

TNO-report

Environmental effects of waste treatment of impregnated wood

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Gasification of waste preserved wood impregnated with toxic inorganic and/or organic chemicals.
STEP-CT-91-0129
Sub report: Environmental effects of waste treatment of impregnated wood

Summary

'Science and Technology for Environmental Protection' (STEP) is a program of the Commission of the European Communities. The title of one of these STEP projects was 'Gasification of waste preserved wood impregnated with toxic inorganic and/or organic chemicals' (STEP-CT 91-0129). The project group participants are:

- DTI - The Danish Technological Institute
Department of Environmental Technology
- TNO - The Netherlands Organization for Applied Scientific Research
Institute of Environmental and Energy Technology
- VTT - Technical Research Centre of Finland
Combustion and Thermal Engineering Laboratory

The overall objective of the project was to reduce or eliminate emissions of toxic compounds by disposal of preserved wood by gasification as an alternative method to incineration.

This study focuses on the environmental impact of disposal of products as part of total Municipal Solid Waste (MSW). Consumer products will eventually become waste. This is also true for impregnated wood and its products. In most cases, waste wood will be handled as part of the MSW. Final disposal consists of landfill or incineration. These options are dealt with in this report. The results of this analysis are used to specify the environmental gain in the case that the impregnated is gasified.

The composition of the waste and the disposal technique essentially decide the potential emissions. TNO has developed a method for the allocation of the emissions of incineration and landfilling to specific waste fractions. The method (allocation model) has been developed for the inventory step in LCA studies.

The method is based on mass balances for the input and output data of the emitted pollutants. Although the model is still an approximation of reality, it is considerably more accurate than a 'black box' approach which treats all feed wastes in MSW as identical.

For the environmental analysis, it is necessary to differentiate for the impregnating means.

This study will consider the following types of waste wood:

- CCA impregnated wood (noted as 'cca scrap')
- creosote impregnated wood (noted as 'creo scrap')
- PCP impregnated wood (noted as 'solv. scrap')
- CCA: copper, chromium, arsene
- PCP: pentachlorophenol.

The impregnating means differ in application and market share. The weight of a volume of 300,000 m³ wood is assumed to be 210,000 tonnes. This study assumes that impregnating leads to an increase in specific weight of the wood. Thus, the resulting total weight of 300,000 m³ of impregnated wood is 219,060 tonnes, as can be calculated with retention figures.

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In order to be able to use real input-data, the calculation in this study is based upon the situation in the Netherlands. However, the results can be extrapolated to other situations.

One of the important assumptions in the calculation is that:

- a. the impregnated wood is part of the mix of municipal solid waste. This means that average data about composition of MSW are **inclusive** of the woodwaste considered.
- b. the impregnated wood is not a part of the mix of municipal solid waste. This means that average data about composition of MSW are **exclusive** of the woodwaste.

In reality, both assumptions may not be correct (an overestimation and an underestimation of allocated emissions, respectively) as described in this report.

The assumption about the relationship between MSW and wood (MSW data inclusive of wood) (a) leads to some discrepancies between the calculated results and the data about quantities and composition of the wood.

In order to overcome these discrepancies, the opposite assumption (b) has been worked out.

Some of the calculated results presented in Table S1 on the environmental impact of incineration and in Table S2 on the environmental impact of landfill result in a range. These must be considered as 'minimum values' and 'maximum values', respectively. These calculated impacts of disposal and incineration of impregnated wood require careful interpretation.

It can be concluded that the allocation needs further refinement. Although the model is still an approximation of reality, it is considerably more accurate than a 'black box' approach which treats all feed wastes in MSW as identical.

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Table S.1 Environmental impact if 300,000 m³ of preserved wood is incinerated together with MSW

Total waste wood scrap (tonne): 219,060				
		minimum value	average value	maximum value
Utility input				
NaOH 50%	kg		1.63E+05	
CaO	kg		1.63E+06	
Cokes	kg	1.75E+06	-	1.76E+06
Ammonia	kg	6.07E+05	-	6.15E+05
gas	m3	1.70E+06	-	1.72E+06
Co-products output				
electricity	MJ		8.16E+08	
metal scrap	kg		1.25E+05	
Emissions airborne				
CO ₂	kg		3.40E+08	
NO _x	kg	6.30E+04	-	5.85E+04
SO ₂	kg	1.57E+04	-	1.43E+04
HCl	kg	2.01E+04	-	2.05E+04
HF	kg	5.71E+02	-	6.23E+02
As	kg	3.36E+03	-	4.01E+03
Cr	kg	1.30E+03	-	1.55E+03
Cu	kg	7.55E+02	-	9.00E+02
aerosols	kg	1.19E+04	-	1.20E+04
hydrocarb.inc msw	kg		2.39E+04	
CO	kg	1.19E+05	-	1.20E+05
PAH	kg		1.91E-01	
TEQ	twe	2.39E-04	-	2.41E-04
Waste materials				
Rgrr AVI (TW)	kg	3.25E+06	-	3.26E+06
Fly ash AVI (TW)	kg		4.08E+06	
Slag AVI	kg		3.65E+06	

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Table S.2 *Environmental impact if 300,000 m³ of preserved wood is landfilled together with MSW*

Total waste wood scrap (tonne): 219,060				
Utility input		Minimum value	Average value	Maximum value
diesel	kg	7.35E+05	2.22E+05	7.36E+05
electricity	MJ		-	
light fuel oil	kg		2.33E+05	
Emissions airborne				
CO ₂	kg		6.38E+07	
CO	kg		1.24E+06	
H ₂	kg		7.56E+04	
NH ₃	kg		2.68E+03	
H ₂ S	kg		7.48E+03	
methane and other hydrocarbons	kg		2.62E+07	
aromatic hydrocarbons	kg		4.15E+05	
halogenated hydrocarbons	kg		4.90E+05	
NO _x	kg		1.31E+04	
SO ₂	kg		7.24E+03	
aerosols	kg		1.12E+03	
incineration of hydrocarbons	kg		2.26E+03	
incineration of heavy metals	kg		1.14E+01	
Emissions to soil				
SO ₄	kg	7.35E+01	-	7.58E+01
Cl	kg		2.37E+03	
As	kg		6.72E+00	
Cr	kg		3.22E+00	
Cu	kg		2.79E-02	
PAH	kg		8.76E-03	
aromatic hydrocarbons	kg		2.70E+01	
halogenated hydrocarbons	kg		3.60E-01	
BOD	kg		1.22E+04	
COD	kg		1.98E+04	
phenol	kg		1.31E+00	
CN	kg		8.76E-02	
NH ₄	kg		8.40E+02	
N-total	kg		1.55E+03	
Emissions waterborne				
SO ₄	kg	2.57E+03	-	2.61E+03
Cl	kg	1.15E+04	-	1.16E+04
As	kg	8.56E+01	-	3.29E+02
Cr	kg	3.09E+01	-	4.15E+01
Cu	kg	9.89E-01	-	9.99E-01
PAH	kg		4.29E-02	
aromatic hydrocarbons	kg	1.32E+03	-	4.56E+02
halogenated hydrocarbons	kg	1.76E+01	-	4.98E+00
BOD	kg	8.09E+02	-	8.23E+02
COD	kg	2.43E+03	-	2.47E+03
phenol	kg		4.29E+00	
CN	kg		2.15E+00	
NH ₄	kg	8.09E+02	-	8.23E+02
N-total	kg	8.09E+02	-	8.23E+02
Solid waste				
residue cleaning leachate (TW)	kg	3.03E+05	-	3.04E+05
sludge cleaning leachate	kg		5.04E+05	
definite waste	kg		1.14E+08	

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The results of the calculation can be analysed in various ways. The ultimate question is if the emissions, due to waste disposal of impregnated wood are acceptable or not. If the emissions due to the disposal of impregnated wood, are related to the total amount of emissions due to all activities in the reference area, the significance of the various emission can be argued.

Table S.3 shows these comparison.

Table S.3 Major emissions, due to incineration and landfill of impregnated wood (scenario B) compared with total emission (of all sources)

Emission	Incineration	Landfill	Total all sources	Fraction
	kg	kg	kg	%
Airborne				
As	3,360	-	790	425
Cr	1,300	-	6,960	19
Cu	755	-	55,300	1.3
Aromatic HC		27	1.2E+06	0
Halogenated HC		36	3.8E+06	0
Waterborne				
As		329	18,800	1.8
Cr		41.5	62,400	0
Cu		1	239,000	0
Aromatic HC		1,320	32,700	4
Halogenated HC		17.6	632,000	0

The conclusion is that As and Cr emissions are significant high in case of incineration. Cu emission is not neglectable.

In case of landfill the waterborne emissions of As and aromatics are not neglectable.

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1 Introduction

'Science and Technology for Environmental Protection' (STEP) is a program of the Commission of the European Communities. The title of one of these STEP projects was 'Gasification of waste preserved wood impregnated with toxic inorganic and/or organic chemicals' (STEP-CT 91-0129). The project group participants are:

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Institute of Environmental and Energy Technology
- VTT - Technical Research Centre of Finland
Combustion and Thermal Engineering Laboratory

The overall objective of the project was to reduce or eliminate emissions of toxic compounds by disposal of preserved wood by gasification as an alternative method to incineration.

This study focuses on the environmental impact of the present way of disposal of impregnated wood.

Final waste disposal

Consumer products will eventually become waste. This is also true for impregnated wood and its products. In most cases, waste wood will be handled as part of the municipal waste stream¹⁾ (MSW). Final disposal is landfill or incineration. These options are dealt with in this report.

Disposal of waste does have environmental impacts (emissions of pollutants to soil, water and air). Which pollutants and the quantity of the emitted pollutants depends on the following parameters:

- a. The composition of the total **mix** of municipal solid waste (MSW).
Composition includes an overview of all materials (plastics, metals, organics etc.) and the total content of potential pollutants (heavy metals, halogens, sulphur, etc.)
- b. The process conditions of the disposal.
(design of landfill, type and degree of flue gas cleaning, type of leachate treatment, etc.)

In essence, the composition of the waste (a) decides the potential emissions. For example, in the case of the presence of chlorine in the waste, an emission of HCl by the flue gas is possible when the waste is incinerated. Of course, the 'availability' or 'state of aggregation' of the waste, especially the Cl- containing fractions, will affect the actual emission, as Cl in e.g. PVC reacts in a different way in the incinerator from Cl in a brick.

The actual emissions, however, depend on the process conditions of the disposal (b). The main factors which control the actual emissions by the flue gas are the process conditions in the furnace and the flue gas cleaning.

¹⁾ This study will not pay attention to impregnated wood that degrades as application (e.g. sheet-piling).

At landfilling, these factors are the construction and covering of the landfill, the lining and the leachate treatment.

Life Cycle Assessment

In order to analyse the environmental impact of a product, or to compare the environmental impacts of product alternatives, the method of life cycle assessment has been developed [ref. 13, 14]. Life cycle assessment always includes the final step of waste disposal.

A 'default' convention in the LCA method is to allocate environmental data between inputs of multi-input processes on the basis of a simple measure (e.g. weight basis). In the case of MSW incineration or landfill this 'default' approach treats all waste feed in MSW as identical. That, however, is an unsupportable assumption because this way of allocation leads to results, in which a part of the energy generation of an incinerator is contributed to inert material, or a part of the chlorine emission is allocated to polyethylene. It is obvious that this way of allocation leads to useless discussions. In the case of a comparison of the environmental impacts of specific products, one should take into account the effect of the products' composition.

Allocation model for waste disposal

TNO has developed a method for the allocation of the emissions of incineration and landfilling to specific waste fractions. The method (allocation model) is developed for the inventory step in LCA studies.

The method is based on mass balances for the input and output data of the emitted pollutants. Although the model is still an approximation of reality, it is considerably more accurate than a 'black box' approach which treats all feed wastes in MSW as identical.

The allocation method employed by TNO has the following characteristics:

- The apportioning is unambiguous. All emissions are allocated without any double-counting or overlap (the '100%' rule).
- The method is based on a causal relationship.
Emissions must be allocated either to components of the various waste fractions or to the process conditions.
- The method is based on a well-defined situation. This makes allowance for a complete calculation to be made for which the '100%' rule applies.
An example of the well-defined situation is that in the case of incineration the final emission to air meets the standards given in specific regulations (e.g. German 17 BImSchV, 1990, or the E.C. directive).

In this report, the above-mentioned method will be used to analyse the environmental effects of the disposal of impregnated wood.

Chapter 2 gives a survey of the relevant data of impregnated wood (quantities and composition). The allocation method is described in chapter 3.

The results of the analysis are presented in chapter 4. An evaluation and a discussion of these results are given in chapter 5.

2 Volume of impregnated woodwaste (illustrated by the situation in the Netherlands)

According to the inventory, the quantity of impregnated wood which is discarded as waste in the Netherlands is estimated at 300,000 m³ per year.

This study focuses on the environmental impact of the disposal of 300,000 m³ of impregnated wood as part of total MSW in the Netherlands.

In order to be able to use real input data for the environmental analysis, the calculation in this study is based upon the situation in the Netherlands.

For the environmental analysis, it is necessary to differentiate for the impregnating means. The most important impregnating means are salts (CCA), creosote and solvents (PCP).

This study will consider the following types of waste wood:

- CCA impregnated wood (noted as 'cca scrap')
- creosote impregnated wood (noted as 'creo scrap')
- PCP impregnated wood (noted as 'solv. scrap')
- CCA: copper, chromium, arsene
- PCP: pentachlorophenol.

The impregnating means differs in application and market share. Table 2.1 presents retention data and Dutch figures for market shares.

This study assumes that impregnating leads to an increase in specific weight of the wood. Specific weight of wood preceding impregnation is assumed 700 kg/m³. Resulting total weight of 300,000 m³ of impregnated wood is 219,060 tonnes, as can be calculated with retention figures in Table 2.1

The retention qualities of the respective impregnating means (Table 2.1) are based on conservative estimates. These qualities are quite high.

As the environmental impacts in waste processing are partially proportional with the retention qualities stated for impregnated wood, this study will also separately indicate the resulting environmental impacts when processing 300,000 m³ (210,000 tonnes) of non-impregnated wood (= 'clean' wood). This gives an opportunity to calculate (interpolation) the effects for other retention qualities, as given in Table 2.1.

Table 2.1 Impregnating means: market share and retention

Means	Retention per kg/m ³ of wood	Share (vol %)
cca scrap	8	65
creo scrap	100	15
solv scrap	50	20

3 Description of the allocation model for combined waste disposal

Allocation of the environmental impacts of a multi-input waste disposal process to the different input products is based on two elements:

- The composition data of the waste (both total mix and the particular waste product) have to be considered. The composition of the total mix allows a definition to be made of the relationship between input and output. The composition of the specific product, in this case the impregnated woodwaste, gives a basis for calculating and apportioning the 'product-related' impacts.
- A model description of the process itself (archetype) allows to define the 'process-related' impacts.

Allocation to the specific product can be made by an allocation factor, which is either process-related or (waste) product-related.

3.1 MSW incineration

3.1.1 Description of the MSW incinerator plant

The present emission standards of MSW incinerators in Germany, the Netherlands and Switzerland, correspond more or less with the present status of flue gas cleaning. However, technology development goes on. The majority of the incinerators, which are in operation in the EEC, were designed a long time ago and do not meet the emission standards mentioned above. It appears that there is a wide variety of incinerators. Each of them must be considered as a unique process with respect to input, type of incinerator, furnace, operational standards, flue gas cleaning, etc.

All input data for the allocation model should be based on a specific well-defined plant in order to generate the relevant data. The design for this study should reflect the present state of art. Unfortunately, it appears that there are hardly any consistent data of a well described plant available. Most of the literature data are fragmented and focus on specific phenomena. Real consistent, average data are not available. Therefore, hypothetical data will be used which does reflect the best estimate from literature.

The description of the TNO allocation model for MSW incineration in this study is based on a hypothetical status of an MSW incinerator (an archetype) according to the Dutch flue gas cleaning standards listed in Table 3.1. It is clear that the same approach for an allocation model can be applied for other types of incinerators. The model incinerator shows the following features:

- Flue gas cleaning with electrostatic precipitator.
- A flue gas scrubber (two stage) with a closed water cycle.
Therefore, aqueous effluent from the MSW incinerator is taken as zero.
- A denox plant incorporated in the flue gas cleaning.
- An activated carbon adsorber in the flue gas cleaning to meet the dioxine standards.

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- Energy recovery output by means of generating electricity: the recovery rate is 25% of Lower Heating Value (LHV) of the MSW feed.

Table 3.1 Dutch flue gas emission standards for MSW incinerators

	Hour average (mg/nm ³ - 11% O ₂ stp)
dust	5
CO	50
HCl	10
HF	1
SO ₂	40
NO _x	70
organics (C)	10
Hg	0.05
Cd	0.05
heavy metals ¹⁾	1
dioxins ²⁾	0.1

1) Sum: As + Cu + Cr + Pb + Mn + Ni + Sb + V + Sn + Se + Te + Co

2) in nanogram TEQ/nm³

Table 3.2 Input and output data of model MSW incinerator¹⁾

Input	per metric tonne of MSW	Output	per metric tonne of MSW
CaO	10 kg	Slag	300 kg
Coke	5 kg	Fly ash	30 kg
NaOH	1 kg	Residue	20 kg
NH ₃	5 kg	Scrap	0.8 kg
Natural gas	14 m ³	Flue gas	6.8 nm ³
Power	100 kWh	Electricity	618 kWh

Both input of utilities and output of waste streams is (among other things) dependant on the composition of the MSW feed. For typical Dutch MSW composition, the input and output data of the model incinerator are shown in Table 3.2.

The allocation model employed by TNO links the environmental outputs (emissions of flue gas and the input & output figures) to specific waste products or waste fractions in the MSW feed.

¹⁾ Input/output data if composition of MSW is in accordance with Table 4.1.

3.1.2 Allocation rules for incineration

Assumptions for the model

Input and output figures to be apportioned to specific waste products are flue gas emissions (to atmosphere), solid wastes to be disposed of (residues) and utilities.

Emissions into the atmosphere by flue gas from MSW incineration can be categorised either as (waste) product-specific or process-specific.

- So-called product-specific pollutants are those for which there is a theoretical basis for calculation emissions direct from the composition of the waste. For product-specific pollutants, the emissions by the untreated flue gas can be estimated by a mass balance based on the waste composition (if ashes and slags are also considered in that balance).
- For so-called process-specific pollutants, the composition offers no clear basis for allocation of the emissions. The emissions of all these pollutants cannot be assigned to specific waste products in MSW. It is assumed that the contribution of the various waste fractions to the pollutants in the untreated (raw) flue gas is related to the contribution to the incineration process itself. The amount of flue gas generated by the specific waste fraction is a criterion.

Table 3.3 gives a survey of both categories of pollutants. Process-specific pollutants include dioxins and furanes. The position of these pollutants in the allocation model is based upon findings of research work which indicate that emissions of dioxins etc. are not dependent on the chlorine or Cu content of the feed waste above certain minimum levels which are substantially exceeded in average MSW [ref. 10, 15].

In the model, the actual pollutant emissions to the air are dependent on the flue gas volume generated by MSW and the actual flue gas concentrations required (Table 3.1). The cleaning efficiency is calculated in the model from figures of raw flue gas concentrations and the actual flue gas concentrations required.

Table 3.3 Flue gas MSW incineration: (waste) product-specific and process- specific pollutants

Product-specific pollutants	Process-specific pollutants
CO ₂	Dust
SO ₂	CO
NO _x	Organics (CH)
HCl	PAH
HF	Dioxins/furanes
Heavy metals	

The first step in the model is the determination of the concentration in the raw flue gas. Raw flue gas concentration for process-specific pollutants have been obtained from literature data and product-specific pollutants from mass balancing and MSW composition.

The next step is the determination of the cleaning efficiency of the flue gas by

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comparison with the required standards. It is obvious that this procedure leads to some simplification. In a real situation, emissions fluctuate and the cleaning efficiency of the flue gas is a result of a set of process parameters and a fluctuating raw gas concentration. However, in order to meet the main requirement of the '100%' rule, it is necessary to simplify the real situation to some extent. For this reason, it is justifiable to fix the output at a regulatory level.

The allocation model is valid for the chosen composition of MSW. If the MSW composition changes, the raw gas concentration changes and this affects the allocation of the product-specific pollutants. In the model, only the process-specific pollutants are not affected by the MSW composition.

In the situation that Dutch flue gas cleaning standards are met for some heavy metals (excl. Hg and Cd), there is an integral standard (1 mg/nm³; Table 3.1). The 'overall' cleaning efficiency follows from the total of all heavy metals in the raw gas and the integral emission standard. In the model it is assumed that the same efficiency applies for all heavy metals.

No standards exist for some pollutants (PAH, CO₂ and some heavy metals, such as Zn). Nevertheless, these pollutants are emitted and are dealt with in the allocation model. For PAH, a cleaning efficiency of 95% is assumed.

Allocation procedure

Apportioning pollutants in flue gas

Apportioning of the **process**-specific pollutants has been made on the basis of the amount of flue gas generated. The amount of flue gas can be calculated from composition data (both for the total mix of MSW and the specific product). The ratio between these flue gas volumes is a measure for the contribution of the specific waste product to the **process**-specific pollutants.

Example:

Suppose that incineration of 1 kg of MSW gives a flue gas volume of y_{MSW} m³. This causes an emission of a'_{MSW} kg of a process-specific pollutant (e.g. CO). On the basis of the macro composition of the specific product it can be calculated that incineration of 1 kg of the waste product results in y_{waste} m³ of flue gas. The CO emission (a'_{waste}) which can be allocated to 1 kg of the specific product is:

$$a'_{\text{waste}} = (y_{\text{waste}} / y_{\text{MSW}}) * a'_{\text{MSW}}$$

N.B. The sum of all individual contributions must be equal to the macro emission of MSW incineration!

Apportioning of the **product**-related pollutants has been made on the basis of the elemental composition. This composition must be compared with the elemental composition of the total mix in MSW. However, it is not allowed to calculate the apportioning on the basis of the 'composition' ratio directly. The state of aggregation of the specific product and the elements in this product *and* the distribution of the

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pollutant over the output (slag, fly ash, scrubber residue, flue gas) must be determined.

Example:

Suppose that incineration of 1 kg MSW results in a raw flue gas emission of m_{MSW} kg of a product-specific pollutant (e.g. HCl). The amount of this pollutant (Cl) in MSW is n_{MSW} kg. The distribution of this pollutant to the raw flue gas is therefore $p_{\text{MSW}} = m_{\text{MSW}} / n_{\text{MSW}}$. The cleaning efficiency of the flue gas for HCl is Z (which should fulfil the standard as given in Table 3.1).

The emission to the atmosphere of HCl as a result of the incineration of MSW is a'_{MSW} kg, with:

$$a'_{\text{MSW}} = (1 - Z) * m_{\text{MSW}} = (1 - Z) * p_{\text{MSW}} * n_{\text{MSW}}.$$

The amount of pollutant (Cl) in the specific waste product (per kg) is n_{waste} kg, the distribution to the raw flue gas is p_{waste} and the contribution of Cl in the raw gas is m_{waste} . Note that the distribution factor p may differ. The emission of HCl to the air which can be apportioned to 1 kg of the specific product is a'_{waste} with:

$$a'_{\text{waste}} = (m_{\text{waste}}/m_{\text{MSW}}) * a'_{\text{MSW}} = (p_{\text{waste}}/p_{\text{MSW}}) * (n_{\text{waste}}/n_{\text{MSW}}) * a'_{\text{MSW}}$$

The contribution of specific products to the environmental impact is expressed per quantity of weight. This means that the particular concentration of the product considered in the total mix of MSW is not of direct importance. Of course, it has an indirect effect in the case that the average composition of the MSW is being changed. If this occurs, then the raw flue gas composition is changed and the basis of the allocation should be recalculated.

Apportioning residues and utilities

Next to flue gas emissions there is an output of solid residues (fly ash, slag and scrubber residue) and the electricity generated. There is also an input of utilities which has to be apportioned.

The apportioning of solid residue fly-ash is coupled directly with the emission of dust, which is a process-specific pollutant. Consequently, apportioning fly-ash is process-specific. The apportioned amount of fly-ash is proportional to the amount of flue gas. The solid residue slag (including iron-scrap) is considered to be product-specific. The amount of slag is dependent on the amount of 'inert' in the product. In the actual calculation of the contribution of a specific product to slag and iron-scrap, a correction should be made for the 'inerts' which are emitted by the fly-ash and the scrubber residues.

The scrubber residue is also product-specific. The amount of residue is dependent on the SO_2 , HCl and HF concentrations in the raw flue gas and these pollutants are product-specific. The allocation of the residue is based on the sum of the stoichiometric concentrations of these pollutants in the raw flue gas.

For the other input and outputs, the following applies:

- The apportioned amount of CH_4 and NH_3 (both input streams for the denox plant) is proportional to the amount of NO_x in the flue gas.
- The apportioned amount of cokes (input for dioxin filter) is proportional to the amount of flue gas.
- The apportioned input of electricity is proportional to the weight of the waste products.
- The apportioned output of electricity is proportional to the lower heating value (LHV) of the waste products.

3.2 MSW landfill

3.2.1 Description of the MSW landfill site

Landfill practices vary widely across Western Europe. There are moves to standardise the approaches to some extent, for example by the proposed EC Directive on landfilling. There will, nonetheless, continue to be significant differences in geology, technical practices and the restrictions on substances which may be landfilled in different countries.

Environmental data from landfill in literature vary tremendously. Therefore the description of the allocation model of TNO in this study is based on a hypothetical landfill site for mixed MSW (combined organic and inorganic waste) with the following features:

- Lining with geosymmetric membrane (Dutch ICM criteria)
- Collection and treatment of leachate
- Landfill gas is *not* recovered
- Landfill is covered after the operation time (covering stops leachate).

Hypothetical data used in this study reflect a best estimate from literature.

Environmental impacts arise from landfill gas and leachate. Leachate is caused by rainfall during the operation time of the landfill. Most of the leachate is treated in a purification plant. In this study, 2% of the leachate is stated as leak to the soil. Treatment of leachate (biological followed by filtration + evaporation) is in accordance with the guidelines (non-official standards) for Dutch surface water quality. The landfill site for MSW with typical Dutch composition has the following characteristics:

- Landfill gas: 180 m^3 per tonne of MSW during the total lifetime of the landfill (if MSW composition is in accordance with Tables 4.1 and 4.2). Both volume and composition of the landfill gas depend on the composition of MSW). Pollutants in landfill gas are listed in Table 3.4
- Leachate: 200 litres of leachate per tonne of MSW.
About 40% of the leachate has an acid composition and 60% of the leachate has a methanogenic composition.
- Energy requirements *per tonne of MSW landfilled* resulting from landfill operation activities and resulting from leachate treatment depend on the composition of

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MSW. For typical Dutch MSW composition¹⁾, these figures are per tonne of MSW:

- light fuel oil for leachate treatment : 69.3 MJ
- fuel (diesel) for landfill-handling activities : 42.5 MJ
- electricity : 4.14 MJ
- The model landfill has output by solid residues. Volumes depend on the composition of MSW. For typical Dutch MSW composition, these figures are per tonne of MSW:
 - Organic sludge from leachate treatment : 1.2 kg
 - Inorganic residue from leachate treatment : 2.2 kg
- After a purification process, the leachate is emitted to the surface water. The quality of the effluent meets the requirements of the Dutch guidelines, as given in Table 3.5.

Table 3.4 Pollutants in landfill gas

Composition
CO ₂
CO
H ₂
NH ₃
H ₂ S
aromatic hydrocarbons
halogenated hydrocarbons
methane and other hydrocarbons
H ₂ O

¹⁾ Composition of MSW in accordance with Table 4.1

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Table 3.5 *Pollutants in leachate, limits for surface water and reduction required for leachate of a typical Dutch MSW composition*

In mg/m³ component	Concentration surface water limit	Reduction required
SO ₄	250000	28.6%
Cl	200000	90.0%
Na	150000	89.3%
Fe	500	99.9%
As	50	0.0%
Cd	5	66.7%
Cr	50	73.7%
Cu	50	27.5%
Hg	1	50.0%
Pb	50	81.5%
Zn	50	99.0%
Rest heavy metals	20	99.1%
PAH	1	90.0%
BTEX	300	0.0%
EOX	3	0.0%
BOD	10000	99.9%
COD	30000	99.7%
Phenol	100	93.3%
CN	50	50.0%
NH ₄ -N	10000	98.0%
N-total	10000	98.9%

3.2.2 Allocation rules for landfill

Assumptions for the model

All input and output of MSW landfill have to be allocated, including emissions to air (landfill gas), emissions to soil and surface water (leachate), solid residue's (leachate treatment) and input utilities.

Pollutant emissions into the atmosphere by landfill gas are all categorised as product-specific. There is a semi-empirical basis for calculating emissions by landfill gas by mass balance [ref. 4, 5, 6].

In case of apportioning to a specific waste product (like impregnated wood), the major factor which controls the emission into the air is not the composition as such, but the fact to which cluster of waste the product belongs.

The number of sub-fractions (cluster) defines the quantity and composition of the landfill gas. This means that:

- All aromatics in landfill gas are apportioned to the sub-fraction organic solvents in MSW (organic solvents are categorised as a sub-fraction of the MSW fraction hazardous waste (TW)).

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- All halogenated organics in landfill gas are apportioned to sub-fraction halogenated solvents in MSW (halogenated solvents is categorised as a sub-fraction of the MSW fraction hazardous waste (TW)).
- Other pollutants and components in landfill gas are all apportioned to the organic fraction (= putrescibles and fines) in the MSW.

In the model, the output of landfill gas directly results in actual emissions into the air, because no landfill gas is recovered.

Emissions to soil are caused by the leaking of leachate. In the allocation model, some pollutants in the leachate are process-specific, but most of the pollutants are product-specific.

In the allocation model, concentrations of process-specific pollutants in the leachate are derived from literature data. Phenolics, CN and PAH in the leachate are assumed to be process-specific. For these specific pollutants, there is no clear basis for calculating leachate concentrations from composition data [ref. 5]. Apportioned concentrations of these pollutants in the leachate are identical for all waste products in MSW.

Process-specific pollutants in leachate include PAH. That position of PAH in the model is based upon findings of research work which indicate that most of PAH pollutants in leachate from MSW landfill are not dependent on the PAH content of the feed waste nor on specific waste fractions in MSW [ref. 5].

Other pollutants in the leachate (except phenolics, CN and PAH) will be apportioned in the product-specific way. Some of the pollutants are apportioned by means of the contribution of the waste product to specific (sub-)fractions of MSW. Other product-specific pollutants, however, are apportioned by means of the pollutant concentration in the waste product (elemental composition).

Apportioning rules are:

- COD, BOD, total N and the concentration of NH_4 in the leachate are related to the organic fraction of MSW.
- EOX in the leachate is related to the sub-fraction halogenated solvents (fraction hazardous waste) of MSW.
- BTEX (total aromatics) in the leachate is related to the sub-fraction aromatic solvents (fraction hazardous waste) of MSW.
- For all other product-specific pollutants, the leachate concentration is related to the composition of the waste product.

All actual emissions to the soil are the result of the leaking of leachate.

About 2% of the leachate (= 4 l/tonne of waste) leaks to the soil.

Actual emissions to the surface water generate from the leachate drained to the surface water, after part of the leachate has been cleaned.

The required pollutant concentrations in the drained leachate are listed in Table 3.5. In the model, the cleaning efficiency of the treatment plant is calculated from raw leachate concentrations and these standards.

The basis for the apportioning soil and surface water emissions to the specific products is the pollutant concentration in the raw leachate. In the case of the emissions to the surface water, the emission standards or guidelines should be taken into account.

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Note: Major variations in the composition of MSW could result in a variation of the pollutant concentrations in the leachate. As the emission standards do not vary in that situation, the cleaning efficiency could change (The same holds for the amount and composition of the landfill gas; both figures are also product-related).

Apportioning pollutants in landfill gas

Pollutants in landfill gas are summarised in Table 3.4. All pollutants are categorised as product-specific.

The pollutants in landfill gas are each related to specific (sub-)fractions of the waste, which has already been explained. This means that the question arises to what extent the product considered contributes to the relevant sub-fraction of MSW.

For example, the allocation of Halogenated hydrocarbons:

The concentration of halogenated hydrocarbons in the landfill gas is directly related to the sub-fraction of halogenated solvents in MSW.

Assume that the sub-fraction of halogenated hydrocarbons in the MSW = xHh_{MSW} and the emission by landfill gas of halogenated hydrocarbons per kg MSW = a'_{MSW} . Suppose otherwise that a part xHh_{waste} of the specific waste product belongs to the halogenated solvents sub-fraction (if the total product must be considered as part of the halogenated solvents sub-fraction, then $xHh_{waste} = 1$).

The emission of halogenated hydrocarbons by landfill gas, which must be apportioned to 1 kg of waste product is:

$$a'_{waste} = (xHh_{waste} / xHh_{MSW}) * a'_{MSW}$$

Apportioning pollutants in leachate

Leachate results in emissions to soil and water. The basis for the apportioning of these emissions is the pollutant concentration in the leachate. Most of the pollutants are product-specific. Some product-specific pollutants are related to the elementary composition; all others are related to particular sub-fractions.

For example, the allocation of EOX:

EOX in the leachate (concentration $C_{EOX_{MSW}}$, see Table 3.4) is linked to only one sub-fraction of the MSW mix. That particular sub-fraction is sub-fraction halogenated solvents. The portion of the sub-fraction halogenated solvents in MSW = xHh_{MSW} and a portion xHh_{waste} of the waste product belongs to that sub-fraction.

The concentration in leachate ($C_{EOX_{waste}}$) which is allocated to the specific product is:

$$C_{EOX_{waste}} = (xHh_{waste} / xHh_{MSW}) * C_{EOX_{MSW}}$$

If the product-specific pollutant is related to the elementary composition of the waste composition figures of both waste product and MSW mix are the basis for the allocation. It is also important to consider the aggregation of the components in terms of availability for leaching.

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For example, the allocation of Cl:

Assume for MSW:

$$\begin{aligned} \text{Cl concentration in the leachate} &= C_{\text{Cl}_{\text{MSW}}} \text{ (see Table 3.4).} \\ \text{The quantity of Cl in MSW} &= n_{\text{MSW}} \text{ kg.} \\ \text{Fraction of Cl available for leaching} &= q_{\text{MSW}}. \end{aligned}$$

Assume for the waste product:

$$\begin{aligned} \text{The quantity of Cl in the waste product} &= n_{\text{waste}} \text{ kg.} \\ \text{Fraction of Cl available for leaching} &= q_{\text{waste}}. \end{aligned}$$

The Cl concentration in the leachate which is allocated to the waste product is:

$$C_{\text{Cl}_{\text{waste}}} = (q_{\text{waste}} / q_{\text{MSW}}) * (n_{\text{waste}} / n_{\text{MSW}}) * C_{\text{Cl}_{\text{MSW}}}$$

Not all pollutants in the leachate are product-specific. Concentrations of phenolics, CN and PAH in the leachate are assumed to be process-specific.

For these pollutants the concentration in leachate for all waste products in MSW is identical (for example: $C_{\text{pah}_{\text{waste}}} = C_{\text{pah}_{\text{MSW}}}$). Allocation is, therefore, on a weight basis.

When calculating the emission to soil, the leakage percentage is important.

In this study, a percentage of 2% is used ($Y = 2\%$). The total amount of leachate per tonne of MSW is V litres. In this study, the leachate volume is 200 litres per tonne of MSW. Assume that the concentration of pollutants in the leachate because of the waste product is $C_{i_{\text{waste}}}$ (product-specific or process-specific).

The resulting emission to soil is:

$$a''_{\text{waste}} = Y * V * C_{i_{\text{waste}}}$$

When calculating the emission to the surface water, the standards for the effluent concentrations are important. Assume a standard concentration $C_{i_{\text{standard}}}$ (see Table 3.4). The cleaning efficiency Z for pollutant i is:

$$Z = (1 - C_{i_{\text{standard}}}) / C_{i_{\text{MSW}}}$$

The emission to the surface water per tonne of waste product is:

$$a'''_{\text{waste}} = (1 - Y) * V * (1 - Z) * C_{i_{\text{waste}}}$$

As is the case with incineration, the environmental impacts are allocated per unit weight of the waste product.

Apportioning of input utilities and output solid waste

Next to the emissions into the air by the landfill gas and the emissions to soil and water by the leachate, other (solid waste) outputs should be considered as well:

- (organic) sludge of the leachate treatment plant,
- (inorganic) solid residue of the leachate treatment plant,
- the final waste (the rest which remains landfilled).

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The amount of sludge as a result of the leachate treatment is related to the BOD content in the leachate (this is a product-specific parameter, because it is related to the fraction of organics). The same is true for the energy consumption of the leachate treatment process.

The amount of residue from the leachate treatment process is related to the amount of inorganics (minerals). So this is product-related. The same relationship applies to the related energy consumption.

The final amount of (ultimate) waste in the landfill, after correction of the output via gas and leachate, is estimated at 748 kg per tonne of MSW for the model landfill with a typical Dutch MSW composition. Per unit weight of the specific product, this final amount may differ as a result of the varying apportioning.

The energy consumption (fuel for the compactors) needed for handling and processing of the waste on the site is independent of the composition of the waste. Emissions due to these processes are allocated on a weight basis (see Table 3.6).

Table 3.6 Emission factors for fuel consumption for leachate treatment (gas) and fuel for handling activities (diesel) in mg/MJ input

Pollutant	Handling fuel input (diesel)	Leachate treatment (light fuel oil)
Hydrocarbons	240	8
CO ₂	73000	78000
CO	470	10
SO ₂	100	666
NO _x	1200	200
dust	100	20
heavy metals	0.2	1

4 Environmental effects when processing preserved woodscrap together with MSW

4.1 Input data for allocation, including composition of preserved woodscrap and composition of MSW

In the Netherlands, approximately 14,300,000 tonnes of MSW are annually being processed (1991). The large majority of this waste is incinerated or landfilled. The following table concerns the Netherlands:

— Incineration	2,800 ktonne of MSW/year	(= 19.6%)
— Landfill	11,500 ktonne of MSW/year	(= 80.4%)
— Total MSW to be disposed of	14,300 ktonne of MSW/year	(= 100.0%)

The quantity of impregnated wood which is discarded as waste with MSW in the Netherlands is estimated to be 219,060 tonnes per year (see chapter 2).

This study will treat this quantity of impregnated waste wood as part of the municipal waste stream (MSW).

The allocation method described in Chapter 3 is based on, amongst other things, a mutual comparison of the composition of MSW mix, on the one hand, and the composition of the impregnated waste wood, on the other hand. Therefore, the point of departure regarding MSW mix should be carefully established in the allocation. Subsequently, the question is posed to what extent the estimated annual quantity of impregnated wood is part of the annual quantity of MSW (14,300 ktonnes) in the Netherlands, because both total figures are calculated on the basis of information from different sources (literature sources). The quantity of impregnated wood is, in this respect, certainly quite a high assessment¹⁾.

Literature data are available concerning the composition of the average MSW mix in the Netherlands. The available data on the composition of MSW mix are based on long-term investigations of Dutch domestic waste [ref. 7].

However, the question remains to what extent this involves MSW, including the quantity of impregnated wood waste mentioned. If the 219,060 tonnes of additional impregnated wood should also be taken into account for the composition of the MSW, this would change the composition of the resulting MSW considerably, on a number of points (e.g. the average As content in this MSW).

¹⁾ As the relative assessment of the quantity of impregnated waste wood is rather high, the following aspects apply:

- All waste wood, including impregnated wood that is processed in the Netherlands with MSW, involves a quantity of about 400,000 tonnes per year at the most, according to [11,12]. This total figure comprises considerably more items than just impregnated wood. Apart from impregnated wood, these 400,000 tonnes also comprise non-impregnated waste wood from building and demolition, discarded furniture, etc. On the basis of the figures in the current study, more than half of all wood in the MSW flow would consist of impregnated wood! Such a large contribution, however, is to be doubted.
- In practice, not all impregnated wood will be collected and processed with MSW. An unknown, but possibly quite significant part of the discarded impregnated wood is 're-used' (at the premises of the discarder himself) or is not discharged at all (e.g. railway sleepers, sheet pilings, etc.; these remain behind in the ground).

As the allocation of environmental outputs of MSW disposal to impregnated woodscrap depends on the composition of preserved woodscrap *and on the composition of MSW (mix)*, as shown in Chapter 3, two extremes are therefore assessed within this framework, with respect to the present share of impregnated woodwaste in the annual quantity of MSW. This is carried out in the following ways:

Scenario A

Starting points:

Assumption: The total quantity of 219,060 tonnes of impregnated wood per year is already part of the MSW mix that is annually being processed in the Netherlands.

Therefore, the elementary composition etc.¹⁾ of the average MSW mix, as it is known from the literature, relates in this scenario to MSW including the total quantity (219,060 tonnes) of impregnated wood. For incineration, it is furthermore assumed that all impregnated wood is solely present in the 2,800,000 tonnes of MSW that are incinerated.

For landfilling, however, it is assumed that all impregnated wood is present in the 11,500,000 tonnes of MSW that is annually landfilled.

Note: This is an overestimation of both options. In the Netherlands, 19.6% of the MSW is incinerated and 80.4% landfilled. On the basis of those figures, only 19.6% of the impregnated woodwaste would actually be incinerated ultimately, whilst 80.4% (= 248,545 tonnes) would be landfilled.

In this scenario A, the same data are assumed for both landfilling and incineration, as far as the composition of the MSW mix is concerned. In essence, however, this is not quite consistent, as the quantity of MSW to be incinerated differs from the quantity of MSW to be landfilled, so that the influence of 219,060 tonnes of impregnated wood differs in this.

The calculation of the environmental impacts in accordance with scenario A is therefore explicitly an extrapolation.

Scenario B

Starting points:

Assumption: The annual quantity of 219,060 tonnes of impregnated wood **is no part** of the total of 14,300,000 tonnes of MSW per year. If, however, all impregnated wood is to be processed together with the MSW, then an annual total of 14,519,060 tonnes of waste will be processed.

The literature data concerning elementary composition, etc. of the average MSW that are used in this study are considered to relate in this scenario to MSW without the mentioned quantity of impregnated wood.

¹⁾ Apart from the elementary composition, the distribution data (with respect to the incineration of residues) and the spreading data (with respect to the sensibility of leaching) are of importance.

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In essence, therefore, two different elaborations hold in this scenario B for landfilling and incineration, with respect to the composition of the combination of MSW and the impregnated wood:

1. For incineration: total quantity 3,010,090 tonnes
(= 2,800,000 tonnes of MSW combined with 219,060 tonnes of impregnated wood)
2. For landfilling: total quantity 11,719,060 tonnes
(= 11,500,000 tonnes of MSW together with 219,060 tonnes of impregnated wood).

Note: A particular point which needs some explanation is the fact that incineration and/or landfill of creosote impregnated wood with allocating assumptions in chapter 3 does not result in an increased emission of PAH. In the allocation model, PAH is considered to be process-specific. This means that no direct relationship between input and output of PAH is assumed. The available information about the actual process of incineration and landfill of wood and MSW is limited and fragmented. Available data leads to an estimate of 0.05% PAH in the MSW because of creosote-impregnated wood. The question arises if it is justified to assume a process-specific relationship at this level of contribution. It is probably more conceivable to assume a product-specific relationship for PAH.

4.2 Calculations with method A

In this paragraph it is assumed that impregnated wood is a part of MSW. This assumption means that total impregnated wood is included already in the average data for composition of the MSW mix. In chapter 4.2.4, the results of this assumption will be further discussed.

Calculations for incineration and landfill are based on the same MSW mix composition [ref. 7]. Although in practice there exists a slight preference for incineration of 'organic' waste and landfilling of 'inorganic' waste, it is not possible to incorporate this difference into the composition.

4.2.1 Input data method A

Composition of MSW:

The available data for the composition of MSW mix are based on Dutch domestic waste [ref. 7]. See Table 4.1.

Composition of woodwaste:

Data of the composition of impregnated wood is based on the data for 'clean' (i.e. not impregnated) wood, as given in Tables 4.1 and 4.2 [ref. 8].

In combination with retention and share figures in Table 2.1, the composition figure of impregnated wood can be calculated (see Tables 4.1 and 4.2).

Table 4.1 gives the composition data for woodwaste which refer to incineration, whilst Table 4.2 presents a classification of the MSW in sub-fractions, as far as these sub-fractions are relevant for the allocation.

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Table 4.1 *Input data for allocating environmental effects of MSW incineration: composition MSW and woodwaste (method A)*

	MSW	Clean wood	Scrap
Heating value of waste	MJ/kg	MJ/kg	MJ/kg
LHV	8.75	16.00	16.09
Elementary composition	wght %	wght %	wght %
H (combustible)	4.00%	5.70%	5.56%
C (combustible)	30.00%	41.26%	41.65%
N	0.30%	0.10%	0.17%
O (combustible)	15.00%	37.00%	35.72%
S	0.40%	0.10%	0.10%
Cl	0.70%	0.04%	0.95%
F	0.01000%	0.00400%	0.00383%
As	0.00065%		0.09970%
Cr	0.01400%		0.13531%
Cu	0.17000%		0.07834%
Other elements & inert	19.41%	0.80%	1.17%
H ₂ O	30.00%	15.00%	14.38%

Table 4.2 *Input data (additional) for allocating environmental effects of MSW landfill: composition MSW mix and woodwaste (method A)*

	MSW	Clean wood	Scrap
Fraction	wght %	wght %	wght %
Organics fraction	50.00%	100.00%	95.86%
Toxic waste fraction			
aromatic solvents	0.0200%		2.0543%
halogenated solvents	0.0100%		1.3695%
other toxic waste	0.9700%		0.7122%
Other waste fractions	49.00%		

4.2.2 MSW incineration method A

The distribution of the pollutants to the various outputs (gas, slag, fly ash, scrubber residue) differs for incineration of wood compared with incineration of MSW. MSW contains a larger inert fraction. Table 4.3 presents data for the distribution to crude gas (only for the product-related emissions). All MSW data in Table 4.3 data is based on material balances. Distribution in the case of MSW is based on literature figures [ref. 2]. The data for impregnated wood is

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based on experimental results of separate incineration experiments [ref. 8] and, in some cases, extrapolation of the MSW figures.

Table 3.2 gives a survey of the input (utilities) and output (residues) for MSW incineration under the standard conditions.

The apportioning of these utilities and residues to the waste wood is given in Table 4.4.

Note: Clean waste wood has been taken into account in Table 4.4 and other tables. This offers the possibility of recalculating the results in the case of retention data different from Table 2.1.

It can be concluded from Table 4.4 that the allocation model leads to a production of scrubber residue per kg of waste for impregnated woodscrap which is 25% smaller than compared with MSW.

Concentrations of product-specific pollutants in the flue gas are allocated to the waste wood. These allocated concentrations differ from the actual situation in the case of incineration of MSW, because the composition of waste wood differs from that of MSW. The same relationship exists after flue gas cleaning, because the cleaning efficiency does not change.

Table 4.5 presents the allocated concentrations in the flue gas.

The allocated emissions per kg waste wood are given in Table 4.6.

Note: The emission of As allocated to woodscrap is 18.3 g As/tonne of waste. This emission is 214 times the emission from MSW (0.0852 g As/tonne of waste). This means that the fraction of impregnated wood (with a content of 65% CCA scrap, Table 2.1) in the total mix of MSW cannot be higher than: $0.0852/18.3 * 100\% = 0.47\%$.

This is in conflict with the total quantity of 219,060 tonnes of impregnated wood in 2,800,000 tonnes of MSW.

Table 4.3 *Incineration of MSW and woodscrap: distribution to crude gas (method A)*

	MSW	Clean wood	Scrap
Element	% to crude gas	% to crude gas	% to crude gas
C *	98.00%	100.00%	100.00%
N *	40.00%	40.00%	40.00%
S *	50.00%	50.00%	50.00%
Cl *	50.00%	50.00%	50.00%
F *	10.00%	50.00%	50.00%
As	50.00%	70.00%	70.00%
Cr	10.00%	20.00%	20.00%
Cu	5.00%	20.00%	20.00%
Inert	6.00%	50.00%	50.00%

Note: Crude gas is defined including fly ash, except for elements/pollutants noted *, where crude gas is excluding ash.

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Table 4.4 *Incineration of MSW and woodscrap: allocation of utilities and co-products (method A)*

		Allocation	Allocation	Allocation
per kg of waste		MSW	clean wood	woodscrap
Input				
NaOH	kg	1.00E-03	1.63E-04	7.44E-04
CaO	kg	1.00E-02	1.63E-03	7.44E-03
Cokes	kg	5.21E-03	8.36E-03	8.37E-03
NH ₃	kg	5.00E-03	1.68E-03	2.81E-03
nat. gas	m ³	1.40E-02	4.71E-03	7.86E-03
electricity-in	kWh	1.00E-01	1.00E-01	1.00E-01
Output				
residue	kg	2.00E-02	3.25E-03	1.49E-02
fly ash	kg	3.00E-02	7.92E-03	1.86E-02
slag	kg	3.00E-01	8.31E-03	1.67E-02
scrap	kg	8.00E-03		5.72E-04
electricity-out	kWh	6.18E-01	1.13E+00	1.13E+00

Table 4.5 *Incineration of MSW and woodscrap: allocation of pollutant concentrations in flue gas (method A)*

		MSW	Clean wood	Woodscrap	Cleaning efficiency
Flue gas volume p.kg waste:					
m ³ flue gas (dry)		6.80	10.91	10.92	
m ³ of flue gas (wet)		7.78	11.96	11.95	
Allocated concentration in clean flue gas unit					
Waste specific					
CO ₂	g/m ³	1.61E+05	1.41E+05	1.42E+05	0.0%
NO _x	mg/m ³	7.00E+01	1.47E+01	2.45E+01	85.4%
SO ₂	mg/m ³	4.00E+01	6.26E+00	5.97E+00	93.2%
Cl	mg/m ³	1.00E+01	3.58E-01	8.42E+00	98.1%
F	mg/m ³	1.00E+00	2.51E-01	2.39E-01	32.0%
As	mg/m ³	1.25E-02		1.68E+00	97.4%
Cr	mg/m ³	5.40E-02		6.50E-01	97.4%
Cu	mg/m ³	3.28E-01		3.76E-01	97.4%
Process-specific					
Dust/particles	mg/m ³	5.00E+00	5.00E+00	5.00E+00	99.9%
CH	mg/m ³	1.00E+01	1.00E+01	1.00E+01	90.0%
CO	mg/m ³	5.00E+01	5.00E+01	5.00E+01	50.0%
PAH	mg/m ³	8.00E-05	8.00E-05	8.00E-05	95.0%
TEQ *	ng/m ³	1.00E-01	1.00E-01	1.00E-01	99.9%

Note: *] = TEQ concentration in ng toxic waste equivalents per nm³

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Table 4.6 shows allocated figures for emissions by flue gas per tonne of waste. Table 4.7 presents the emissions (and other input and output figures) for the incineration of a total of 219,060 tonnes of impregnated wood as part of the total mix of MSW. Figures are also presented for the incineration of a total of 2,800,000 tonnes of MSW mix and for 210,000 tonnes of 'clean' wood waste as part of the total mix of MSW. This way of presentation offers the possibility of calculating the data for different retention figures as described in chapter 2.

Table 4.6 Incineration of MSW and woodscrap: allocation of emissions to air (method A)

Allocation per tonne of waste unit		MSW average	Wood clean	Wood scrap
Utility input				
NaOH 50%	kg	1.00E+00	1.63E-01	7.44E-01
CaO	kg	1.00E+01	1.63E+00	7.44E+00
cokes	kg	5.00E+00	8.02E+00	8.03E+00
ammonia	kg	5.00E+00	1.68E+00	2.81E+00
gas	m ³	1.40E+01	4.71E+00	7.86E+00
Co-products output				
electricity	MJ	1.87E+03	3.70E+03	3.72E+03
metal scrap	kg	8.00E+00		5.72E-01
Emissions airborne				
CO ₂	kg	1.09E+03	1.54E+03	1.55E+03
NO _x	kg	4.76E-01	1.60E-01	2.67E-01
SO ₂	kg	2.72E-01	6.79E-02	6.51E-02
HCl	kg	6.79E-02	3.88E-03	9.18E-02
HF	kg	6.79E-03	2.72E-03	2.61E-03
As	kg	8.52E-05		1.83E-02
Cr	kg	3.67E-04		7.10E-03
Cu	kg	2.23E-03		4.11E-03
aerosols	kg	3.40E-02	5.45E-02	5.46E-02
hydrocarb.inc msw	kg	6.79E-02	1.09E-01	1.09E-01
CO	kg	3.40E-01	5.45E-01	5.46E-01
PAH	kg	5.43E-07	8.72E-07	8.73E-07
TEQ *	twe	6.79E-10	1.09E-09	1.09E-09
Waste materials				
Rgrr AVI (TW)	kg	2.00E+01	3.25E+00	1.49E+01
Fly ash AVI (TW)	kg	3.00E+01	7.92E+00	1.86E+01
Slag AVI	kg	3.00E+02	8.31E+00	1.67E+01

Note: *] = in ng toxic waste equivalents per kg of waste

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Table 4.7 Total environmental effects of incineration of 300,000 m³ of preserved wood or unpreserved (clean) wood as part of 2,800,000 tonnes of MSW (method A)

		MSW average	Wood clean	Wood scrap
Total waste (tonne)		2.80E+06	2.10E+05	219060
Utility input				
NaOH 50%	kg	2.80E+06	3.42E+04	1.63E+05
CaO	kg	2.80E+07	3.42E+05	1.63E+06
cokes	kg	1.40E+07	1.69E+06	1.76E+06
ammonia	kg	1.40E+07	3.53E+05	6.15E+05
gas	m ³	3.92E+07	9.89E+05	1.72E+06
Co-products output				
electricity	MJ	5.22E+09	7.77E+08	8.16E+08
metal scrap	kg	2.24E+07		1.25E+05
Emissions airborne				
CO ₂	kg	3.06E+09	3.23E+08	3.40E+08
NO _x	kg	1.33E+06	3.36E+04	5.85E+04
SO ₂	kg	7.61E+05	1.43E+04	1.43E+04
HCl	kg	1.90E+05	8.15E+02	2.01E+04
HF	kg	1.90E+04	5.71E+02	5.71E+02
As	kg	2.39E+02		4.01E+03
Cr	kg	1.03E+03		1.55E+03
Cu	kg	6.24E+03		9.00E+02
aerosols	kg	9.51E+04	1.14E+04	1.20E+04
hydrocarb.inc msw	kg	1.90E+05	2.29E+04	2.39E+04
CO	kg	9.51E+05	1.14E+05	1.20E+05
PAH	kg	1.52E+00	1.83E-01	1.91E-01
TEQ	twe	1.90E-03	2.29E-04	2.39E-04
Waste materials				
Rgrr AVI (TW)	kg	5.60E+07	6.83E+05	3.26E+06
Fly ash AVI (TW)	kg	8.40E+07	1.66E+06	4.08E+06
Slag AVI	kg	8.40E+08	1.74E+06	3.65E+06

4.2.3 MSW landfill method A

Allocated parameters are emissions from landfill gas and leachate. The MSW mix contains many materials, apart from wood. Depending on the local micro climate, leaching will start. The susceptibility for leaching differs for the various materials. Heavy metals in glass are well-immobilised; however, they contribute to the average composition of MSW.

Table 4.8 presents differences in leaching characteristics of waste specific pollutants. For each pollutant, the available fraction for leaching is given.

It is assumed that all pollutants in impregnated wood are available for leaching.

More input parameters for allocation are listed in Tables 4.9 and 4.10. Table 4.9 gives for MSW the pollutant concentrations in landfill gas. Table 4.10 shows the pollutant concentrations in leachate.

Chapter 3, Tables 4.1 and 4.2, gives, for typical Dutch MSW composition, a survey of all input (utilities) and output for the model landfill, according to the Dutch standards and the required effluent quality.

The results of the allocation of these inputs and outputs to the waste wood is given in Table 4.11. Also in this case, the figures for clean wood and for MSW (mix) are added. It appears from Table 4.11 that the allocation of leachate treatment to woodscrap results in a quantity of residue which is almost 0.63 times more than is the case with MSW.

The concentrations in the leachate of all product-specific pollutants are also allocated to the impregnated waste wood. These allocated concentrations differ from the actual leachate concentrations for MSW (mix), because the compositions of MSW mix and impregnated wood are different. The same ratio applies to the differences in the allocated concentrations after leachate treatment. The cleaning efficiency of the leachate treatment does not change.

The allocation model is based upon an amount of 0.2 m³ of leachate per tonne of waste with a leakage of 2% to the soil. Tables 4.12 and 4.13 present the allocated emissions to water and soil. Table 4.14 shows the same for the emissions to air (emissions from landfill gas and input of utilities, like fuel combustion, to evaporate the water in the residues).

It appears that for impregnated woodscrap, the As emission is here too a limiting factor. For woodscrap, the emission of As to surface water is 1.5 g/tonne of waste. This allocated figure is 154 times the emission of As from MSW (9.8 mg/tonne waste). This means that MSW cannot contain more than $0.0098/1.5 * 100\% = 0.65$ w % woodscrap.

Table 4.15 shows the emissions and input and output for landfilling 300,000 m³ of impregnated wood together with MSW, as well as figures for 300,000 m³ of clean wood and a total of 11,500,000 tonnes of MSW.

Table 4.8 Landfill of MSW and woodscrap: susceptibility of pollutants for leaching (method A)

Element	MSW	Clean wood	Scrap
S	100.00%	100.00%	100.00%
Cl	100.00%	100.00%	100.00%
As	100.00%		100.00%
Cr	50.00%		100.00%
Cu	100.00%		100.00%

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Table 4.9 Landfill of MSW and woodscrap: composition of landfill gas (method A)

Pollutant	g/m ³	ppm
CO ₂	825.000	450000
CO	16.333	14000
H ₂	1.000	12000
NH ₃	0.035	50
H ₂ S	0.099	70
aromatic hydrocarbons	0.103	26
halogenated hydrocarbons	0.091	20
methane and other hydrocarbons	347.154	520230
H ₂ O	2.703	3604
Total	1192.518	1000000

Table 4.10 Landfill of MSW and woodscrap: composition of leachate and limits for surface water (method A)

Composition of leachate and limits for surface water			
Component	Concentration in mg per m ³		Reduction required %
	Leachate average	Surface water limit	
SO ₄	350000	250000	28.6%
Cl	2000000	200000	90.0%
As	50	50	0.0%
Cr	190	50	73.7%
Cu	69	50	27.5%
PAH	10	1	90.0%
BTEX	300	300	0.0%
EOX	3	3	0.0%
BOD	7272000	10000	99.9%
COD	11800000	30000	99.7%
phenol	1500	100	93.3%
CN	100	50	50.0%
NH ₄ -N	500000	10000	98.0%
N-total	920000	10000	98.9%

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Table 4.11 Landfill of MSW and woodscrap: allocation of utilities and co-products (method A)

		Average	Allocation	Allocation
per kg of waste		MSW	clean wood	woodscrap
Input				
diesel	MJ	4.25E-02	4.25E-02	4.25E-02
electricity	MJ	4.14E-03	1.32E-03	3.36E-03
fuel oil	MJ	6.93E-02	3.14E-03	4.36E-02
Output				
residue leach.cleaning	kg	2.20E-03	9.98E-05	1.38E-03
sludge leach.cleaning	kg	1.20E-03	2.40E-03	2.30E-03
definite waste	kg	7.48E-01	5.00E-01	5.19E-01

Table 4.12 Landfill of MSW and woodscrap: allocation of emissions to surface water (method A)

Emissions to surface water per kg of waste landfilled (meet the limits for emissions to vulnerable surface waters)			
	MSW	Clean wood	Woodscrap
m ³ of leachate/kg of waste to water	1.96E-04	1.96E-04	1.96E-04
Emissions in mg/kg of waste to surface water after cleaning			
SO ₄	49.0	12.3	11.7
Cl	39.2	2.2	53.0
As	0.00980		1.50323
Cr	0.00980		0.18944
Cu	0.00980		0.00452
PAH	0.00020	0.00020	0.00020
BTEX	0.059		6.039
EOX	0.00059		0.08053
BOD	2.0	3.9	3.8
COD	5.9	11.8	11.3
phenol	0.020	0.020	0.020
CN	0.010	0.010	0.010
NH ₄ -N	2.0	3.9	3.8
N-total	2.0	3.9	3.8

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Table 4.13 Landfill of MSW and woodscrap: allocation of emissions to soil

Emissions to soil per kg of waste landfilled (leachate leak = 2%)			
	MSW	Clean wood	Woodscrap
m ³ of leachate/kg of waste to soil	4.00E-06	4.00E-06	4.00E-06
Emissions in mg/kg of waste to soil by leachate leaking			
SO ₄	1.4	0.4	0.3
Cl	8.0	0.5	10.8
As	0.00020		0.03068
Cr	0.00076		0.01469
Cu	0.00028		0.00013
PAH	0.00004	0.00004	0.00004
BTEX	0.00120		0.12325
EOX	0.00001		0.00164
BOD	29.1	58.2	55.8
COD	47.2	94.4	90.5
phenol	0.00600	0.00600	0.00600
CN	0.00040	0.00040	0.00040
NH ₄ -N	2.0	4.0	3.8
N-total	3.7	7.4	7.1

Table 4.14 Landfill of MSW and woodscrap: allocation of emissions to air (method A)

	MSW	Clean wood	Woodscrap
m ³ of landfillgas/kg of waste	0.1800	0.3599	0.3485
Emissions in g/kg of waste by landfill gas:			
CO ₂	148.5	297.0	284.7
CO	2.940	5.880	5.637
H ₂	0.180	0.360	0.345
NH ₃	0.006	0.013	0.012
H ₂ S	0.018	0.036	0.034
aromatic hydrocarbons	0.018		1.897
halogenated hydrocarbons	0.016		2.237
methane and other hydrocarbons	62.5	125.0	119.8
by utilities:			
CO ₂	8.508	3.348	6.504
CO	0.020	0.020	0.020
NO _x	0.065	0.052	0.060
SO ₂	0.050	0.006	0.033
aerosols	0.0056	0.0043	0.0051
incineration of hydrocarbons	0.0105	0.0100	0.0103
incineration of heavy metals	0.00008	0.00001	0.00005

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Table 4.15 Total environmental effects of landfill of 300,000 m³ of preserved or unpreserved wood and 11,500,000 tonnes of MSW (method A)

	unit	MSW mix	Wood clean	Wood scrap
Total waste	tonne	1.17E+07	2.10E+05	219060
Utility input				
diesel	kg	1.19E+07	2.13E+05	2.22E+05
electricity	MJ	4.86E+07	2.78E+05	7.35E+05
fuel oil	kg	1.98E+07	1.61E+04	2.33E+05
Emissions airborne				
CO ₂	kg	1.84E+09	6.31E+07	6.38E+07
CO	kg	3.47E+07	1.24E+06	1.24E+06
H ₂	kg	2.11E+06	7.56E+04	7.56E+04
NH ₃	kg	7.47E+04	2.68E+03	2.68E+03
H ₂ S	kg	2.09E+05	7.48E+03	7.48E+03
methane and other hydrocarbons	kg	7.32E+08	2.62E+07	2.62E+07
aromatic hydrocarbons	kg	2.16E+05		4.15E+05
halogenated hydrocarbons	kg	1.91E+05		4.90E+05
NO _x	kg	7.60E+05	1.08E+04	1.31E+04
SO ₂	kg	5.86E+05	1.33E+03	7.24E+03
aerosols	kg	6.60E+04	9.06E+02	1.12E+03
hydrocarbons incineration	kg	1.24E+05	2.10E+03	2.26E+03
heavy metals incineration	kg	9.12E+02	2.45E+00	1.14E+01
Emissions to soil				
SO ₄	kg	1.64E+04	7.35E+01	7.35E+01
Cl	kg	9.38E+04	9.60E+01	2.37E+03
As	kg	2.34E+00		6.72E+00
Cr	kg	8.91E+00		3.22E+00
Cu	kg	3.23E+00		2.79E-02
PAH	kg	4.69E-01	8.40E-03	8.76E-03
aromatic hydrocarbons	kg	1.41E+01		2.70E+01
halogenated hydrocarbons	kg	1.41E-01		3.60E-01
BOD	kg	3.41E+05	1.22E+04	1.22E+04
COD	kg	5.53E+05	1.98E+04	1.98E+04
phenol	kg	7.03E+01	1.26E+00	1.31E+00
CN	kg	4.69E+00	8.40E-02	8.76E-02
NH ₄	kg	2.34E+04	8.40E+02	8.40E+02
N-total	kg	4.31E+04	1.55E+03	1.55E+03
Emissions waterborne				
SO ₄	kg	5.74E+05	2.57E+03	2.57E+03
Cl	kg	4.59E+05	4.70E+02	1.16E+04
As	kg	1.15E+02		3.29E+02
Cr	kg	1.15E+02		4.15E+01
Cu	kg	1.15E+02		9.89E-01
PAH	kg	2.30E+00	4.12E-02	4.29E-02
aromatic hydrocarbons	kg	6.89E+02		1.32E+03
halogenated hydrocarbons	kg	6.89E+00		1.76E+01
BOD	kg	2.30E+04	8.23E+02	8.23E+02
COD	kg	6.89E+04	2.47E+03	2.47E+03
phenol	kg	2.30E+02	4.12E+00	4.29E+00
CN	kg	1.15E+02	2.06E+00	2.15E+00
NH ₄	kg	2.30E+04	8.23E+02	8.23E+02
N-total	kg	2.30E+04	8.23E+02	8.23E+02
Solid waste				
residue cleaning leachate (TW)	kg	2.58E+07	2.10E+04	3.03E+05
sludge cleaning leachate	kg	1.41E+07	5.04E+05	5.04E+05
final residue	kg	8.76E+09	1.05E+08	1.14E+08

4.2.4 Discussion method A

The total environmental impacts of incineration and landfill of combined disposal of MSW and impregnated wood, which can be allocated to the impregnated wood are shown in Table 4.7 and Table 4.15.

This report mainly focuses on the allocation method. This allocation method has been presented on the basis of data which reflects the Dutch situation, together with the data from the previous reported inventory in this project.

One of the important basic assumptions in the calculation of chapter 4.2 (method A) is that the impregnated wood is part of the mix of municipal solid waste. This means that literature data about composition of MSW are **interpreted inclusive** of the wood.

In reality, this assumption may not be correct, as described already in chapter 4.1.

Moreover, the results presented in Table 4.7 and 4.15 about the environmental impact of incineration or landfill must be considered 'maximum values'.

Firstly, because in practice both disposal methods are applied and, secondly, because not all the impregnated wood is present in the MSW.

The actual distribution of the applied disposal methods for impregnated wood is not known. The presented results, however, allow for conclusions for any chosen distribution of the disposal method.

The assumption that impregnated wood is already part of MSW gives a discrepancy between the input data of impregnated wood and the calculated results. The data about the quantities of wood and the retention of the impregnating means does not correspond very well with the calculated results.

For example: the calculated As emission to soil and water in the case of landfilling 219,060 tonnes of impregnated waste wood, is considerably larger than As emissions to soil and water in the case of landfilling a total of 11,500,000 tonnes of MSW mix (see Table 4.15). This is not realistic, more so as it is not realistic to ignore other sources of As in the MSW. It is evident that the As emissions of impregnated wood in MSW should be even lower than the total As emission from MSW!

Therefore, one could argue that the results in Tables 4.7 and 4.15 are not consistent. But it is also conceivable that the input data for composition of MSW and wood are responsible for this discrepancy. For the mentioned case of As, the following reasons could be considered:

- retention of CCA scrap is smaller than indicated in Table 2.1
- the market share of CCA scrap is smaller than indicated in Table 2.1
- not all wood waste is disposed of, together with MSW
- the data used in this calculation are not representative of this waste mix (data relates to household waste.).

Other pollutants may also lead to discrepancies. For example, in the case of landfill the contribution of impregnated wood to the emission of EOX (solv. scrap) and BTEX (creos. scrap) is remarkable.

The conclusion is that the basic assumption that waste wood is already completely part of the MSW mix (starting point for method A) is not correct.

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4.3 Calculations method B

In the following scenario B, it is assumed that the impregnated waste wood should still be added to the MSW. Thus, in this calculation, the data regarding the composition of MSW (originating from literature, etc.) are interpreted as relating to the composition of MSW without the impregnated waste wood.

4.3.1 Input data method B

On the basis of the allocation principles, a new set of data has to be defined for the composition of MSW and distribution, susceptibility for leaching and input of utilities. The result of this calculation with respect to composition, etc. of the resulting MSW mix, however, differs for landfill and incineration.

For calculations regarding MSW incineration, 2,800,000 tonnes of MSW are assumed here, to which 219,060 tonnes of impregnated waste wood should be added. The resulting 3,019,060 tonnes of MSW mix will be indicated below as MSW @.

In the calculations regarding the incineration, however, 11,500,000 tonnes of MSW are assumed, to which 219,060 tonnes of impregnated waste wood should be added. The resulting 3,019,060 tonnes of MSW mix will be indicated below as MSW @@.

Therefore, the basics regarding the allocation of emissions, utilities, etc. are identical to those in Chapter 4.2. The elaboration and the results of the calculations, respectively, are summarised in section 4.3.2 (incineration of impregnated wood with MSW @) and section 4.3.3 (landfill of impregnated wood with MSW @@).

4.3.2 MSW incineration method B

Compared with the presentation of the starting points in Chapter 4.2, the starting points have in this elaboration been summarised in Table 4.16 (composition waste) and Table 4.17 (distribution pollutants to crude flue gas).

The results of the allocation are summarised in Table 4.18 up to and including Table 4.21.

Note: The input of utilities, etc. (Table 4.18) as well as the cleaning efficiency of the flue gases (Table 4.19) differ from the data mentioned in Chapter 4.2, at least concerning those items with product-specific allocation. This has its origins, on the one hand, in the changed composition of MSW @ (compared with MSW in Chapter 4.2); on the other hand, the threshold value that the flue gases must meet, is fixed (see Table 3.1).

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Table 4.16 Input data for allocating environmental effects of MSW @ incineration: composition of MSW @ and woodwaste (method B)

	MSW @	Clean wood	Scrap
Heating value of waste	MJ/kg	MJ/kg	MJ/kg
LHV	9.28	16.00	16.09
Elementary composition	wght %	wght %	wght %
H (combustible)	4.11%	5.70%	5.56%
C (combustible)	30.85%	41.26%	41.65%
N	0.29%	0.10%	0.17%
O (combustible)	16.50%	37.00%	35.72%
S	0.38%	0.10%	0.10%
Cl	0.72%	0.04%	0.95%
F	0.00955%	0.00400%	0.00383%
As	0.00784%		0.09970%
Cr	0.02280%		0.13531%
Cu	0.16335%		0.07834%
other elements & inert	18.08%	0.80%	1.17%
H ₂ O	28.87%	15.00%	14.38%

Table 4.17 Incineration of MSW @ and woodscrap: distribution to crude gas (method B)

	MSW @	Clean wood	Scrap
Element	% to crude gas	% to crude gas	% to crude gas
C *	98.20%	100.00%	100.00%
N *	40.00%	40.00%	40.00%
S *	50.00%	50.00%	50.00%
Cl *	50.00%	50.00%	50.00%
F *	10.00%	10.00%	10.00%
As	68.46%	70.00%	70.00%
Cr	14.31%	20.00%	20.00%
Cu	5.52%	20.00%	20.00%
Inert	6.31%	50.00%	50.00%

Note: Crude gas including fly ash, except for elements/pollutants noted *, which is crude gas excluding ash

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Table 4.18 Incineration of MSW @ and woodscrap: allocation of utilities and co-products (method B)

		Allocation	Allocation	Allocation
per kg of waste		MSW @	clean wood	woodscrap
Input				
NaOH	kg	9.77E-04	1.62E-04	7.42E-04
CaO	kg	9.77E-03	1.62E-03	7.42E-03
cokes	kg	5.20E-03	8.01E-03	8.02E-03
NH ₃	kg	4.78E-03	1.66E-03	2.77E-03
nat. gas	m ³	1.34E-02	4.65E-03	7.76E-03
electricity-in	kWh	1.00E-01	1.00E-01	1.00E-01
Output				
residue	kg	1.95E-02	3.23E-03	1.48E-02
fly ash	kg	2.92E-02	7.92E-03	1.86E-02
slag	kg	2.79E-01	8.31E-03	1.67E-02
scrap	kg	7.46E-03	0.00E+00	5.72E-04
electricity-out	kWh	6.55E-01	1.13E+00	1.13E+00

Table 4.19 Incineration of MSW @ and woodscrap: allocation of pollutant concentrations in flue gas (method B)

		MSW @	Clean wood	Woodscrap	Cleaning efficiency
Flue gas volume p.kg of waste:					
m ³ of flue gas (dry)		7.08	10.89	10.90	
m ³ of flue gas (wet)		8.07	11.94	11.93	
Allocated concentration in clean flue gas unit					
Waste specific					
CO ₂	g/m ³	1.59E+05	1.41E+05	1.43E+05	0.0%
NO _x	mg/m ³	7.00E+01	1.58E+01	2.64E+01	84.3%
SO ₂	mg/m ³	4.00E+01	6.89E+00	6.59E+00	92.5%
Cl	mg/m ³	1.00E+01	3.62E-01	8.57E+00	98.0%
F	mg/m ³	1.00E+00	2.72E-01	2.61E-01	25.9%
As	mg/m ³	1.67E-01	1.41E+00		97.8%
Cr	mg/m ³	1.01E-01	5.46E-01		97.8%
Cu	mg/m ³	2.80E-01	3.16E-01		97.8%
Process-specific					
Dust/particles	mg/m ³	5.00E+00	5.00E+00	5.00E+00	99.9%
CH	mg/m ³	1.00E+01	1.00E+01	1.00E+01	90.0%
CO	mg/m ³	5.00E+01	5.00E+01	5.00E+01	50.0%
PAH	mg/m ³	8.00E-05	8.00E-05	8.00E-05	95.0%
TEQ	ng/m ³	1.00E-01	1.00E-01	1.00E-01	99.9%

Note *) = TEQ concentration in ng toxic waste equivalents per nm³

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Table 4.20 Incineration of MSW @ and woodscrap: allocation of emissions to air (method B)

Allocation per tonne of waste unit		MSW @ mix	Wood clean	Wood scrap
Utility input				
NaOH 50%	kg	9.77E-01	1.63E-01	7.42E-01
CaO	kg	9.77E+00	1.63E+00	7.42E+00
cokes	kg	5.20E+00	8.02E+00	8.00E+00
ammonia	kg	4.78E+00	1.68E+00	2.77E+00
gas	m ³	1.34E+01	4.71E+00	7.76E+00
Co-products output				
electricity	MJ	2.00E+03	3.70E+03	3.72E+03
metal scrap	kg	7.46E+00		5.72E-01
Emissions airborne				
CO ₂	kg	1.13E+03	1.54E+03	1.55E+03
NO _x	kg	4.96E-01	1.60E-01	2.87E-01
SO ₂	kg	2.83E-01	6.79E-02	7.19E-02
HCl	kg	7.08E-02	3.88E-03	9.34E-02
HF	kg	7.08E-03	2.72E-03	2.84E-03
As	kg	1.18E-03		1.54E-02
Cr	kg	7.18E-04		5.95E-03
Cu	kg	1.98E-03		3.45E-03
aerosols	kg	3.54E-02	5.45E-02	5.45E-02
hydrocarb.inc msw	kg	7.08E-02	1.09E-01	1.09E-01
CO	kg	3.54E-01	5.45E-01	5.45E-01
PAH	kg	5.67E-07	8.72E-07	8.72E-07
TEQ	tw	7.00E-10	1.10E-09	1.10E-09
Waste materials				
Rgrr AVI (TW)	kg	1.95E+01	3.25E+00	1.48E+01
Fly ash AVI (TW)	kg	2.92E+01	7.92E+00	1.86E+01
Slag AVI	kg	2.79E+02	8.31E+00	1.67E+01

Note: *] = in ng toxic waste equivalents per kg of waste

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Table 4.21 Total environmental effects of incineration of 3,019,060 tonnes of MSW @ and 300,000 m³ of preserved wood or unpreserved (clean) wood, as part of MSW @ (method B)

		MSW @ mix	Wood clean	Wood scrap
Total waste (tonne)		3.02E+06	2.10E+05	219060
Allocation total				
Utility input				
NaOH 50%	kg	2.95E+06	3.42E+04	1.63E+05
CaO	kg	2.95E+07	3.42E+05	1.63E+06
cokes	kg	1.57E+07	1.69E+06	1.75E+06
ammonia	kg	1.44E+07	3.53E+05	6.07E+05
gas	m ³	4.04E+07	9.89E+05	1.70E+06
Co-products output				
electricity	MJ	6.04E+09	7.77E+08	8.16E+08
metal scrap	kg	2.25E+07		1.25E+05
Emissions airborne				
CO ₂	kg	3.40E+09	3.23E+08	3.40E+08
NO _x	kg	1.50E+06	3.36E+04	6.30E+04
SO ₂	kg	8.55E+05	1.43E+04	1.57E+04
HCl	kg	2.14E+05	8.15E+02	2.05E+04
HF	kg	2.14E+04	5.71E+02	6.23E+02
As	kg	3.56E+03		3.36E+03
Cr	kg	2.17E+03		1.30E+03
Cu	kg	5.99E+03		7.55E+02
aerosols	kg	1.07E+05	1.14E+04	1.19E+04
hydrocarb.inc msw	kg	2.14E+05	2.29E+04	2.39E+04
CO	kg	1.07E+06	1.14E+05	1.19E+05
PAH	kg	1.71E+00	1.83E-01	1.91E-01
TEQ	twe	2.11E-03	2.31E-04	2.41E-04
Waste materials				
Rgrr AVI (TW)	kg	5.90E+07	6.83E+05	3.25E+06
Fly ash AVI (TW)	kg	8.81E+07	1.66E+06	4.08E+06
Slag AVI	kg	8.44E+08	1.74E+06	3.65E+06

4.3.3 MSW landfill method B

Comparable with the overview of all starting points in Chapter 4.2, the starting points for landfill are in this elaboration summarised in Tables 4.22 and 4.23 (composition of waste), as well as Table 4.24 (availability of respective pollutants for leaching). Table 4.25 gives the data concerning the composition of the landfill gas, while Table 4.26 gives the data concerning the composition of the percolate.

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The results of the allocation are summarised in Table 4.27 up to and including Table 4.31.

Note: The input of utilities etc. (Table 4.27) as well as the composition of the landfill gas (Table 4.15) and also the cleaning efficiency of the percolate (Table 4.26) differ from the data used in Chapter 4.2, at least with respect to those items with product-specific allocation. This can be traced back, on the one hand, to the changed composition of MSW @@ (compared with MSW in Chapter 4.2); on the other hand, also in this scenario the concentration threshold limit which the discharged (cleaned) percolate should meet (see Table 3.4), is fixed.

Table 4.22 *Input data for allocating environmental effects of MSW @@ landfill: composition MSW @@ and woodwaste (method B)*

	MSW @@	Clean wood	Scrap
Elementary composition	wght %	wght %	wght %
H (combustible)	4.03%	5.70%	5.56%
C (combustible)	30.22%	41.26%	41.65%
N	0.30%	0.10%	0.17%
O (combustible)	15.39%	37.00%	35.72%
S	0.39%	0.10%	0.10%
Cl	0.70%	0.04%	0.95%
F	0.00988%	0.00400%	0.00383%
As	0.00250%	0.00000%	0.09970%
Cr	0.01627%	0.00000%	0.13531%
Cu	0.16829%	0.00000%	0.07834%
other materials (inert)	19.06%	0.80%	1.17%
H ₂ O	29.71%	15.00%	14.38%

Table 4.23 *Input data (additional) for allocating environmental effects of MSW @@ landfill: composition of MSW @@ (mix) and woodwaste (method B)*

	MSW @@	Clean wood	Scrap
Element	wght %	wght %	wght %
Organics fraction	50.86%	100.00%	95.86%
Toxic waste fraction			
aromatic solvents	0.0580%		2.0543%
halogenated solvents	0.0354%		1.3695%
other toxic waste	0.9652%		0.7122%
Other waste fractions	48.08%		

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Table 4.24 Landfill of MSW @@ and woodscrap: susceptibility pollutants for leaching (method B)

Element	MSW @@	Clean wood	Scrap
S	100.00%	100.00%	100.00%
Cl	100.00%	100.00%	100.00%
As	100.00%		100.00%
Cr	57.77%		100.00%
Cu	100.00%		100.00%

Table 4.25 Landfill of MSW @@ and woodscrap: composition of landfill gas (method B)

Component	g/m ³	ppm
CO ₂	824.969	449983
CO	16.333	13999
H ₂	1.000	12000
NH ₃	0.035	50
H ₂ S	0.099	70
aromatic hydrocarbons	0.293	74
halogenated hydrocarbons	0.316	70
methane and other hydrocarbons	347.141	520211
H ₂ O	2.657	3543
Total	1192.844	1000000

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Table 4.26 Landfill of MSW @@ and woodscrap: composition of leachate and limits for surface water (method B)

Composition leachate and limits for surface water			
Component	Composition in mg per m ³		Reduction required %
	Leachate average	Surface water limit	
SO ₄	356001	250000	29.8%
Cl	2013155	200000	90.1%
As	192	50	74.0%
Cr	255	50	80.4%
Cu	68	50	26.8%
PAH	10	1	90.0%
BTEX	870	300	65.5%
EOX	11	3	71.8%
BOD	7396689	10000	99.9%
COD	12002328	30000	99.8%
phenol	1500	100	93.3%
CN	100	50	50.0%
NH ₄ -N	508573	10000	98.0%
N-total	935775	10000	98.9%

Table 4.27 Landfill of MSW @@ and woodscrap: allocation of utilities and co-products (method B)

		Allocation	Allocation	Allocation
per kg of waste		MSW @@	clean wood	woodscrap
Input				
diesel	MJ	4.25E-02	4.25E-02	4.25E-02
electricity	MJ	4.14E-03	1.33E-03	3.36E-03
fuel oil	MJ	6.90E-02	3.19E-03	4.36E-02
Output				
residue leach.cleaning	kg	2.19E-03	1.01E-04	1.39E-03
sludge leach.cleaning	kg	1.22E-03	2.40E-03	2.30E-03
definite waste	kg	7.44E-01	5.00E-01	5.19E-01

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Table 4.28 Landfill of MSW @@ and woodscrap: allocation of emissions to surface water (method B)

Emissions to water per kg of waste landfilled (leachate leak = 2%) (meet the limits for emissions to vulnerable surface waters)			
	MSW @@	Clean wood	Woodscrap
m ³ of leachate/kg of waste to water	1.96E-04	1.96E-04	1.96E-04
Emissions in mg/kg of waste to surface water after cleaning			
SO ₄	49.0	12.4	11.9
Cl	39.2	2.2	52.6
As	0.00980		0.39059
Cr	0.00980		0.14109
Cu	0.00980		0.00456
PAH	0.00020	0.00020	0.00020
BTEX	0.059		2.082
EOX	0.00059		0.02274
BOD	2.0	3.9	3.7
COD	5.9	11.6	11.1
phenol	0.020	0.020	0.020
CN	0.010	0.010	0.010
NH ₄ -N	2.0	3.9	3.7
N-total	2.0	3.9	3.7

Table 4.29 Landfill of MSW @@ and woodscrap: allocation of emissions to soil (method B)

Emissions to soil per kg of waste landfilled (leachate leak = 2%)			
	MSW @@	Clean wood	Woodscrap
m ³ of leachate/kg of waste to soil	4.00E-06	4.00E-06	4.00E-06
Emissions in mg/kg of waste to soil by leachate leak			
SO ₄	1.4	0.4	0.3
Cl	8.1	0.5	10.8
As	0.00077		0.03068
Cr	0.00102		0.01469
Cu	0.00027		0.00013
PAH	0.00004	0.00004	0.00004
BTEX	0.00348		0.12326
EOX	0.00004		0.00164
BOD	29.6	58.2	55.8
COD	48.0	94.4	90.5
phenol	0.00600	0.00600	0.00600
CN	0.00040	0.00040	0.00040
NH ₄ -N	2.0	4.0	3.8
N-total	3.7	7.4	7.1

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Table 4.30 Landfill of MSW @@ and woodscrap: allocation of emissions to air (method B)

	MSW @@	Clean wood	Woodscrap
m ³ of landfill gas/kg of waste	0.1831	0.3598	0.3484
Emissions in g/kg of waste			
by landfill gas:			
CO ₂	151.0	297.0	284.7
CO	2.990	5.880	5.637
H ₂	0.183	0.360	0.345
NH ₃	0.006	0.013	0.012
H ₂ S	0.018	0.036	0.034
aromatic hydrocarbons	0.054		1.897
halogenated hydrocarbons	0.058		2.237
methane and other hydrocarbons	63.6	125.0	119.8
by utilities:			
CO ₂	8.484	3.351	6.507
CO	0.020	0.020	0.020
NO _x	0.065	0.052	0.060
SO ₂	0.050	0.006	0.033
aerosols	0.0056	0.0043	0.0051
hydrocarbons incineration	0.0105	0.0100	0.0103
heavy metals incineration	0.00008	0.00001	0.00005

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Table 4.31 Total environmental effects of landfill of 300,000 m³ of preserved or unpreserved wood and 11,719,060 tonnes of MSW @@ (method B)

	unit	MSW @@ mix	Wood clean	Wood scrap
Total waste	tonne	1.17E+07	2.10E+05	219060
Utility input				
diesel	kg	1.19E+07	2.13E+05	2.22E+05
electricity	MJ	4.86E+07	2.78E+05	7.35E+05
fuel oil	kg	1.98E+07	1.61E+04	2.33E+05
Emissions airborne				
CO ₂	kg	1.84E+09	6.31E+07	6.38E+07
CO	kg	3.47E+07	1.24E+06	1.24E+06
H ₂	kg	2.11E+06	7.56E+04	7.56E+04
NH ₃	kg	7.47E+04	2.68E+03	2.68E+03
H ₂ S	kg	2.09E+05	7.48E+03	7.48E+03
methane and other hydrocarbons	kg	7.32E+08	2.62E+07	2.62E+07
aromatic hydrocarbons	kg	2.16E+05		4.15E+05
halogenated hydrocarbons	kg	1.91E+05		4.90E+05
NO _x	kg	7.60E+05	1.08E+04	1.31E+04
SO ₂	kg	5.86E+05	1.33E+03	7.24E+03
aerosols	kg	6.60E+04	9.06E+02	1.12E+03
hydrocarbons incineration	kg	1.24E+05	2.10E+03	2.26E+03
heavy metals incineration	kg	9.12E+02	2.45E+00	1.14E+01
Emissions to soil				
SO ₄	kg	1.64E+04	7.35E+01	7.35E+01
Cl	kg	9.38E+04	9.60E+01	2.37E+03
As	kg	2.34E+00		6.72E+00
Cr	kg	8.91E+00		3.22E+00
Cu	kg	3.23E+00		2.79E-02
PAH	kg	4.69E-01	8.40E-03	8.76E-03
aromatic hydrocarbons	kg	1.41E+01		2.70E+01
halogenated hydrocarbons	kg	1.41E-01		3.60E-01
BOD	kg	3.41E+05	1.22E+04	1.22E+04
COD	kg	5.53E+05	1.98E+04	1.98E+04
phenol	kg	7.03E+01	1.26E+00	1.31E+00
CN	kg	4.69E+00	8.40E-02	8.76E-02
NH ₄	kg	2.34E+04	8.40E+02	8.40E+02
N-total	kg	4.31E+04	1.55E+03	1.55E+03
Emissions waterborne				
SO ₄	kg	5.74E+05	2.57E+03	2.57E+03
Cl	kg	4.59E+05	4.70E+02	1.16E+04
As	kg	1.15E+02		3.29E+02
Cr	kg	1.15E+02		4.15E+01
Cu	kg	1.15E+02		9.89E-01
PAH	kg	2.30E+00	4.12E-02	4.29E-02
aromatic hydrocarbons	kg	6.89E+02		1.32E+03
halogenated hydrocarbons	kg	6.89E+00		1.76E+01
BOD	kg	2.30E+04	8.23E+02	8.23E+02
COD	kg	6.89E+04	2.47E+03	2.47E+03
phenol	kg	2.30E+02	4.12E+00	4.29E+00
CN	kg	1.15E+02	2.06E+00	2.15E+00
NH ₄	kg	2.30E+04	8.23E+02	8.23E+02
N-total	kg	2.30E+04	8.23E+02	8.23E+02
Solid waste				
residue cleaning leachate (TW)	kg	2.58E+07	2.10E+04	3.03E+05
sludge cleaning leachate	kg	1.41E+07	5.04E+05	5.04E+05
definite waste	kg	8.76E+09	1.05E+08	1.14E+08

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4.3.4 Discussion method B

One of the most important assumptions in the calculation of chapter 4.3 is that the impregnated wood is not part of the mix of municipal solid waste. This means that rough data about the composition of MSW are **exclusive** of the woodwaste. In reality, this assumption may not be correct (an underestimation) as described in 4.1.

The results for incineration presented in Tables 4.21 and 4.31 about the environmental impact of incineration or landfill must be considered 'minimum values,' compared with Tables 4.7 and 4.15, respectively.

Based on the new set of data for elementary composition of MSW, distribution, susceptibility for leaching and input of utilities, the calculated results in Tables 4.21 and 4.31 show no discrepancy with input data.

5 Conclusions

The results in chapters 4.2 and 4.3 about the environmental impact of disposal of impregnated wood require careful interpretation.

The assumption about the relationship between MSW and wood (MSW data inclusive of wood) (chapter 4.2) leads to some discrepancies between the calculated results and the data about quantities and composition of the wood.

In order to overcome these discrepancies the opposite assumption has been worked out in Chapter 4.3, in case MSW data about composition excludes wood. It might be concluded that scenario B gives a better insight into the environmental effects of co-disposal of impregnated wood and Municipal Solid Waste (MSW).

The results of the calculations, are presented in figures 1 - 12. If the analysis is restricted to scenario B, the following can be concluded for impregnated wood compared with MSW:

- a. In case of incineration the airborne emission of As and Cr is very clear.
- b. In case of landfill the airborne emission of aromatic and halogenated hydrocarbons are considerably. For the waterborne emissions As, CR, Cu, aromatics and halogenated are exceptional.

The results of the calculation can be analysed in various ways. The ultimate question is if the emissions, due to waste disposal of impregnated wood, are acceptable or not. In order to get insight in the significance of the calculated emissions, the emission can be compared with the total amount of emissions (of all sources) in The Netherlands. This kind of comparison shows the significance of the emissions, instead of the comparison with MSW.

Table 5.1 Major emissions, due to incineration and landfill of impregnated wood (scenario B) compared with total emission (of all sources)

Emission	Incineration	Landfill	Total all sources	Fraction
	kg	kg	kg	%
Airborne				
As	3,360	-	790	425
Cr	1,300	-	6,960	19
Cu	755	-	55,300	1.3
Aromatic HC		27	1.2E+06	0
Halogenated HC		36	3.8E+06	0
Waterborne				
As		329	18,800	1.8
Cr		41.5	62,400	0
Cu		1	239,000	0
Aromatic HC		1,320	32,700	4
Halogenated HC		17.6	632,000	0

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Conclusion is that As and Cr emissions are signficated high in case of incineration.
Cu emission is not neglectable.

In case of landfill the waterborne emissions of As and aromatics are not neglectable.

Table 5.2 Explanation of abbreviations in figures 1 - 12

Aër	Aërosols
HC	Hydro carbons
Rgrr	Flue gas cleaning residu
HCl	methane and other hydrocarbons
HC2	Aromatic HC
HC3	Halogenated HC
HC4	Hydro carbons incineration
HM	Heavy metals incineration
Phen	Phenol
Waste	Final waste
Residu	Residu cleaning leachate

It can be concluded that the allocation needs further refinement (e.g. PAH). Although the model is still an approximation of reality, it is considerably more accurate than a 'black box' approach which treats all feed wastes in MSW as identical.

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6 References

- [1] Chem Systems and TNO, 1993 (in draft form available)
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Gasification of waste preserved wood impregnated with toxic inorganic and/or organic chemicals.

STEP-CT-91-0129

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Gasification of waste preserved wood impregnated with toxic inorganic and/or organic chemicals.
STEP-CT-91-0129
Sub report: Environmental effects of waste treatment of impregnated wood

7 Authentication

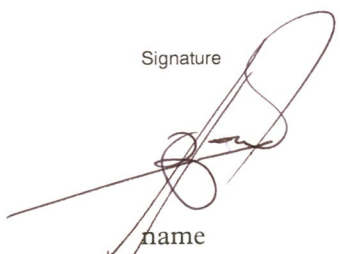
Name and address of the principal
Commission of the European Communities
Directorate-General for Science,
Research and Development
Joint Research Centre
Environment and Waste Recycling
DG XII/E-1
Rue de la Loi 200
B-1049 Brussels

Names and functions of the cooperators

Names of establishments to which part of the research was put out to contract

Date upon which, or period in which, the research took place

Signature



name
research coordinator

Approved by

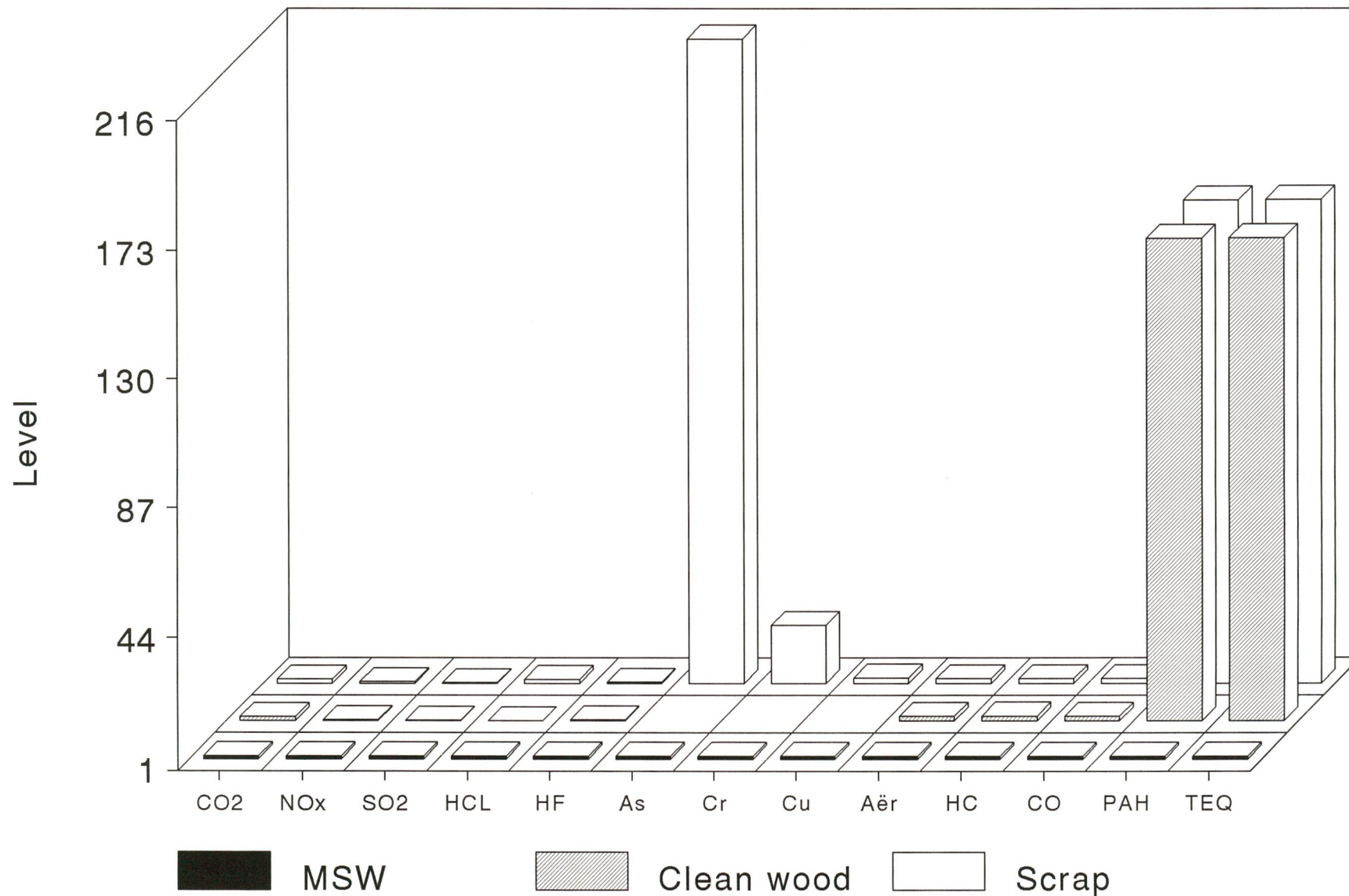


name
section leader

Incineration, method A

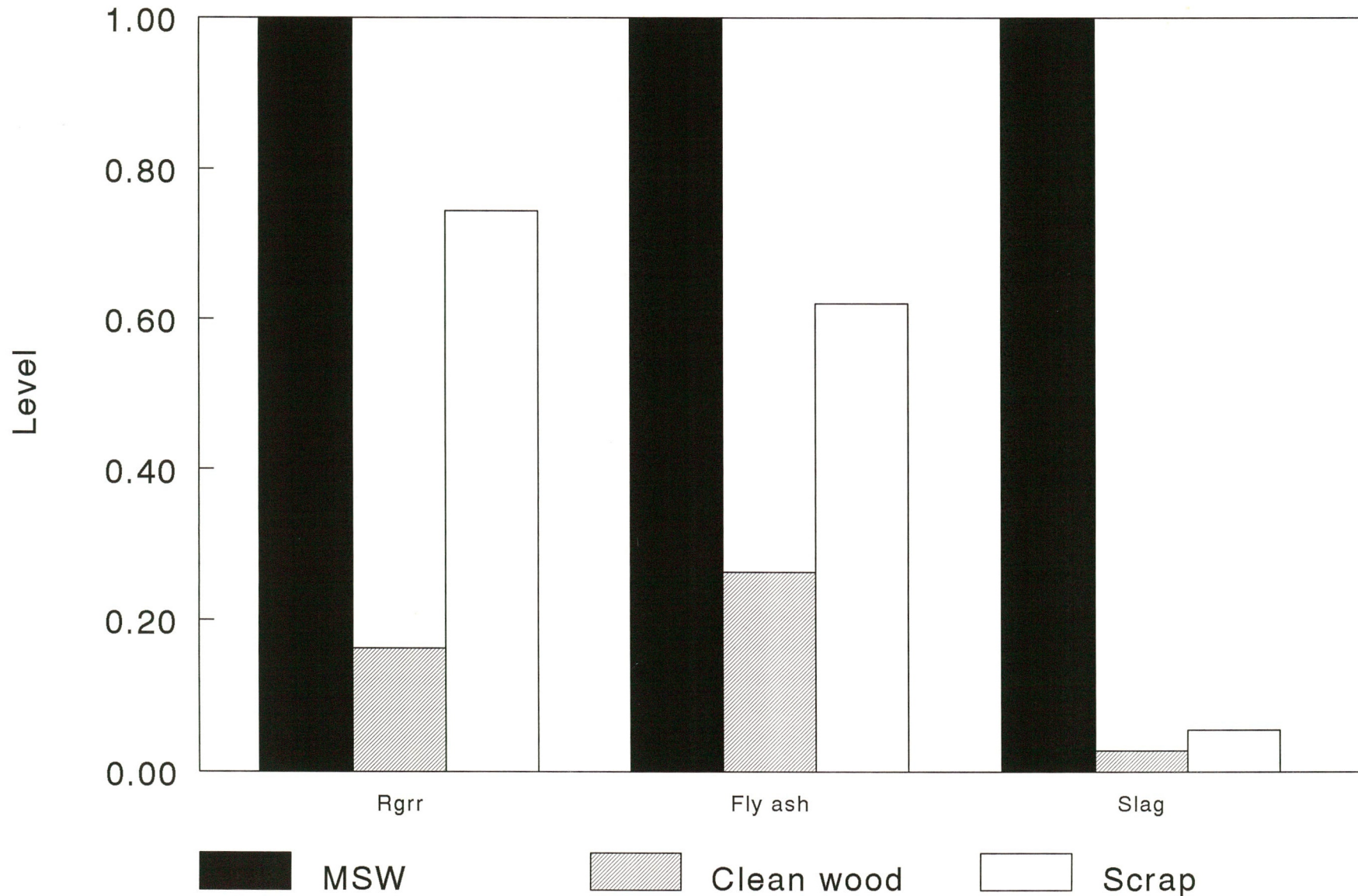
Airborne emissions (MSW level = 1)

Figure 1



Incineration, method A

Waste materials (MSW level = 1)



Landfill, method A

Airborne emissions (MSW level = 1)

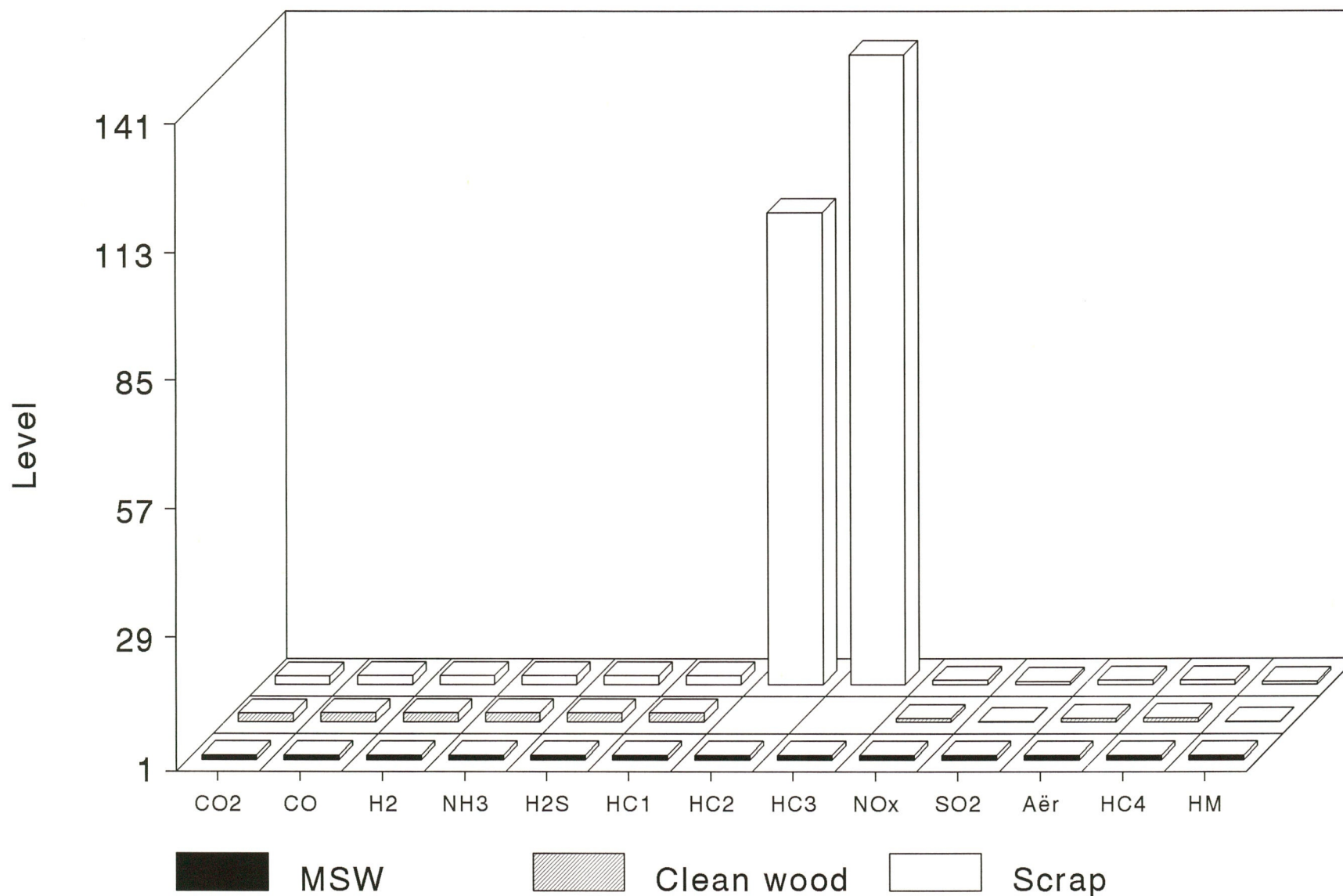
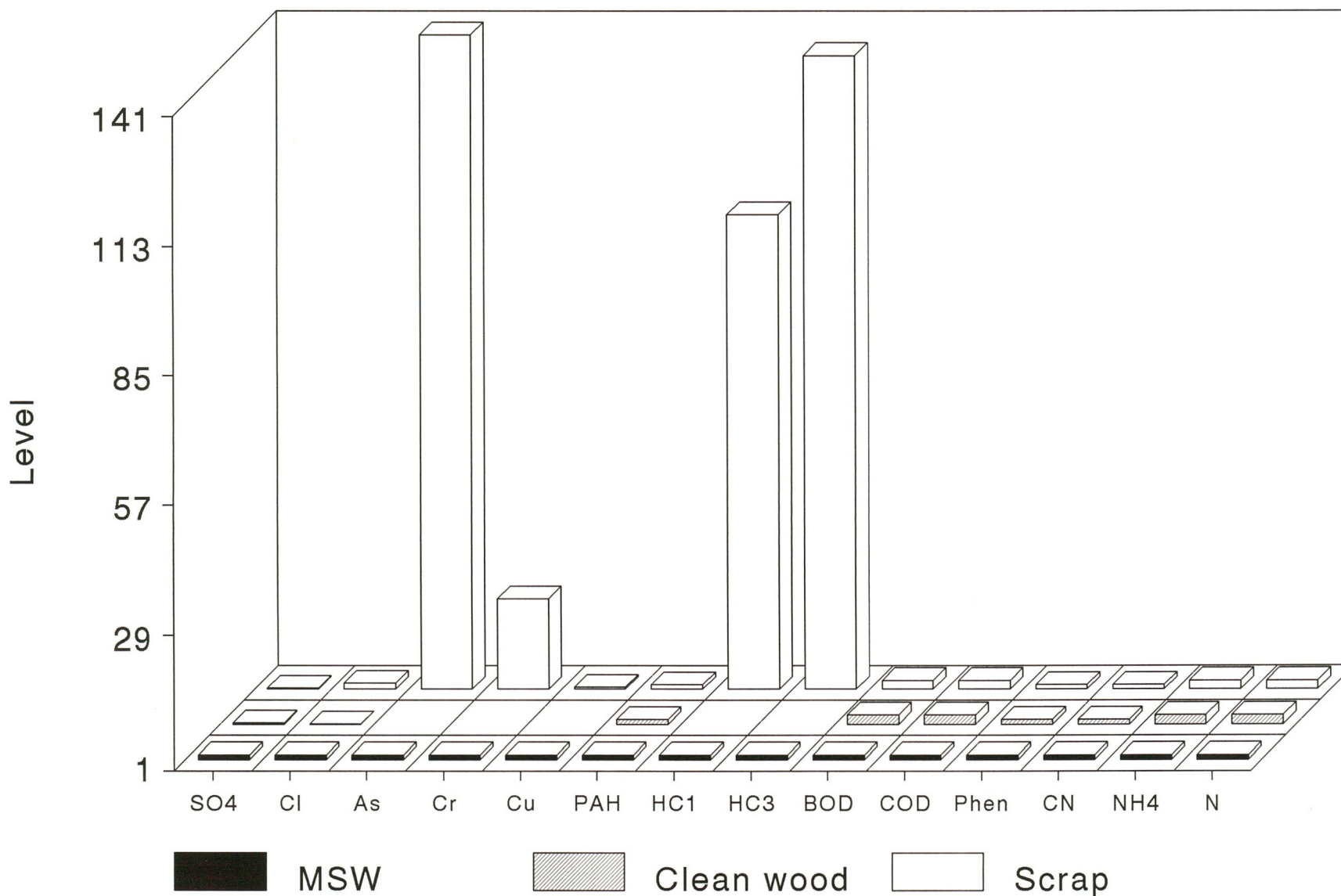


Figure 3

Landfill, method A

Emissions to soil (MSW level = 1)

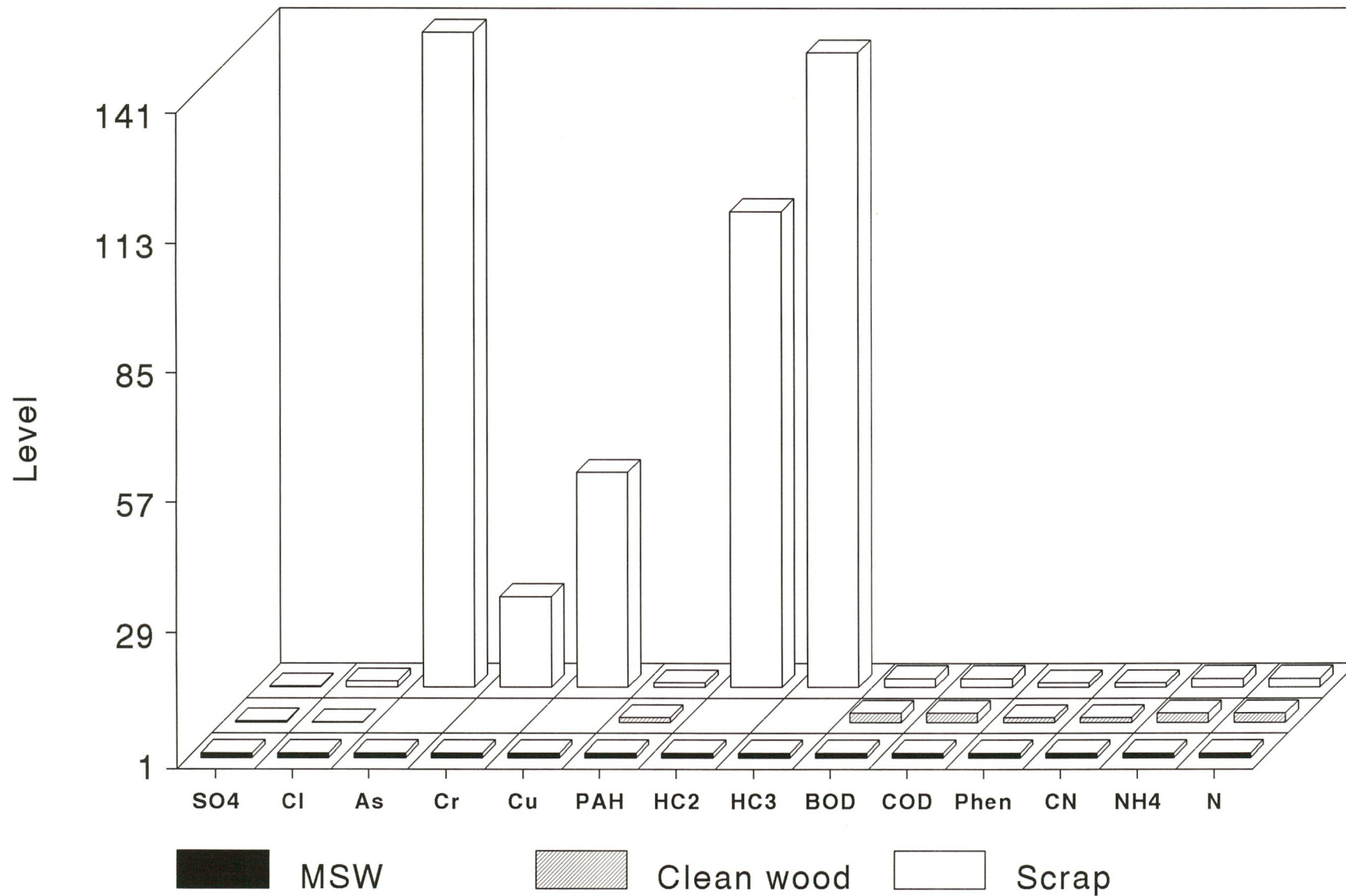
Figure 4



Landfill, method A

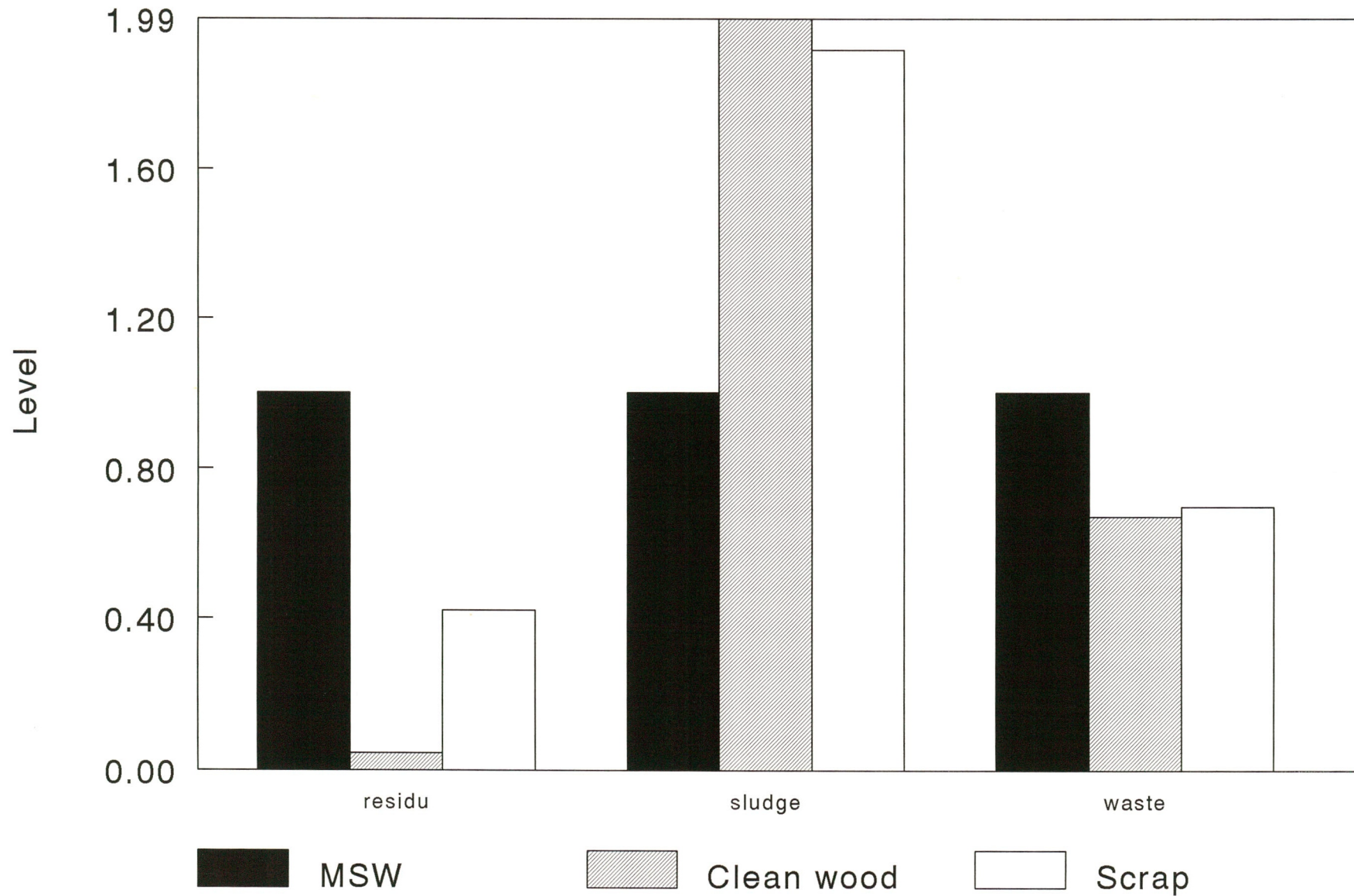
Waterborne emissions (MSW level = 1)

Figure 5



Landfill, method A

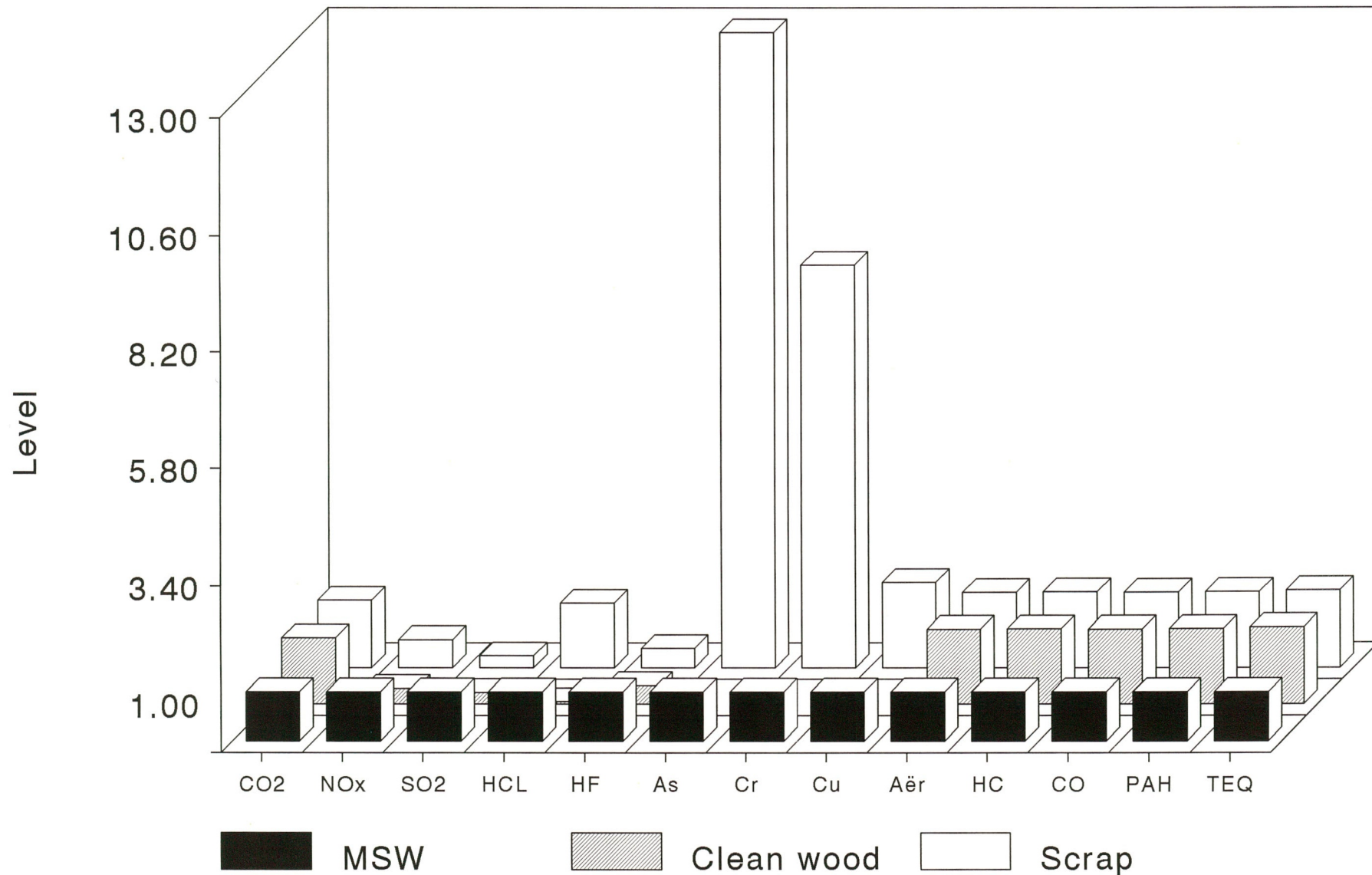
Solid waste (MSW level = 1)



Incineration, method B

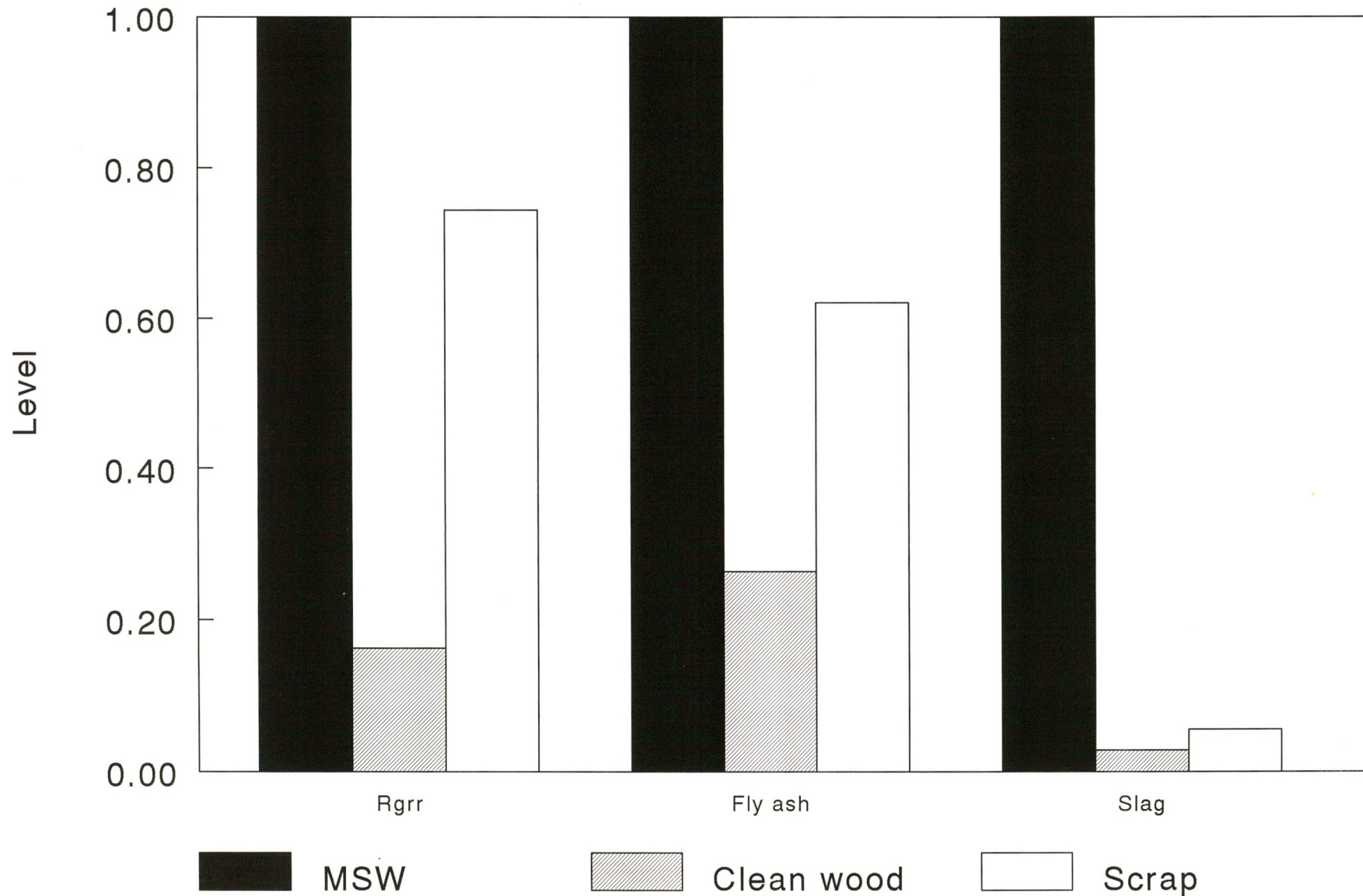
Airborne emissions (MSW level = 1)

Figure 7



Incineration, method B

Waste materials (MSW level = 1)



Landfill, method B

Airborne emissions (MSW level = 1)

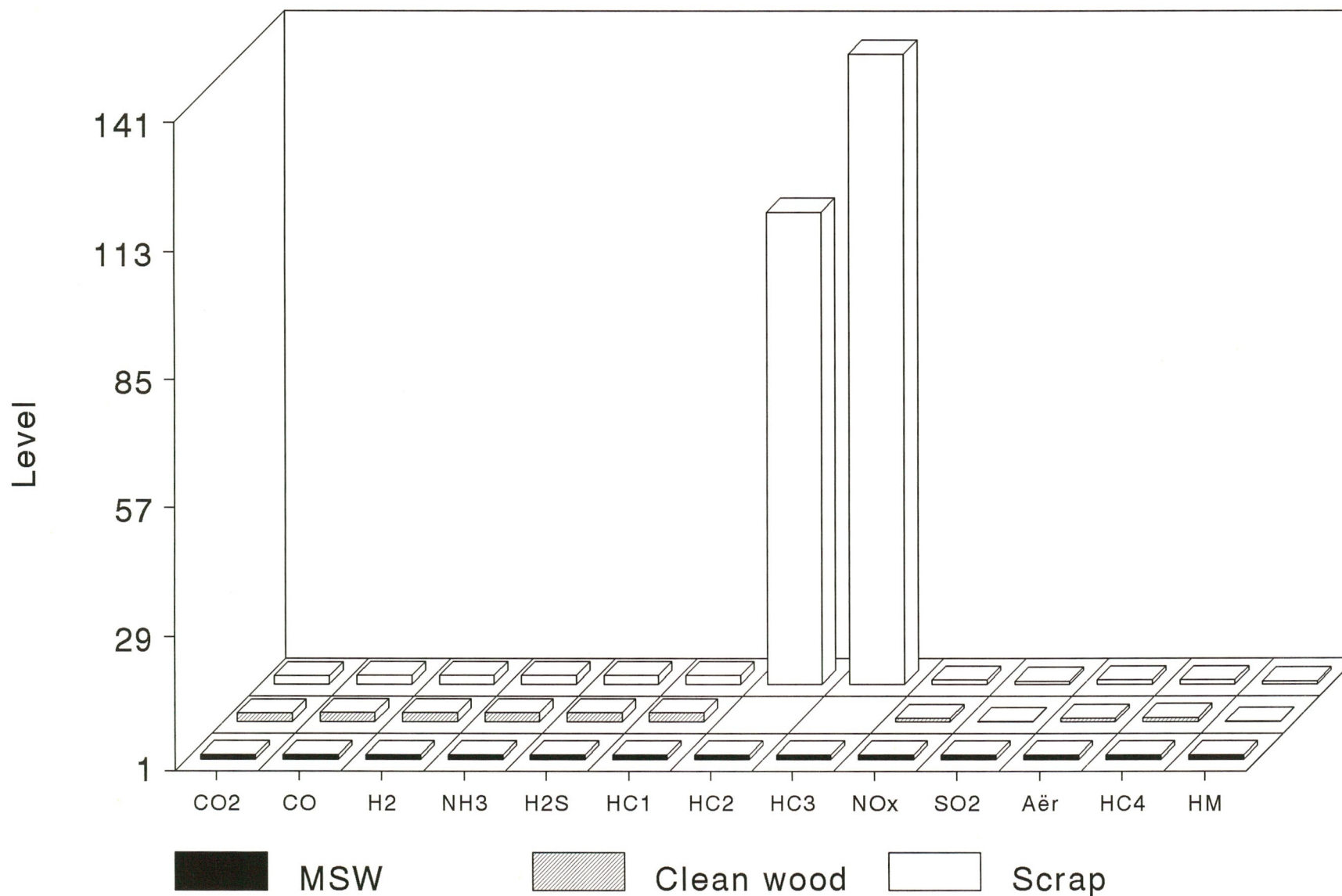
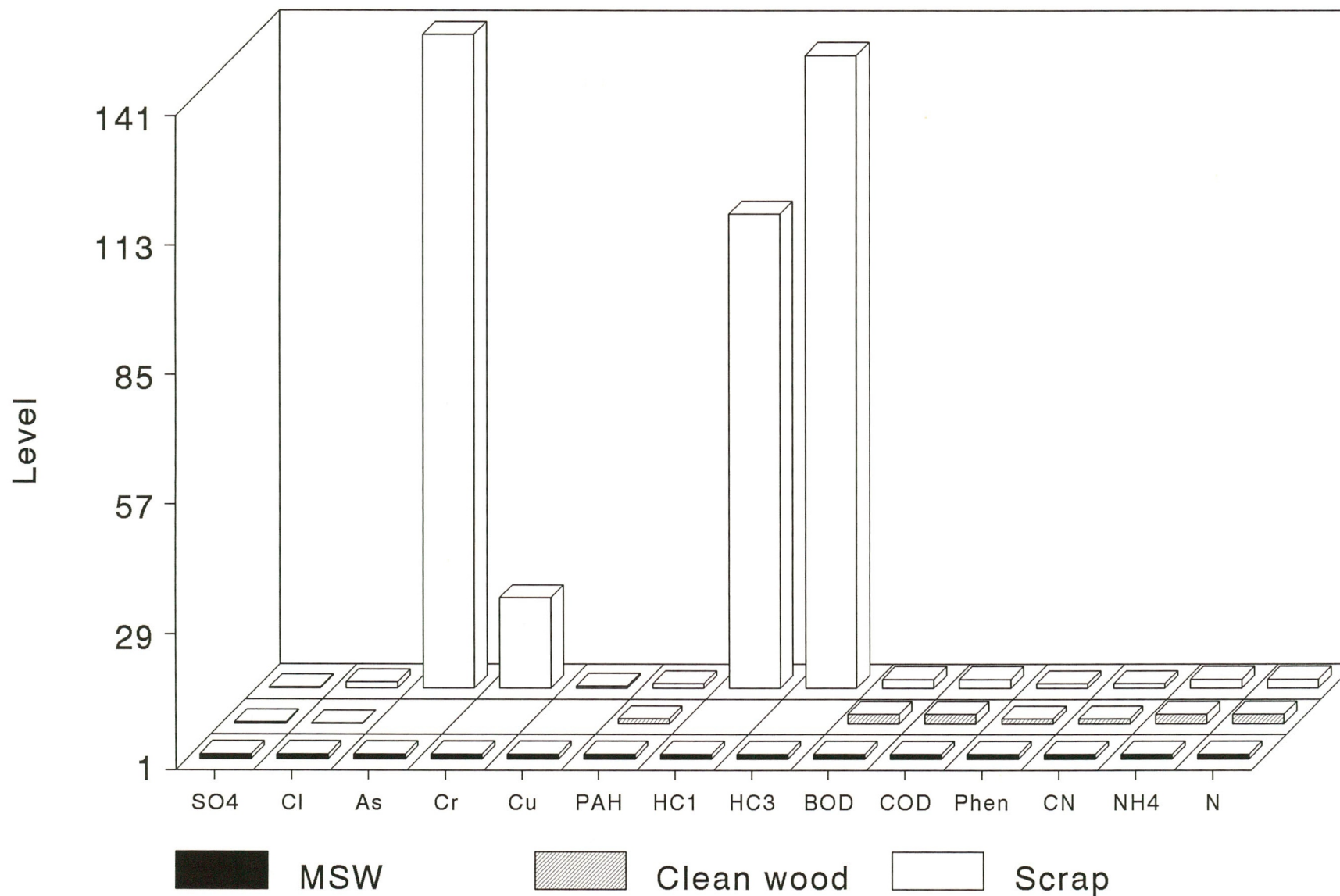


Figure 9

Landfill, method B

Emissions to soil (MSW level = 1)

Figure 10



Landfill, method B

Waterborne emissions (MSW level = 1)

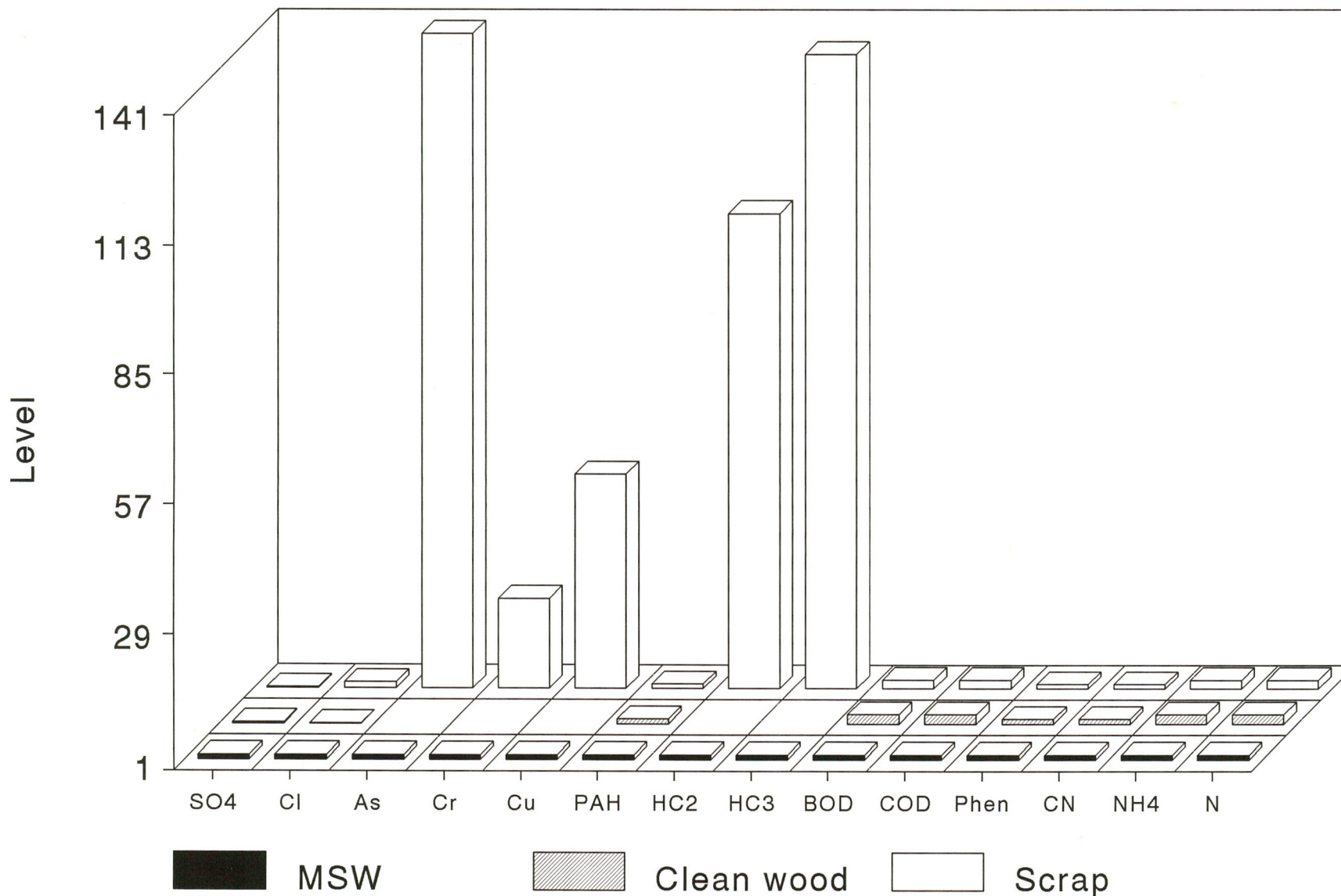


Figure 11

Landfill, method B

Solid waste (MSW level = 1)

