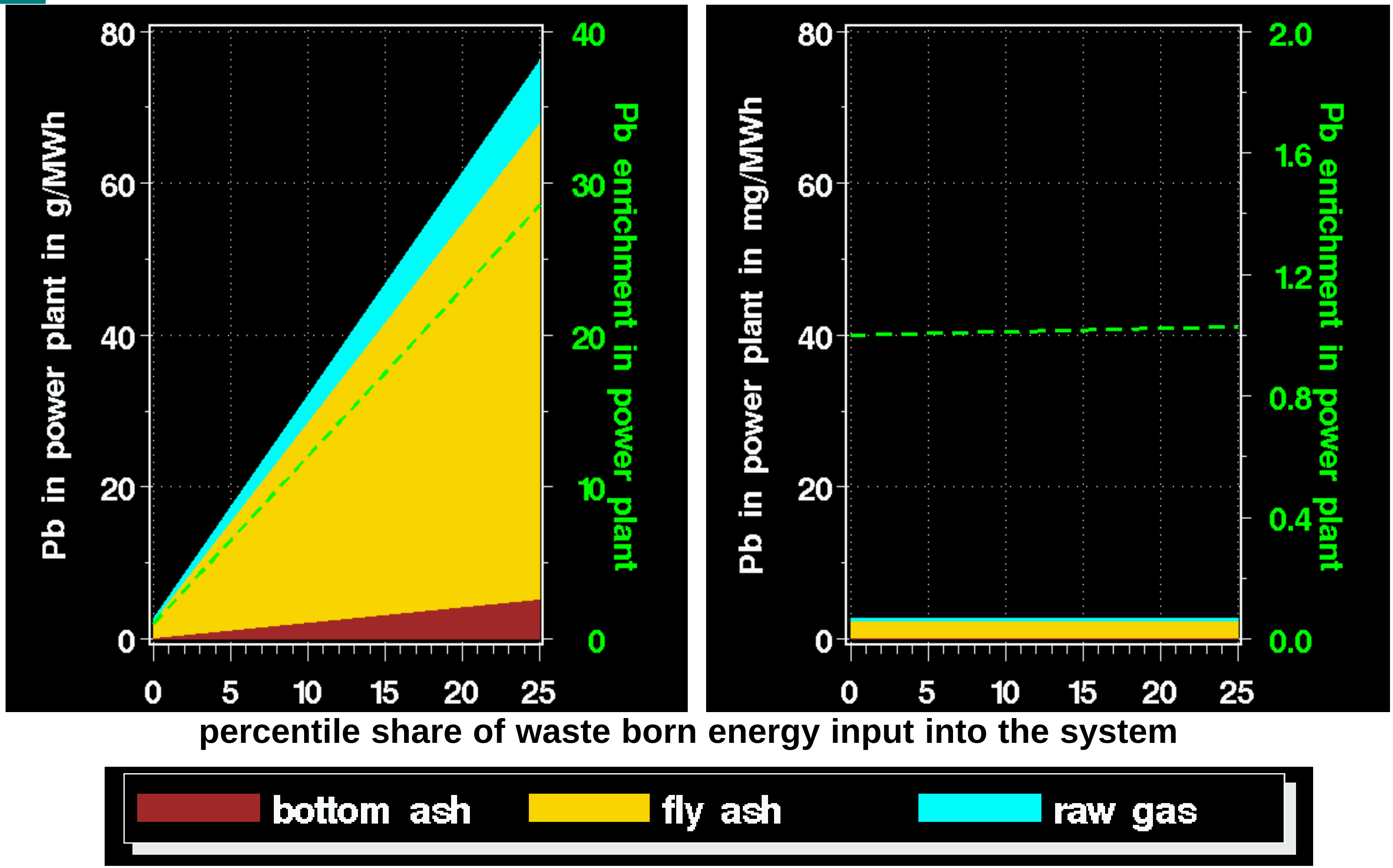
inventory, partitioning, and enrichment of Cl in power plant



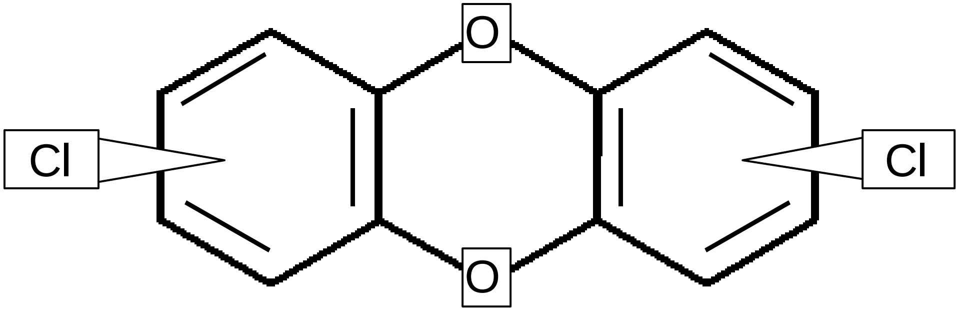
inventory, partitioning, and enrichment of Hg in power plant

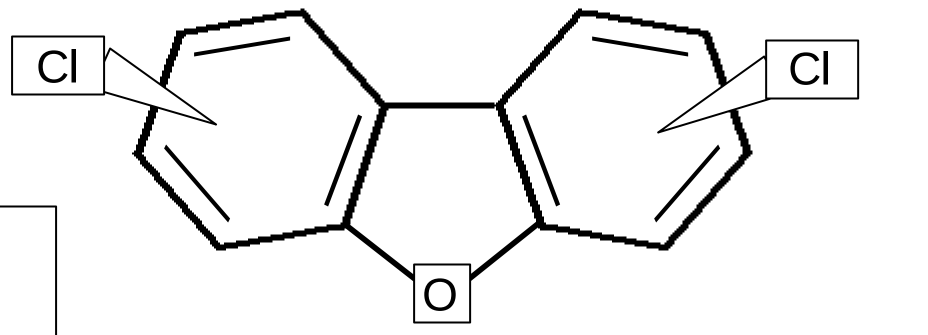


inventory, partitioning, and enrichment of Cd in power plant



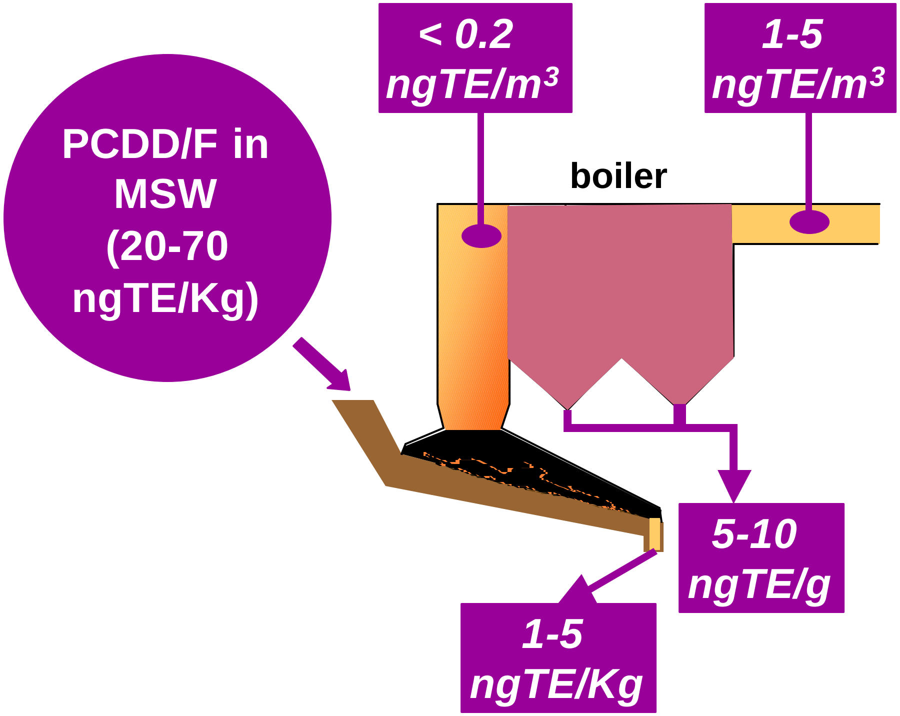
inventory, partitioning, and enrichment of Pb in power plant





congeners:	
dioxins	**75**
furans	**135**

polychlorinated dibenzo-p-dioxins and dibenzofurans



ingredients:

- PICs (e.g. soot)
- halogenides (Cl^-)
- catalysts (Cu)

conditions:

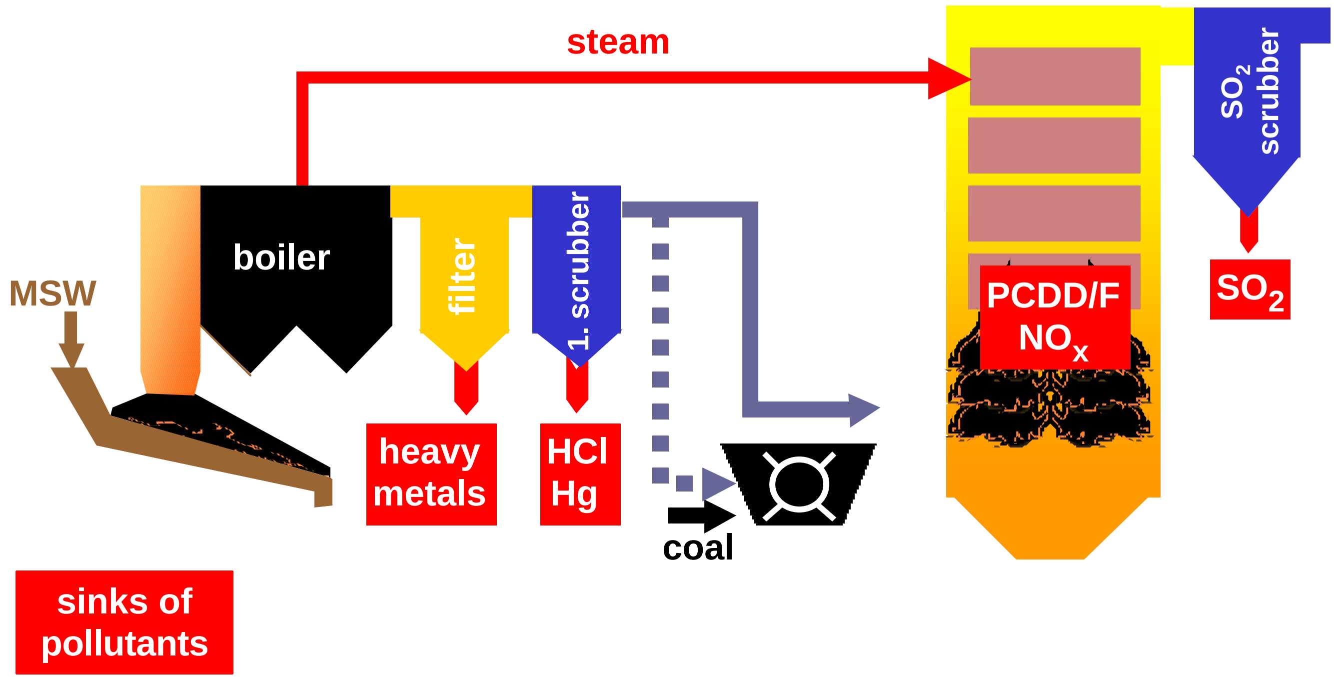
- oxidising atmosphere
- T > 200 °C

PCDD/F formation in waste incineration

conclusions for PCDD/F

- **in waste incineration**
  - **typical raw gas level approx. 1 ng(TE)/m^3**
- **in coal fired power plants**
  - **negligible**
- **in UPSWING Process**
  - **destruction in combustion chamber of power plant**

➔ **to clarify: elevated Cl inventory in fuel**



sink of pollutants in the UPSWING Process

conclusions

- **co-combustion**
  - **all waste born pollutants end up in the power plant**
  - **risk of emission of Hg**
  - **utilisation of residues endangered**

- **UPSWING Process**
  - **separation of waste born pollutants**
  - **no problems concerning emission and utilisation**

CONTRIBUTION TO IEA BIOENERGY JOINT TASK SEMINAR 'OPERATING EXPERIENCE AND TECHNO-ECONOMIC BENEFITS AND ENVIRONMENTAL BENEFITS OF ENERGY RECOVERY FROM RENEWABLE WASTE MATERIALS', Tokyo, October 28, 2003

UPSWING – A NOVEL CONCEPT TO REDUCE COSTS WITHOUT CHANGING THE ENVIRONMENTAL STANDARDS OF WASTE COMBUSTION

Jürgen Vehlow, Hans Hunsinger, Siegfried Kreisz, Helmut Seifert
Institute for Technical Chemistry - Division Thermal Waste Treatment
Forschungszentrum Karlsruhe GmbH - Technik und Umwelt
Karlsruhe, Germany

ABSTRACT
The paper describes a concept for the combination of a municipal solid waste combustion plant and a coal fired power plant in such a way that the dedusted and pre-cleaned offgas of the waste combustion serves as primary air or as carrier gas for the pulverized coal in the power plant. The coal combustion cares for the destruction of PCDD/F and the SO_2 from waste combustion is removed in the SO_2 scrubber of the power plant. A comparison with co-combustion and a theoretical consideration of the fate of waste originated pollutants indicates that this concept guarantees a minimum transfer of pollutants into the power plant and looks economically attractive.

1 ECONOMICAL PROBLEMS OF WASTE COMBUSTION

About twenty years ago interest groups started to criticize waste combustion for partly real, partly assumed environmental impacts, first of all emissions of the 'ultimate poison' polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F). In some Central European countries, e.g. in Germany, such debates resulted in a strong opposition of wide parts of the public against this technology. It must be admitted that in the early eighties the environmental standards of waste combustion were far away from what we are used to accept today and there was reason to decrease the limits of air emissions as well as to increase the quality requirements of solid residues.

The tightened legislative regulations caused the implementation of high sophisticated technical measures for upgrading old and optimizing new plants. Especially in Germany the ecological quality had a high priority and economical constraints were not considered. Multi-stage gas cleaning systems with all kinds of recovery options for e.g. residues from gas cleaning pushed the investment as well as the processing cost to extremely high levels.

The financial burden caused customers to look for other and cheaper disposal options and a substantial share of waste from commerce and industry was diverted from the local public waste management system to other, cheaper and often obscure places. This development reduced the throughput of the existing waste combustion plants and consequently the tipping fee had to be increased again.

Hence today the economical aspect of thermal waste treatment is gaining interest again. The challenge is the development of simple strategies in order to minimize the investment and operational costs without changing the reached environmental standards.

2 OPTIONS TO IMPROVE THE ECONOMY

A first approach in that direction has been made with the concept of head-end techniques in waste combustion [Vogg & Vehlow 1993, Vehlow 1996]. Primary measures, especially optimized combustion control are simple and efficient ways

- to reduce the formation of pollutants in the raw gas, e.g. PCDD/F,
- to reduce the efforts for abatement of such species, and
- to improve the bottom ash quality and make it fit for utilisation.

Two perspectives to minimize the expenses for waste combustion can be taken into consideration:

- the combustion or co-combustion of waste or waste fractions in other thermal processes like coal fired power plants or cement kilns or
- the combination of waste combustion and other combustion units in order to use some units like the boiler or the air pollution control system for both processes.

In the following only coal fired power plants will be considered as alternative thermal processes for co-combustion or combination. A short description of various process concepts will be followed by a more detailed discussion of the fate of pollutants. The pollutants to be dealt with will be limited to chlorine, a number of volatile heavy metals, and to PCDD/F.

3 PROCESS DESCRIPTION

3.1 Co-combustion

The co-combustion of waste in industrial furnaces like power plants or cement kilns is practiced in some European countries. Problems associated with co-combustion are potential air emission and operating problems like boiler corrosion caused by waste ingredients, especially the high chlorine inventory in the waste. Hence in most cases pretreated waste or special waste fractions only are used. It is e.g. obvious that a size reduction of typical municipal solid waste in order to make it suitable for firing in a pulverized coal fired power plant is not easy. The fuel conditioning has to be paid for and reduces the economical benefit. On the other hand, however, fuel from waste is subsidized by the public waste management system and hence economically attractive.

Various national legislative regulations set limits for the replacement of regular fuel by waste (25 % of the energy input in Germany) as well as for the air emission in case waste is co-combusted. In Germany the fraction of a pollutant in the offgas which is theoretically generated by the waste input has to meet the standards for air emission from waste combustion whereas the residual fraction of the same pollutant has to be handled according to the regulations for the respective thermal process.

In fact co-combustion makes use of the differences in emission standards for different processes or of the typically lower pollutant load in the industrial plant's off-gas and can be looked upon as a kind of dilution of waste combustion flue gas in the offgas of the respective process. For the time being the environmental compatibility of co-combustion of waste is subject of controversial debates.

Another often neglected aspect is the disposal of the residual waste stream if high calorific and low polluted waste fractions are diverted from the public waste collection system and are used to substitute regular fuel. The residual waste may be characterized by low heating values in combination with high levels of pollutants and may require additional fuel in order to maintain the high temperatures required for complete burnout in the waste combustor. Such strategies would mean that the public subsidizes the fuel from waste and spends money again to compensate for the lack of heating value in the waste combustion plant by regular fuel.

3.2 Combination of Waste Combustion and Power Plant

3.2.1 Overview

The combination of a waste combustion facility and a coal fired power plant can principally be performed in different ways:

a) transfer of the hot raw gas directly into the furnace of the power plant (Satellite Combustion [Hölter 1997]),
b) transfer of the steam from the waste boiler to the boiler of the power plant,
c) option b) plus transfer of the partially cleaned offgas to the primary air of the power plant (UPSWING Process, see Fig. 1),
d) option b) plus transfer of the partially cleaned offgas to the gas cleaning system of the power plant.

For the time being only option b) is realized in full scale in a new German waste incineration plant.

In the following these concepts will be described in short terms but the UPSWING Process only will be discussed in view of environmental topics of concern and will be compared with co-combustion in a coal fired power plant.

3.2.2 Satellite Combustion Concept

To avoid the waste sorting and preconditioning which is required for co-combustion and to accomplish, nevertheless, a thermal treatment of the entire municipal solid waste, the 'Satellite Combustion' process proposes to burn waste in a separate combustion chamber and to feed the hot flue gas - without energy recovery or any cleaning - directly into the combustion chamber of a coal fired power plant [Hölter 1997]. This concept cares for the exclusion of the waste bottom ash from the residues of the power plant, however, it transfers the fly ashes and along with these all volatilised heavy metals into the power plant.

3.2.3 Combination of Steam Circuits

The option b), the transfer of the steam from the waste boiler into that of the power station saves the turbine in the waste combustion plant. This simple strategy has recently been realised in a new German waste incineration plant. The combination of both steam circuits can be performed in different ways. The waste boiler can be used for preheating the steam of the power plant's boiler. In this case the boiler parameters can be kept low with maximum steam temperatures of 250 °C. If the waste boiler, however, is operated at the higher temperature of the power plant's boiler the risk of boiler corrosion increases significantly. This risk can be reduced if the superheater in the waste boiler is separated and heated by e.g. natural gas [Albert 1997].

3.2.4 UPSWING Process

A more far-reaching integration can be accomplished by the UPSWING Process (**U**nification of **P**ower plant and **S**olid **W**aste **IN**cineration on the **G**rate), a concept which has been developed at the Forschungszentrum Karlsruhe and the scheme of which is depicted in Fig. 1. According to option c) the waste combustion flue gas is dedusted - preferentially by means of a fabric filter - and partially cleaned in a simple acid wet scrubbing stage. This procedure guarantees the almost total removal of particle bound heavy metals, of more than 95 % of HCl and of approx. 90 % of mercury.

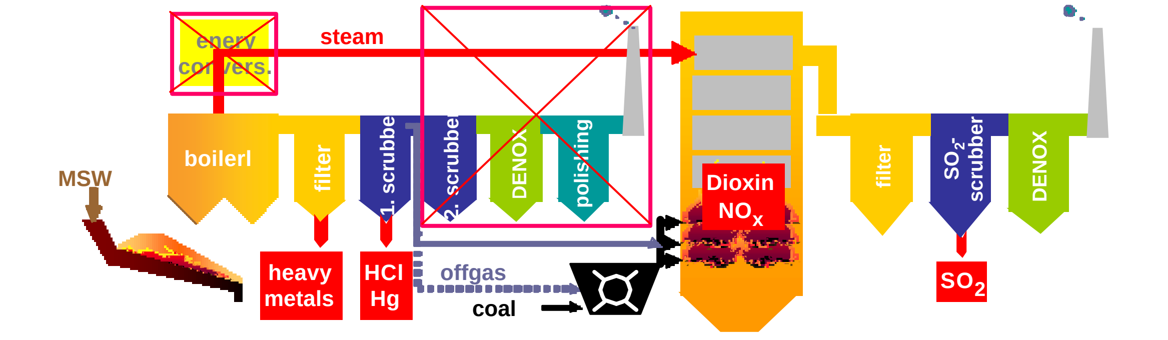


Fig. 1: Scheme of the UPSWING Process with indication of the saved components in the waste incineration plant and the sinks of pollutants

The partially cleaned gas contains still SO_2 and NO_x as well as the gaseous PCDD/F and is ought to replace part of the primary air in a pulverized coal fired power plant. Another option is to use it as carrier gas in the coal mills. The PCDD/F will totally be destroyed inside the combustion chamber. NO_x is converted in the reburn zone and SO_2 is removed in the respective abatement system of the power plant.

The process keeps the waste combustion specific pollutants consequently away from the power plant thus maintaining the certification for the utilisation of the power plant's solid residues.

The high thermal destruction capability of waste combustion for organic compounds has not only been found at the Karlsruhe TAMARA pilot plant for waste combustion [Vehlow & al. 1990, Rittmeyer & al. 1994] but also in full scale [Vehlow & al. 1997]. To demonstrate the practicability of the proposed process, synthetic waste combustion offgas with non-toxic PCDD/F cogeners, SO_2 and NO_x will be added to the primary air of a coal fired dry bed boiler test plant in order to investigate the operation of the burner and the substitution of the waste combustion offgas by recycled flue gas in case of failure in the waste combustion system.

3.2.5 Combination of the Gas Cleaning Systems

As further option the direct transfer of the dedusted fluegas from waste combustion into the gas cleaning systems of the power plant has been proposed. The critical components in the dedusted raw gas of waste combustion are mercury, PCDD/F, and hydrohalogens. Sulfur and nitrogen oxides are common in both facilities. The hydrohalogens are removed along with the SO_2 in the sulfur scrubber of the power plant. PCDD/F and mercury may create air emission problems as well as unwanted contamination of the gypsum typically produced in the sulfur scrubber.

4 ENVIRONMENTAL ASPECTS

The UPSWING Process strategy needs to be checked in view of its environmental compatibility and the results will be compared to the situation in co-combustion in a pulverised coal fired power plant. Municipal solid waste is characterized by lower heating value, substantially higher ash content and higher humidity and on top of that of higher loads of heavy metals and halogens than hard coal. Furthermore specific products of incomplete combustion, especially PCDD/F, may be present in the residues from waste combustion. The occurrence and fate of these waste originated contaminants in the two processes will be discussed briefly.

Coal fired power plants as well as waste combustion plants have to meet specific standards concerning air emissions and the quality of the various solid residues. In most countries the air emission limits for waste combustion are more stringent than those for power plants although these differences will become negligible in future. The definition of so-called 'regular fuel' for power plants, however, prevents waste from being burnt in these facilities. Exceptions like in cases of co-combustion have been regulated in some countries.

In coal fired power plants the bottom ashes, the coarse ashes discharged from the combustion chamber, and the fly ashes discharged in the dust precipitation system are almost totally utilised as aggregates in the building sector. The regulations concerning their elution stability are easily met. For concrete application especially the inventory of chlorides and hexavalent chromium are critical parameters. The effluents from the scrubber comprise mainly sulfur with low chlorine contamination. They are often converted to gypsum which is easily disposed of or even marketed.

Residues from waste combustion are typically higher in pollutant concentration and have to be looked upon more critically. The bottom ashes have - after metal removal, screening and aging - a high potential to be utilised as secondary building material whereas the fly ashes carry high loads of - soluble - heavy metal species and low volatile organic compounds such as polyaromatic hydrocarbons and PCDD/F [International Ash Working Group 1997]. These materials are in most regulations classified as hazardous waste and need special disposal sites or have to be inertized prior to disposal which can easily be performed by means of the 3R Process [Vehlow & al. 1990]. The same is true for the residues of the scrubbing system.

Pollutants of concern which are discussed more in detail in the context of co-combustion and combination strategies are chlorine, some heavy metals and PCDD/F.

5 FATE OF ELEMENTS IN WASTE AND COAL COMBUSTION

5.1 General Considerations

The fate of elements in combustion depends upon their speciation in the fuel, on their transformation in the thermal process and on the volatility of the formed species. Its knowledge is a prerequisite in view of an estimation of their partitioning between the different combustion residue streams. Especially the elements sulfur, chlorine, mercury, cadmium and lead are typically discussed in combustion processes due to their volatility. The respective concentrations in municipal solid waste and in hard coal as well as transfer factors for municipal solid waste combustion and pulverized coal combustion in dry bed boilers are taken from literature and compiled in table 1.

Table 1: Averaged concentration ranges and transfer factors of selected elements for municipal solid waste combustion (MSW) [International Ash Working Group 1997] and for hard coal burnt in a dry bed boiler [Maier & al. 1992, Gerhard & al. 1996, Martel & Rentz 1998, Rentz & al. 1998]

		concentration			transfer factor				
		average	low	high	bottom ash	boiler ash	fly ash	scrub. res.	emission
MSW	S	4000	1000	6000	0.35	0.02	0.25	0.35	0.03
	Cl	7000	3000	9000	0.1	0.003	0.1	0.8	0.005
	Cd	10	3	20	0.12	0.03	0.8	0.03	0.025
	Hg	3	0.5	10	0.02	0.003	0.1	0.8	0.07
	Pb	700	400	1500	0.67	0.01	0.3	0.01	0.01
hard coal	S	7000	4000	15000	0.05		0.05	0.6	0.3
	Cl	1000	100	3000	0.05		0.05	0.7	0.2
	Cd	1	<0.1	2.5	0.05		0.9	0.02	0.02
	Hg	0.12	0.1	0.6	0.02		0.25	0.48	0.25
	Pb	20	10	60	0.07		0.82	0.09	0.02

It is evident that the concentration of the selected elements in waste – with the exception of sulfur - exceeds that in hard coal substantially. The major combustion products of sulfur and chlorine in waste as well as in coal combustion are gaseous, namely SO_2 and HCl. That means these elements will in both processes mainly be found in the gas phase.

Many heavy metals including those selected in table 1 are known for the high vapor pressure of their chlorides. Since there is a comparably high chlorine concentration in municipal solid waste these compounds form easily and are the major volatile species of heavy metals in waste combustion. At higher temperature the metallic form and oxides may contribute to the volatility, too. Vapor pressure curves give a rough estimate in which temperature ranges volatilisation has to be expected. Fig. 2 depicts the vapor pressure curves for the elements, oxides and chlorides of selected heavy metals.

The typical temperature ranges of waste combustion on the grate and of coal combustion in dry or wet bed boilers are marked in the graph. The areas indicate that in the case of waste combustion mainly the chlorides will be evaporated whereas in dry bed boilers and more so in wet bed boilers the oxides contribute substantially to the volatilisation. Hence the volatilisation of the depicted heavy metals should be much higher in coal combustion than it is in waste combustion. These theoretical considerations are verified by published results of element balances in test plants and in full scale [International Ash working Group 1997, Maier & al. 1992, Gerhard & al. 1996, Martel & Rentz 1998, Rentz & al. 1998].

For coal combustion only the today prevailing dry bed boiler is regarded in the following considerations. A visualization of the different partitioning of the elements selected in table 1 in waste and coal combustion is given in Fig. 3.

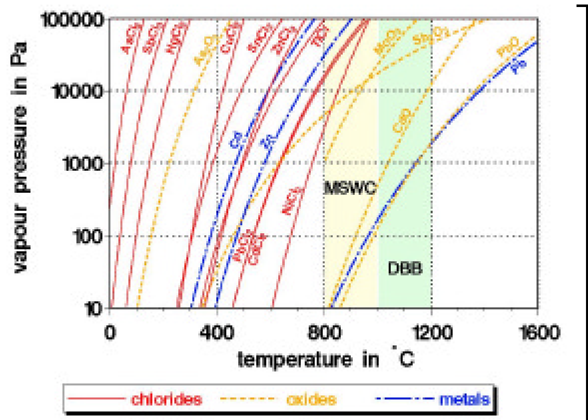


Fig. 2: Vapor pressure curves of selected elements and compounds with temperature ranges of municipal solid waste combustion (MSWC) and coal combustion (DBB: dry bed boiler, WBB: wet bed boiler)

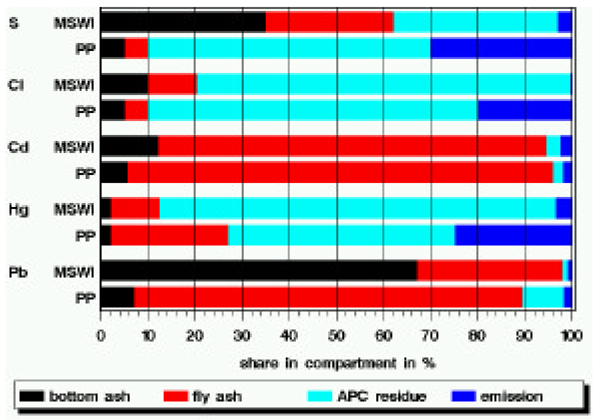


Fig. 3: Partitioning of selected elements in a municipal solid waste combustion plant (MSWI) and in a coal fired dry bed boiler (PP)

5.2 Mass and Volume Flows

In order to estimate the transfer of the mentioned elements from the waste combustion process to the coal fired power plant and their partitioning in the power plant the mass and volume flows under the given conditions have to be calculated. The specific offgas volumes and the amounts of solid residues used for the calculations are taken from literature and are compiled in Table 2.

Table 2: Lower heating value LHV, specific flue gas volume V and mass streams of residues for municipal solid waste combustion (MSWC) and coal fired dry bed boiler (DBB) [International Ash Working Group 1997, Günther 1994, Gerhardt & al. 1996]

	LHV	V	bottom ash	boiler ash	fly ash
	MJ/kg	m^3/kg	kg/kg fuel	kg/kg fuel	kg/kg fuel
MSWC	10	5	0.25	0.003	0.015
DBB	30	9.6	0.0035		0.046

Since the co-combustion in power plants is limited to an energy substitution by waste fuel of 25 % this will be the upper limit of waste addition in either scenario. On the basis of the data compiled in table 2 the total coal and waste input mass streams and the resulting flue gas volumes are calculated and depicted in fig. 4. All calculations are standardized to an energy input of 1 MWh. The calculations point out that an energy-from-waste contribution of 25 % results theoretically in an equal mass input of coal and waste.

The graph documents that in the case of co-combustion the mass input into the coal fired power plant will increase by 50 % from 120 kg to 180 kg if 25 % of the energy is derived from municipal solid waste. In co-combustion only the coal enters the power plant and the waste is burnt in a separate combustion facility. The flue gas volume will always increase from approx. 1150 m^3/MWh to 1300 m^3/MWh and end up in the power plant.

All following evaluations will distinguish between the inventory of an element in the bottom and filter ashes and in the raw gas of the power plant. For these calculations the transfer factors of elements in coal combustion (compare table 1) are kept constant for all scenarios and no changes in combustion temperature caused by the addition of varying amounts of waste or waste born flue gas will be taken into consideration.

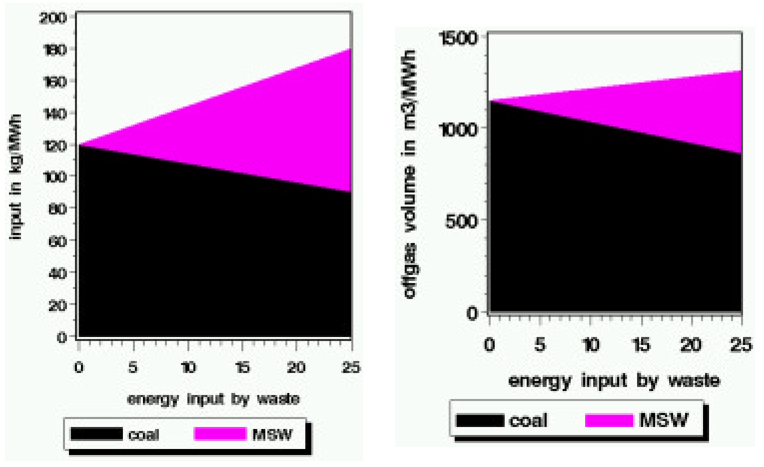


Fig. 4: Mass input (left) and flue gas volume (right) for a total energy input of 1 MWh as a function of the waste attributed energy input

The influence of changed pollutant levels in a solid residue on the elution quality will not be discussed since there are no data for such evaluation. The emission levels and the partitioning into the flue gas cleaning products will also not be discussed since the emission standards have - regardless of the efforts - to be met anyway and the fraction of an element in the gas cleaning product depends on the raw gas level, the emission standard and the applied removal strategy.

It needs to be stated that the legislative limit of 25 % energy share is much higher than the practical limitation in the UPSWING Process where the waste combustion system is intended to produce an offgas volume of approx. 10 % of the combustion air supply which is approximately the volume used for coal transport through the coal mills. In this case waste combustion will contribute approx. 7.5 % of the energy input of the combined system.

5.3 Fate of Chlorine

Chlorine is a high volatile element in waste as well as in coal combustion. The concentration in waste is approx. seven times higher than that in hard coal. Fig. 5 comprises two graphs which illustrate the fate of chlorine in the co-combustion and in the UPSWING Process.

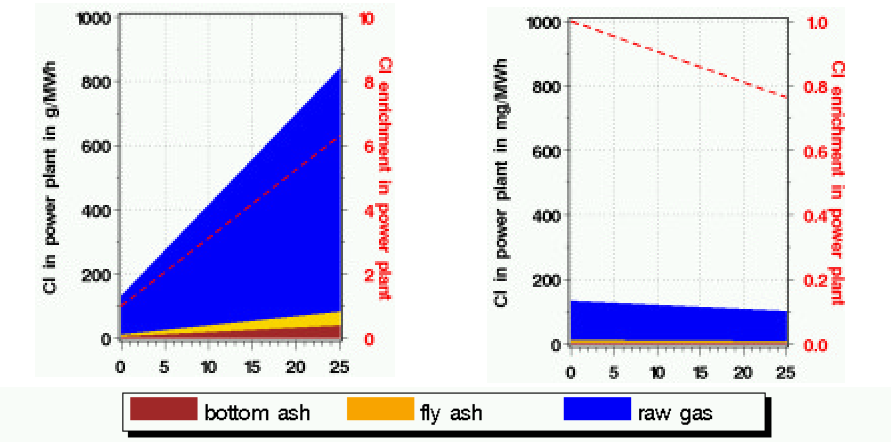


Fig. 5: Cl in a coal fired power plant (PP) in case of co-combustion and for the UPSWING Process

The co-combustion increases the inventory of chlorine in the power plant substantially. The raw gas HCl concentration rises from approx. 100 up to approx. 500 mg/m^3. This increase will not cause any emission problem since the HCl will be removed in the SO_2 scrubber and the resulting increase in chloride concentrations in the gypsum can be eliminated by washing that material. The UPSWING Process reduces the chlorine inventory in the power plant by approx. 20 %.

5.4 Fate of Cadmium

Cadmium is characterized by high volatility in waste combustion where it is mainly evaporated as chloride. According to the lower chlorine level and the higher combustion temperature in coal combustion a volatilisation as oxide should be prevailing.

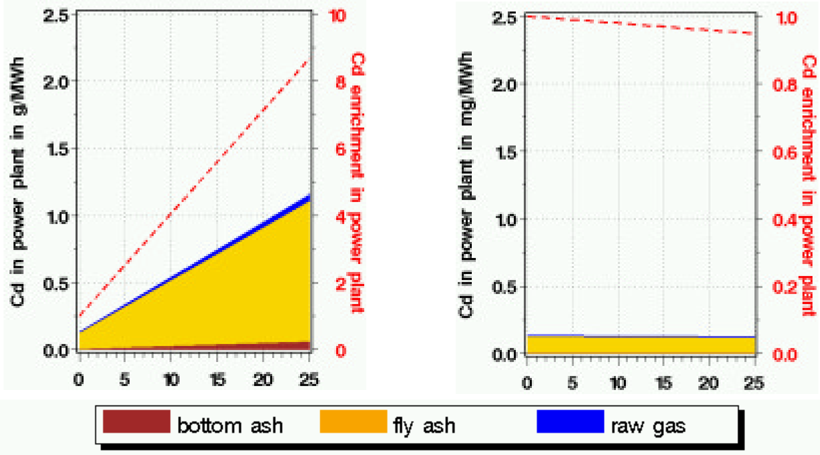


Fig. 6: Cd in a coal fired power plant (PP) in case of co-combustion and for the UPSWING Process

The concentration of cadmium in waste (approx. 10 mg/kg) is typically by a factor of 10 higher than it is in hard coal. Hence in the co-combustion scenario the level of cadmium in the power plant is to a great extent elevated (compare Fig. 6). Cadmium is preferentially routed to the fly ashes and the quality of this residue stream may be altered in an unwanted way. Co-combustion requires a thorough quality control of the fly ashes if utilisation is intended. Since cadmium is mainly removed from the waste combustion raw gas along with the fly ashes the UPSWING Process causes no unwanted effect on its level in the power plant.

5.5 Fate of Mercury

Mercury has the highest volatility of all of the heavy metals. Furthermore, its concentration in municipal solid waste (approx. 3 mg/kg) is by a factor of 20 to 30 higher than it is in hard coal.

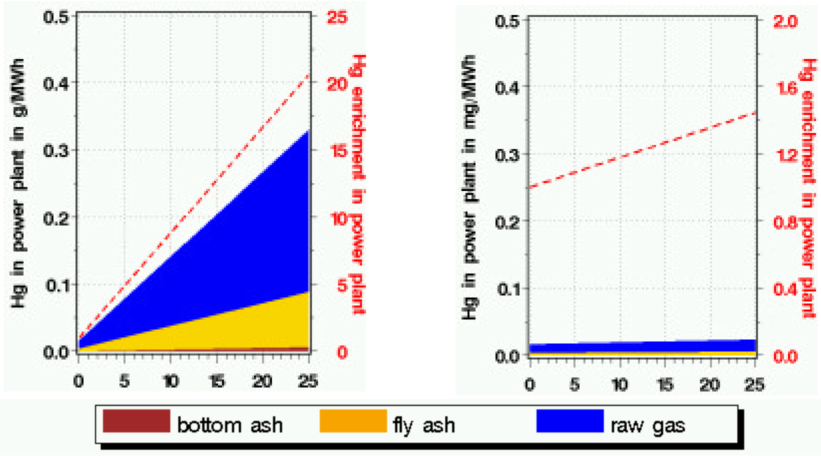


Fig. 7: Hg in a coal fired power plant (PP) in case of co-combustion and for the UPSWING Process

Fig. 7 makes evident that the mercury level in the power plant is substantially influenced by co-combustion. The UPSWING Process causes a small increase in the mercury level of the power plant of approx. 10 – 30 % only.

Mercury enters mainly the gas phase. The mercury level in the raw gas of a coal combustion plant is of the order of 10 g/m^3. If 25 % of the energy input are delivered by municipal solid waste this number increases to about 150 g/m^3, a level which calls for special abatement measures. With respect to the high concentration of SO_2 in the raw gas of the power plant it has to be expected that a substantial fraction of mercury is present in the metallic state. If no charcoal filter is installed the compliance with the emission standards is endangered.

Another problem in co-combustion might be seen in an unwanted mercury contamination of the gypsum produced in the scrubber of the power plant. The effects of mercury on the quality of fly ashes, too, should carefully be observed.

5.6 Fate of Lead

Lead is a common heavy metal found in coal at a level of approx. 20 mg/kg. The typical concentration in municipal solid waste varies between 400 - 1500 mg/kg.

This metal is moderately volatile in municipal solid waste combustion due to the preferred formation of lead chloride. Its behaviour is similar than that of Cd. In coal combustion the volatility of PbO contributes mainly to the volatility. In principle the thermal behavior in both combustion processes resembles that of arsenic. Due to its high enrichment in waste compared to coal, co-combustion causes a significant increase of a factor of approx. 30 in the power plant. The lead is mainly found in the fly ashes. In the case of the UPSWING Process the lead level in the power plant is almost unchanged.

6 THE ROLE OF PCDD/F

This class of compounds is still of high public concern in waste combustion. Its predominant formation route is a heterogeneous oxichlorination reaction inside the heat recovery system. The critical temperature range is 200 - 500 °C. Combustion control to improve the total burnout has been revealed to be the most promising measure to minimize the formation of PCDD/F [Vogg & al. 1991]. Such simple measures guarantee PCDD/F levels of the order of 1 - 5 ng/m^3 in the raw gas downstream of the boiler. The operation of the dedusting device at temperatures below 200 °C is strongly recommended in order to prevent further formation of these compounds [Hunsinger & al. 1996].

Various simple strategies to remove residual PCDD/F from the flue gas have been developed and implemented in full scale plants during the last years. Hence PCDD/F do not cause real problems in modern and well operated waste combustion plants any longer.

The formation of PCDD/F in coal combustion can typically be neglected. The oxygen concentration in the flue gas is very low (3 - 5 vol %) compared to that in waste combustion (7 - 10 vol %). Furthermore, the amount of chlorine is much lower and that of sulfur much higher and the resulting high SO_2 concentrations in the offgas reduce the efficiency of the oxichlorination reaction.

This situation may change if the chlorine level and especially the ration between chlorine and sulfur in a power plant is increased by direct addition of waste. A theoretical consideration is difficult and experimental data are required to reveal real effects.

The introduction of PCDD/F into a coal fired power plant can be looked upon as generating no problems. Such PCDD/F may be present in the municipal solid waste or in the pre-cleaned flue gas. As can be deduced from their thermal properties and as has been experimentally confirmed the conditions inside a combustion chamber cause an almost total thermal destruction of even rather stable organic compounds [Vehlow & al. 1990 and 1997, Rittmeyer & al. 1994].

This fact is of major importance for the UPSWING Process using pre-cleaned flue gas which still contains the gaseous PCDD/F formed in the combustion plant. However, before implementing the process an experimental verification in a test plant is needed.

Today's knowledge allows no final decision about the importance of PCDD/F in the scenarios discussed in this paper. Co-combustion may promote a formation due to the increased chlorine level. The effect, however, should not be of fundamental importance. If feeding pre-cleaned flue gas a total destruction of eventually present PCDD/F is expected. In all cases an experimental investigation of the role of PCDD/F is strongly recommended.

7 CONCLUSIONS AND OUTLOOK

In order to minimize the cost of waste combustion a combination of this process with other thermal processes has been proposed. In the context of this paper the following options have been compared:

- co-combustion of municipal solid waste in a coal fired dry bed boiler,
- the UPSWING Process which utilises partially cleaned flue gas from waste combustion as carrier gas for pulverized hard coal in the power plant.

The comparison of the two concepts has been made on the basis of the legislative limit for co-combustion of waste in Germany which is 25 % of the total energy input in a thermal process.

Regarding inorganic species in waste a significant increase of chlorine and volatile heavy metals, especially of mercury and cadmium is expected if co-combustion is practised. The increase in mercury inventory may cause emission problems. Increased inputs of other volatile metals like cadmium or lead endanger the quality of the solid residues, first of all that of the fly ashes.

More or less no effect on inorganic constituent levels in the coal fired plant are expected if pre-cleaned gas from waste combustion is used as carrier medium for the pulverized coal as foreseen in the UPSWING Process.

Volatile organic compounds in the waste or in the waste combustion flue gas should be destroyed during the coal combustion process. An increased chlorine level should not have serious consequences in view of formation of PCDD/F in the power plant. Our knowledge of the role of PCDD/F in all of these processes, however, is limited and experimental work in this field is strongly recommended before any method is implemented in full scale.

From an environmental perspective the proposed UPSWING Process looks much more promising simple co-combustion. The economical advantage of the latter option does not - at least in the eyes of the authors - compensate for its environmental deficits.
The new process needs a number of open technical questions to be solved before it can be used in full scale:

- the stability of coal combustion by replacing part of the primary air by flue gas reduced in oxygen content,
- measures in case the waste combustion plant has to be shut down, and finally
- the role of PCDD/F has to be investigated in detail.

An EU sponsored research program has been launched to investigate all aspects of coupling of the steam circuits, the best suited injection strategy for the pre-cleaned off-gas, and the thermal destruction of gaseous PCDD/F in a pilot plant for pulverised coal combustion.

8 REFERENCES

Albert. F.W. (1997), Die Niederungen des Alltags: Über den erfolgreichen Betrieb einer Müllverbrennungsanlage, *VGB Kraftwerkstechnik, 77*, 39 - 47

Gerhardt, Th., Rebmann, M., Spliethoff, H. & Hein, K.R.G. (1996), Untersuchungen zur Mitverbrennung von kommunalen Klärschlämmen in Kohlenstaubfeuerungen, *VGB Kraftwerkstechnik, 76*, 403

Günther, R. (1984), *Verbrennung und Feuerungen*, Springer Verlag, Berlin

Hölter, H. (1997), Verfahren zur Verbrennung von fossilem Brennstoff und Abfall, German Patent DE 4442 136 C2 (02.10.97), German Patent DE 196 17 034 C1 (13.11.97)

Hunsinger, H., Kreisz, S. & Vogg, H. (1996), Experiences gained from the sampling of chlorine aromatics in the raw gas of waste incineration plants, *Chemosphere, 32*, 109

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

Maier, H., Dahl, P., Gutberlet, H. & Dieckmann, A. (1992), Schwermetalle in kohlebefeuerten Kraftwerken, *VGB Kraftwerkstechnik, 72*, 439

Martel, C. & Rentz, O. (1997), Analyse der Schwermetallströme in Steinkohlefeuerungen, Teil 1: Kohleklassifizierung, *VGB Kraftwerkstechnik, 78*, 72

Martel, C. & Rentz, O. (1997), Analyse der Schwermetallströme in Steinkohlefeuerungen, Teil 2: Einfluß der Kohleart und des Lastzustandes, *VGB Kraftwerkstechnik, 78*, 134

Rentz, O., Sasse, H., Karl, U., Schleef, H.-J. & Dorn, R. (1998), Maßnahmen zur Emissionsminderung bei stationären Quellen in der Bundesrepublik Deutschland, Band II: - Minderung von Schwermetallemissionen -, *Forschungsbericht 204 02 360, UBA-FB 98-001/2*, Umweltbundesamt Berlin

Rittmeyer, C., Kaese, P., Vehlow, J. & Vilöhr, W. (1994), Decomposition of Organohalogen Compounds in Municipal Solid Waste Incineration Plants. Part II: Co-combustion of CFC Containing Polyurethane Foams, *Chemosphere, 28*, 1455

Vehlow, J., Braun, H., Horch, K., Merz, A., Schneider, J., Stieglitz, L. & Vogg, H. (1990), Semi-Technical Demonstration of the 3R Process, *Waste Management & Research, 8*, 461

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

Vehlow, J., Wanke, T., Bergfeldt, B. & Mark, E. (1997), Co-combustion of E+E waste plastics in the TAMARA test plant. *5th Annual North American Waste-to-Energy Conference (NAWTEC V), Research Triangle Park, N.C.*, April 22-25, 1997

Vogg, H., Hunsinger, H., Merz, A., Stieglitz, L. & Vehlow, J. (1991), Head-end-Techniken zur Dioxinminderung. In *Prozeßführung und Verfahrenstechnik der Müllverbrennung, VDI Berichte 895*, 193

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