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Exploratory investigation into the possibilities of processing ash produced in the combustion of reject wood

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Abstract

The thermal conversion of, for example, reject wood leaves behind ash which, under present circumstances, is dumped. The amount of dumped material is 1.5-3% by weight of the combusted material. The dumping of the ash residue has the following disadvantages:

– high dumping costs;
– because of the fineness of the material, dumping sites usually accept the ash residue only in (plastic) packaging;
– the dumping infringes the aim of benefit as formulated by the Dutch Ministry of Housing, Planning and the Environment (VROM).

The potential for producing energy from biomass is appreciably greater than the energy at present produced from this source. The Third Energy Memorandum sets the objective of generating 10% of the energy from long-lasting sources in the year 2020. The amount of energy obtained from biomass is estimated in this connection at 70 PJ/year, or 2.5% of the energy consumption of the Netherlands. The potential for processing a quantity of ash from biomass can be estimated on the basis of these data at 65000 tonnes/year.

The objective of this study is to obtain an overall insight into the possibilities of beneficially using the ash residue from reject wood combustion within the applicable environmental protection criteria.

In the study, an initial evaluation has been made of the various processing possibilities on the basis of data obtained from published literature, from a private experimental investigation and the relevant legislation and regulations. This evaluation has revealed, among other things, the following:

– The cleaner grate fire and cyclone ash can be processed better than the more polluted filter ash.
– Grate fire and cyclone ash may possibly be used without pretreatment:
    - as a soil improver;
    - as an additive in composting;
    - in road building;
    - in the brick industry;
    - in existing melting processes (cement, glass, rock wool).
– The finer and more polluted filter ashes may possibly be used without pretreatment:
    - in road building;
    - in the brick industry;
    - in existing melting processes (cement, glass, rock wool).
– Before it is possible to proceed to a direct application, questions have to be answered in greater detail relating to:
    - the compliance with environmental protection criteria (soil improver, road building, melting processes);

  - the readiness to use the ashes in current processes (composting, road construction, bricks, melting processes).
- In view of the relatively high current dumping costs (NLG 140 to NLG 200 per tonne), alternative processing possibilities can certainly be stated to be economically attractive.
- Should use without pretreatment prove impossible, pretreatment in particular by washing or dry or wet separation may offer a solution. In that case, optimum process conditions have to be investigated in greater detail.
- It is recommended that, in the first instance, the use of grate fire and cyclone ash as a soil improver and as an additive in composting should be investigated in greater detail. In this connection, it should be remarked that these ashes are already being used abroad as soil improvers.
- It is recommended that a workshop be held to compare the various processing possibilities with one another in a broader framework. The objective of such a workshop may be the formulation of possible further steps in the direction of processing ashes accruing in the production of energy from a biomass.

Nomenclature

c-fly ash	cyclone fly ash
d.m.	dry matter
EPA	electrostatic precipitator fly ash
mv	mean value
GFA	grate fire ash
Industrial reject wood	wood consisting of untreated wood, but contaminated, however, with chipboard, block board, MDF (medium density fibre board), five-ply wood, three-ply wood with or without adhesive residues
L/S	liquid/solid ratio in column test
max.	maximum value
min.	minimum value
n.a.	not analysed
n.d.	not detectable, but regarded as half the limit of detection
Unshaped	material less than 50 cm^3
Reject wood	clean reject wood such as prunings or wood accruing from the manufacture of products (furniture, clog-making, etc.)
Sdev.	standard deviation
Shaped	material greater than 50 cm^3

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1. Introduction

Approximately 150,000 tonnes of reject wood are at present burnt in industrial installations in the Netherlands. This relates, in particular, to the combustion of clean reject wood and industrial reject wood. The number of installations which are fuelled with clean reject wood is in the order of magnitude of 1000. The installed power varies between 0.1 and 5 MW_{th}.

After combustion, the reject wood is left behind as ash which, in present circumstances, is dumped. The amount of dumped material is 1.5-3% by weight of the combusted material. The dumping of the ash has the following disadvantages:

- high dumping costs;
- because of the fineness of the material, dumping sites usually accept the ash residue only in (plastic) packaging;
- the dumping infringes the aim of benefit as formulated by the Ministry of Housing, Planning and Environmental Protection.

The potential for energy production from reject and waste wood is appreciably greater than the energy produced at present from these flows. The Third Energy Memorandum sets the aim of generating 10% of the energy from long-lasting sources in the year 2020. The amount of energy from biomass is estimated in this connection at 70 PJ/year, or 2.5% of the Dutch energy consumption. On the basis of these data, the potential amount of ash to be processed can be estimated at 65,000 tonnes/year.

The aim of this study is to obtain an overall insight into the possibilities of beneficially using the ash residue from reject wood combustion within the applicable environmental protection criteria. This overall insight may serve as a basis for a workshop for interested parties in which possible further steps can be formulated in the direction of processing ashes.

In this study, data have first been collected about the origin, composition and leaching behaviour of ashes originating from the combustion of reject wood by means of a literature study and laboratory experiments. The results of this are given in Chapters 2 and 3. Chapter 4 then elaborates the relevant legislation and regulations relating to the processing and disposal of ashes.
Chapter 5 briefly describes the current cost aspects of dumping the ashes. Chapter 6 elaborates the possible applications in greater detail on the basis of the data obtained in the preceding chapters. In this connection attention has been paid both to environmental protection aspects and to economic aspects. Chapter 7 evaluates the results, after which Chapter 8 summarizes the conclusions and recommendations.

2. Origin and physical properties

2.1 Origin of the ashes

The quantity of ash which accrues in the combustion of wood is strongly dependent on the type of fuel. In many cases, values between 1 and 5% are given. From Table 2.1 it is evident, however, that the ash residue may amount to approximately 15 to 20%, in particular in the combustion of contaminated bark and contaminated reject wood.

Table 2.1 Formation of ashes in the combustion of various types of wood [8].

Type of wood	Amount of ash [wt.%]
Clean wood without bark	<1
Clean bark	3 - 4
Contaminated bark	5 - 15
Clean reject wood	0,5 - 3
Contaminated reject wood	1 - 3
Impregnated wood (organic)	0,5 - 2
Impregnated wood (inorganic)	2 - 5
Contaminated reject wood	0,5 - 19

In general, three fractions accrue in the combustion of reject wood:

- *Grate fire ash (or bed ash)*Grate fire ash is the fraction formed in the combustion chamber and left behind in it. Contamination of the fuel with minerals, such as sand, earth and stones, promotes slag formation and ash sintering because of the lower melting points of the entrained impurities.

- *Cyclone ash*
  This ash consists of fine, mainly organic, ash particles which are entrained with the flue gas stream and are precipitated in the secondary combustion zone, in the boiler and in cyclones downstream of the combustion chamber.

- *Filter ash*
  Filter ash consists of very fine ash particles which still accrue downstream of the cyclone and precipitate in the downstream electrostatic filter, in the cloth filter or in the condensed water. In the case of small combustion units in which a second filter installation is not provided, this ash fraction finishes up in the atmosphere.

Table 2.2 indicates the grate fire ash, cyclone ash and filter ash partitioning. The ash fraction partitioning is approximately the same in the combustion of bark and shredded wood. In the combustion of sawdust, the ash precipitation in the cyclone (cyclone ash) is the greatest. Since the combustion quality influences the ash production and ash precipitation, what is given here is an indication.

Table 2.2 Percentage of the total ash fraction compared with the total amount of ash formed (wt.%) [10].

Ash fraction	**Percentage of the total amount of ash [wt.%]**		
	Bark	**Shredded wood**	**Sawdust**
Grate fire ash	75,0 - 85,0	70,0 - 90,0	20,0 - 30,0
Cyclone ash	15,0- 25,0	10,0 - 30,0	55,0 - 65,0
Filter ash	1,0 - 4,0	3,0 - 6,0	10,0 - 15,0

2.2 Physical properties

For the purposes of re-use, it is important to have information relating to the particle size and particle density of the various fractions.
Table 2.3 shows data relating to the particle size, the mean particle density and the bulk density of wood ashes [10].
The values reported are dependent on the type of fuel and combustion installation. Combustion of, for example, sawdust in a firing installation for bark may result in different values. In the Netherlands, the current concern is, in particular, with the combustion of sawdust, shredded wood, five-ply wood and three-ply wood in mechanical stoker burners [6].

Table 2.3 Aticle size and particle density of ash obtained in the combustion of sawdust and shredded wood.

Type of fuel **Ash fraction**	**Particle size [μm]**	**Bulk density [kg/m^3]**	**Particle density [kg/m^3]**
Sawdust:			
Grate fire ash	10 - 30.000	662	3.021
Cyclone fly ash	2 - 100	283	2.575
Filter ash	0,2 - 5	280	2.420
Shredded wood:			
Grate fire ash	15 - 15.000	960	2.866
Cyclone fly ash	2 - 160	430	2.682
Filter ash	-	-	-

The particle size of a specific ash fraction and the total ash production is determined by the type, fineness, homogeneity and degree of contamination of the fuel to be combusted.
The particle density of a specific ash fraction is dependent on the mineralogical composition.

3. Composition and leaching behaviour

Wood combustion ash is composed of uncombusted carbon and the mineralogical components of wood. These components vary considerably and are, in particular, dependent on the extent of burning in the combustion process and the impurities in the fuel.

3.1 Composition of combustion ashes

3.1.1 Experimental laboratory data

Etiégni and Campbell [8] carried out combustion experiments with sawdust (2.0 mm) at different temperatures in 1991. For this purpose, use was made of an electric furnace in which the samples were combusted at the different temperatures for 6-9 hours or until the weight of the ash formed remained constant. The chemical composition of the ashed wood as a function of the ashing temperature is shown in Table 3.1. These experiments show that the chemical composition of the ash varies as a function of temperature:

- the content of most metals increases with temperature;
- the concentration of K, Na and Zn decreases with increasing temperature;
- the carbonate content decreases with increasing temperature.

Table 3.1 Chemical composition of wood combustion ash as a function of temperature.

Element	**Temperature [°C]**					
	538	**649**	**760**	**871**	**982**	**1093**
Al [µg/g]	0415	12825	13115	10115	13415	11015
Sb [µg/g]	264	142	65	91	94	208
As [µg/g]	<20	<20	<20	54	74	59
Ba [µg/g]	1301	1490	1640	1463	1601	1530
Be [µg/g]	<5	<5	<5	<5	<5	<5
Bi [µg/g]	<30	<30	<30	<30	<30	<30
Cd [µg/g]	<2	<2	<2	<2	<2	<2
Ca [µg/g]	187480	217480	241180	216080	238980	264580
Ce [µg/g]	<40	<40	<40	<40	<40	<40
Cr [µg/g]	52	37	49	20	39	622
Co [µg/g]	<3	<3	<3	<3	<3	<3
Cu [µg/g]	345	620	588	380	437	422
Fe [µg/g]	8796	11951	9981	8219	22411	16781
La [µg/g]	<10	<10	<10	<10	<10	<10
Pb [µg/g]	51	75	200	39	43	685
Li [µg/g]	35	55	70	10	30	10
Mg [µg/g]	59730	68060	76970	69170	80470	89100
Mo [µg/g]	18	21	26	39	56	192
Ni [µg/g]	59	64	151	63	497	8979
P [µg/g]	16950	19060	21720	19370	21030	25460
K [µg/g]	110500	86590	47720	79860	51970	4026
Se [µg/g]	<50	<50	<50	<50	<50	<50
Si [µg/g]	33867	39777	42647	31997	46477	35267
Ti [µg/g]	780	1060	1012	777	957	796
V [µg/g]	13	18	23	17	26	234
Yb [µg/g]	3	3	3	2	5	3
Zn [µg/g]	2678	2139	1001	177	26	55
Carbonates [%]	62,8	60,0	58,4	54,9	53,3	51,4

The production of ash decreases with increasing temperature: at a temperature of approximately 1093°C, the amount is approximately 50% of the amount found at 538°C. This is probably due to the carbon being burnt to a greater extent at higher temperatures.
It is furthermore evident that calcium, potassium, magnesium, phosphorus and iron are among the main constituents of wood ashes.

In [10], experiments are reported which have been carried out with ashes obtained from the combustion of three-ply wood, five-ply wood and reject wood making use of a furnace fired for a long time at a temperature of 500°C in order to achieve complete combustion. The objective of this method was to minimize the evaporation of volatile metals (not comparable with that encountered in practice). The analytical results of this investigation are shown in Table 3.2.

Table 3.2 Mineralogical composition of combustion ashes [10].

Element	Content	Fuel		
		Three-ply and five-ply wood	Chipboard	Reject wood
Ca	%	53,6	26	14,6
Fe	%	1,03	3,25	6,54
K	%	0,92	8,56	6
Mg	%	2,8	9,2	2,24
Mn	%	-	2,11	-
Na	%	-	-	-
P	%	0,6	6,2	2,2
S	%	0,48	4,39	0,1
Si	%	9,2	10,34	12,37
Al	%	1,93	2,07	15,03
Ti	%	0,16	0,32	28

3.1.2 Practical experimental data

Pohlandt [9] carried out combustion experiments with clean and industrial reject wood in a phased combustion apparatus having a capacity of 35 kW_{th}. The results of these practical experiments are shown in Table 3.3. The practical experiments show that, as laboratory experiments have also revealed, calcium, potassium, magnesium, phosphorus and iron are among the main components of wood ashes.

Table 3.4 shows the concentration of Cl, F and heavy metals as a function of the various ash fractions (grate fire ash, cyclone ash, filter ash).

Table 3.3 Chemical composition of wood ash originating from the combustion of clean, industrial and contaminated reject wood.

Element	Content	Clean reject wood	Industrial reject wood (three-ply, five-ply etc.)	Industrially treated wood
Ca	%	8,44 - 41,7	0,9 - 34,3	1,4 - 35,8
Fe	%	0,48 - 2,35	0,29 - 538	n.d.
K	%	2,86 - 10,9	0,17 - 17,0	0,97 - 10,8
Mg	%□	1,00 - 3,45	0,25 - 8,81	0,19 - 9,17
Mn	%	0,16 - 2,62	0,12 - 2,39	0,06 - 3,64
Na	%	0,06 - 0.97	0,08 - 7,67	0,03 - 4,12
P	%	0,67 - 3,52	0,11 - 1,44	0,1 - 2,48
Cl	[µg/g]	33 - 4.510	<10 - 138.000	48 - 53.980
F	[µg/g]	1 - 530	<2 - 564	370 - 23.400
As	[µg/g]	<1 - 35	<2 - 60	n.d.
Cd	[µg/g]	<1 - 20	<5 - 17	n.d.
Co	[µg/g]	6 - 27	<10 - 115	4.400- 196.000
Cr	[µg/g]	<10 - 592	16 - 810	4.000- 156.000
Cu	[µg/g]	99 - 498	43 - 1.450	n.d.
Ni	[µg/g]	20 - 250	18 - 235	n.d.
Pb	[µg/g]	9 - 450	49 -7.300	100 - 6.550
Zn	[µg/g]	54 - 1.900	16 - 6.200	

n.d. = not determined

Table 3.4 Concentration of Cl, F and heavy metals in combustion ash from industrial reject wood as a function of the ash fraction produced [mg/kg dry ash].

Element	Ash fraction		
	Grate fire ash	Cyclone ash	Filter ash
Cl [mg/kg]	<10 - 113	<10 - 14.900	38 - 138.000
F [mg/kg]	<2 - 9	7 - 288	25 - 564
As [mg/kg]	<2	<2 - 47	<2 - 60
Cd [mg/kg]	n.d.	<5	<5 - 17
Co [mg/kg]	n.d.	<10 - 115	<10 - 87
Cr [mg/kg]	26 - 38	16 - 795	17 - 810
Cu [mg/kg]	146 - 1.280	43 - 605	55 - 1.450
Ni [mg/kg]	n.d.	18 - 235	27 - 235
Pb [mg/kg]	n.d.	49 - 1.280	134 - 7.300
Zn [mg/kg]	16 - 133	91 - 1.810	109 - 6.200

The above table reveals that the concentration of the components measured increases as the combustion process proceeds further. One explanation for this is that metals evaporate during the combustion process, after which they condense again at falling flue gas temperatures, in particular on the surfaces of the small fly gas particles.

Obernberger [12] carried out an extensive investigation on wood ashes originating from an installation having a power of 7 MW_{th}. The analytical results are shown in Appendix 1. Table 1 in Appendix 1 shows the characteristic indices of the ash fractions accruing in grate fire ash and cyclone ash. Table 2 in Appendix 1 shows

the elemental distribution in the total ash accrued and in the separate fractions (grate fire ash, cyclone ash). Calcium, magnesium, potassium, phosphorus and zinc have the highest concentrations both in the coarser grate fire ash and in the cyclone ash. Table 3 in Appendix 1 shows the content of heavy metals in the separate ash fractions. Obernberger concluded that, in particular, the elements Cd and Zn exceed the limit values applied in Austria.
In modern installations fired with biomass, it is possible to concentrate 30 to 60% of the Cd total and 25 to 45% of the Zn total in 5 to 10% of the total wood ash produced, in particular the filter ash.
From the study, it is furthermore concluded that the most environmentally harmful metals (Pb, Cd and Zn) finish up in the fly ashes due to the fact that these elements are relatively volatile. Filter ash has the highest adsorption potential for the elements mentioned. The less volatile elements (Co, Ni, Cr and V) finish up in the grate fire ash and, from the environmental point of view, are less relevant in regard to exceeding the limit values applied in Austria (Austrian Standardization Institute, 1990).
The concentrations of Cu, Mo and As are also lower than the limit values imposed in that country.

3.2 Leaching behaviour of combustion ashes

3.2.1 Literature data

In an American investigation [10, Chapter 7], a series of leaching experiments has been carried out with the ashes from the combustion of wood originating from separation installations.
In two separation installations in which the wood supply consisted both of clean reject wood and contaminated reject wood and only clean wood was left after separation, leaching experiments have been carried out with the combustion ashes. The composition of the wood and the mineralogical composition of the ash is shown in Appendix 2. The leaching procedure used is based on the EPA Test ‘Toxicity Characteristic Leachate Procedure’ (TCLP, method 1311).

The results of these experiments are shown in Table 3.5. The percentage of ash varied between 3 and 8.6% by weight and is higher than for combusting clean wood alone because of the contamination with sand.

Table 3.5 Leaching behaviour of heavy metals according to TCLP test with ashes from laboratory experiments (two samples per experiment).

Element	**Separation installation 1**				**Separation installation 2**			
	Mv [mg/l]	**Max.** [mg/l]	**Detection limit** [mg/l]	**Regu-latory limit** [mg/l]	**Mv** [mg/l]	**Max.** [mg/l]	**Detec-tion limit** [mg/l]	**Regu-latory limit** [mg/l]
As	n.d.	n.d.	0,5	5	n.d.	n.d.	0,5	5
Ba	n.d.	n.d.	1	100	n.d.	n.d.	1	100
Cd	n.d.	n.d.	0,2	1	n.d.	n.d.	0,2	1
Cr	1,15	1,2	0,2	5	9,1	12	0,2	5
Pb	n.d.	n.d.	2	5	n.d.	n.d.	2	5
Se	n.d.	n.d.	0,5	1	n.d.	n.d.	0,5	1
Ag	n.d.	n.d.	0,1	5	n.d.	n.d.	0,1	5
Hg	n.d.	n.d.	0,1	0,2	n.d.	n.d.	0,1	0,2

It appears that, according to the American regulation, only Cr is revealed as a critical parameter.

The phosphorus solubility of ash is shown in Table 3.6.

Table 3.6 Comparison of phosphorus content and phosphorus solubility in dilute hydrochloric acid.

Type of ash	**Total phosphorus content** [mg/kg]	**Phosphorus content soluble** [mg/kg]	[% of total]
Bed ash	1.700	617	36,3
Bed ash	2.000	357	17,9
Bed ash	1.400	654	46,7
Bed ash	3.400	438	12,9
Cyclone ash	1.900	n.a.	-
Cyclone ash	7.600	444	5,8
Cyclone ash	4.500	12	0,3

The nitrogen content in ashes is low because most of the nitrogen is emitted via the flue gases.

3.2.2 Experimental data

To determine the possibilities of processing materials, it is a requirement in the Netherlands that, among other things, the leaching behaviour should be known. The leaching behaviour of unshaped materials must be determined by the so-called column test.

In the literature, leaching data are given for ashes obtained from biomass (paragraph 3.2.1). However, these have been determined with the aid of leaching tests other than the column test. In the past it has been found that the translation of leaching data not determined by the column test to leaching data from a column test is frequently unreliable.

In order to be able to determine satisfactorily what disposal possibilities there are, it has therefore been decided to determine the leaching behaviour of ashes experimentally with the aid of the column test. The way in which the results of the column test have to be checked is shown in Appendix 3.
In the column tests, a combination has been used of grate fire ash and cyclone ash from clean reject wood originating from an industrial combustion installation.

The results of the experiments are shown together with the calculations and the checking of the relevant limit values in Appendix 3. The results are evaluated in greater detail in Chapter 6.

4. Relevant legislation and regulations

Among other things, the quality of surface water, soil and ground water plays an important role in the development of the Dutch environmental policy. From the quality criteria, the requirements are derived with which the waste and reject materials must comply if they are beneficially used or dumped, optionally after working-up. In order to obtain an insight into the criteria which the ash residue must fulfil in order to be eligible for beneficial use and which criteria have been imposed for the dumping of reject materials, the relevant regulations are explained in Appendix 4.

Table 4.1 gives a brief general summary of the regulations connected with the disposal of reject materials. Table 4.1 is based on the exploration of the regulations as presented in Appendix 4.

Table 4.1 Brief general summary of regulations relating to the removal of reject materials.

Method of processing reject material	Scope of testing
Beneficial use in soil	Target soil quality values from Milbowa (Environment, soil and water)
Working-up of reject material by e.g. purification and separation	Scope of testing is dependent on the final application of the waste flows
Beneficial use, not as soil	Building Materials Order
(Processing and) dumping	Limit values notice, dumping ban, BAGA (Designation of Hazardous Waste Order)

This chapter will furthermore specifically deal with the regulations which are of importance for the disposal of biomass ash residues. In this connection, the same aspects will be discussed as in Appendix 4.

Priority sequence for disposal methods

At present, the ashes are dumped at a 'standard' dump managed in accordance with IBC (Immobilization, Management and Monitoring) principles. Dumping is the least desirable method of waste disposal and, consequently, any alternative method of disposal will be preferred from the environmental protection point of view.

Beneficial use without treatment

To apply ashes to soil as a manure, an exemption is required from the Rikilt in view of the Dutch Manure Act of 1947. In this connection, consideration is given, in particular, to the agricultural aspects of the ashes. As yet no quality requirements have been imposed on such ashes on the basis of the Dutch Manure

Act of 1986 1). However, for use on soil, a general article in the Dutch Soil Protection Act relating to the 'duty of care' for the soil must be complied with. At present there is no national environmental protection testing framework for this purpose.

However, it can be stated that soil improvers can be applied to the soil without objection if they fulfil the soil quality target values in 'Beleidsstandpunt over de Notitie Milbowa' ('Policy standpoint on the Milbowa notice') dated 5-2-1992 [2] and the 'Third memorandum on water management'. In the three northern provinces, these target values have been adopted as a framework for testing in the Provincial Environmental Regulation relating to the granting of an exemption for the use of organic manures on the soil.

Working up of ash residues by means of purification, separation and the like
The biomass ashes contain such low concentrations of impurities that there is no point in recovering them (from an economic and environmental protection point of view).

Another much used method of working-up waste streams is to separate them into less and more contaminated fractions. During the combustion process, the ash accrues in three fractions: filter ash, cyclone ash and grate fire ash. The fraction having the smallest particles (filter ash) contains, relatively, the greatest amount of impurities. The possibility of processing these fractions together or the necessity for keeping fractions apart depends on the requirements imposed on the intended use. This also applies to the desirability of working these fractions up (for example by washing) before they are used or dumped.
There is no legal environmental protection framework for working up reject and waste materials. The legal framework relates to the final destination of the material flows left over.

Processing and subsequent beneficial use of the product
The processing of the ash residues to a product which can be beneficially used appears possible. In this connection, we may think, for example, of cold immobilization procedures. In these cases, an inorganic material is produced which can be used, for example, as a product in building. The products will have to be tested against the Building Materials Order as described in Appendix 4. That order imposes leaching requirements with respect to inorganic components and composition requirements with respect to organic components. Since this concerns ash residues from a combustion process, few organic impurities are expected and, consequently, the leaching behaviour will primarily be of importance and not so much the composition requirements.

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1) At present this has been elaborated only in the BOOM (Other Organic Fertilizers Order) for purification sludges, compost and black soil in relation to quality requirements for heavy metals. Ashes obtained from biomass have therefore not been elaborated in BOOM.

The Building Materials Order assigns products produced from the ashes to category 1 or category 2 application:

- category 1 building materials: the sole requirement imposed both when used on 'dry' ground and on water-logged ground/in surface water is that the material must be used in a recoverable manner. During use, care has to be taken that the building materials do not mix with the ground;
- category 2 building materials: in addition to the requirement imposed on category 1 building materials, it is required that fairly large quantities must be used together (generally: not less than 10,000 tonnes, except for road building: not less than 1000 tonnes) and that the material can be used only above the ground water with a top seal.

In the case of category 1 applications, no minimum amounts are prescribed. This does apply, however, to category 2 applications. In view of the small amount of ashes accruing per year in the Netherlands (approximately 2500 tonnes per year) in the current situation, category 1 applications or category 2 applications in road building will have to be aimed at. In the near future, a considerable increase is foreseen in the production of energy from biomass, which means that even category 2 applications become relevant outside of road building.

(Processing and subsequent) dumping of the product

The ash residues are currently dumped under the least stringent conditions (IBC criteria only). Working-up and subsequent dumping do not therefore appear to be an alternative unless a dumping ban is introduced on untreated ash residues1) or if the ashes do not (any longer) comply with the requirements imposed on an IBC dumping site.

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1) Ashes from biomass are not included in the recently issued dumping ban.

5. Costs aspects

In addition to the criteria mentioned in Chapter 4 relating to the regulations, economic criteria will also be important for implementing alternative disposal methods. Since the ash residue is dumped in the present situation, this situation will be treated as a reference. A general summary will first be given of the dumping costs and the development of the dumping costs for non-hazardous waste. The dumping costs of the ash residues will then be discussed.

5.1 Development of dumping tariffs

The dumping tariffs in 1992 and 1993 for non-hazardous waste are determined by the province and there are therefore regional variations (see Article 8.14, paragraph 2, Section d, and paragraph 3 of the Dutch Environmental Conservation Act). The tariffs are between the following limits [15]:

Table 5.1 Dumping tariffs for non-hazardous waste

Waste category	**Weighted mean**		**Minimum-maximum**	
	1992 [NLG/tonne]	**1993 [NLG/tonne]**	**1992 [NLG/tonne]**	**1993 [NLG/tonne]**
(Coarse) household waste	74	85	17 - 247	19 - 247
Industrial waste	67	93	11 - 180	17 - 200
Building and demolition waste	63	91	10 - 147	8 - 250
Contaminated soil		104		4 - 250

It can be deduced from this table that the dumping tariffs have risen. Ultimately, the target is to raise the dumping tariffs to the level of the combustion tariffs (approximately NLG 230/tonne). According to expectations, the dumping tariffs have risen/will rise further because:

- as of 1 January 1995, a tax of NLG 30/tonne is being imposed on waste which is dumped(1);
- the conservation of old dumping sites will have to be paid for from levies on the waste which is dumped in future.

The considerable rise in dumping costs has already generally been expected for some time, but in practice it appears it cannot (yet) be pushed through. It is unclear when and to what extent a rise in tariffs will occur.

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(1) Unpurifiable soil (with an SCG (clean soil) certificate), dredged material, GFT (Vegetable, Fruit and Garden waste), paper sludge and dumping on private ground are exempt from the NLG 30/tonne tax.

5.2 Dumping tariffs for ash residues

The dumping tariffs for ash residues largely determine the financial framework for alternative processing. To obtain an insight into this maximum financial framework, an estimate has been made in this connection of the current dumping costs for ash residues.

Ash residue from the combustion of waste wood is a very fine material, as a result of which it can easily atomize.
To prevent atomization of the material, two measures are taken before the ash is transported to a dumping site:

- the ash residues is moistened and then
- the ash is packaged in 'big-bags'.

The moistening of the ash residue, in particular, increases the dumping costs since the addition of water results in an approximate doubling of the mass which finally has to be dumped.
The dumping tariff for big-bags containing moistened ash residue is currently approximately NLG 70 to 100/tonne. Assuming that the mass is doubled by the addition of water, the dumping costs compared with the amount of ashes disposed of is doubled to approximately NLG 140 to 200/tonne.

6. Processing possibilities

In addition to dumping itself, four different ways are in principle possible for disposing of combustion ashes from biomass:

- beneficial use without processing the ashes;
- beneficial use after working-up the ashes;
- beneficial use after processing the ashes;
- dumping the ashes after processing.

In this report a distinction has been made between working-up and processing procedures:

- In the case of working-up procedures, the physical structure of the ashes does not change. After working-up, the ashes may possibly be used as soil improvers, compost improvers or for land filling. The ashes treated will then have to be checked as specified in Section 6.1.
- In the case of processing procedures, the physical structure does change. What legislation and regulations must be referred to in the evaluation is dependent on the use of the final product.

The feasibility of these four possibilities is discussed below. In doing this, both environmental protection and economic aspects have been examined.

6.1 Beneficial use without processing

The literature mentions a number of possibilities for the beneficial use of ashes from biomass without the ashes being fundamentally altered [12]:

- use of the grate fire ash and cyclone ash as a soil improver in agriculture and horticulture;
- use of grate fire ash and cyclone ash as additive in composting;
- use of grate fire ash for land filling.

6.1.1 Use as a soil improver

To apply ashes to the soil as manure, an exemption is required from the Rikilt in view of the Manure Act of 1947. In this connection, consideration is given, in particular, to agricultural aspects of the waste material. In view of the high concentrations of calcium, iron, magnesium, phosphorus and potassium, the ashes are attractive from the point of view of agriculture.

No quality requirements have yet been imposed on the ashes if they are used as soil improvers (clarified in Chapter 4 and Appendix 4). However, it is generally required that, when substances are used on the soil, an article in the Dutch Soil Protection Act relating to 'duty of care' for the soil must be complied with. At present there is no national environmental protection test framework for this. However, it can be stated that soil improvers can be applied to the soil without objection if they fulfil the soil quality target values in 'Beleidsstandpunt over de Notitie Milbowa' ('Policy standpoint on the Milbowa notice') dated 5-2-1992 [2]. These target values have been adopted in the three northern provinces as a testing framework in the Provincial Environmental Regulation relating to the granting of an exemption for the use of organic manures on the soil.
Table 6.1 compares the soil quality target values and the various composition analyses in the literature.

Table 6.1 Milbowa soil quality comparison in relation to inorganic components and composition of ashes.

Element	**Milbowa limit values [mg/kg]**	**Lab. Experiment T = 538° C [mg/kg]**	**Pract. experiment, clean reject wood [9] [mg/kg]**	**Pract. experiment, ind. reject wood [9] [mg/kg]**
As	29	<20	<1 - **35**	**370 - 23.400**
Ba	200	**1.301**	n.a.	n.a.
Cd	0,8	<2	<1- **20**	n.a.
Cr	100	52	<10 - **592**	**4.400 - 196.000**
Co	20	<3	6 - **27**	
Cu	36	**345**	**99 - 498**	n.a.
Hg	0,3	n.a.	n.a.	**4.000- 145.000**
Pb	85	51	9 - **450**	n.a.
Mo	10	**18**	n.a.	n.a.
Ni	35	**59**	20 - **250**	n.a.
Sn	20	n.a.	n.a.	n.a.
Zn	140	**2.678**	54 - **1.900**	n.a.
Br	20	n.a	n.a.	100 - **6.550**
Cl	200	n.a.	33 - **4.510**	n.a.
CN free	1	n.a.	n.a.	48 **- 53.980**
CN complex	5	n.a.	n.a.	n.a.
F	175 + 13Lu	n.a.	1 - **530**	n.a.
S total	2	n.a.	n.a.	**1.600 - 41.800**
				1.1 n.a.

number = value **below** limit value of Milbowa soil quality

number = value **above** limit value of Milbowa soil quality

Table 6.1 Milbowa soil quality comparison in relation to inorganic components and composition of ashes (continued)

Element	Milbowa limit values [mg/kg]	Mixture of grate fire ash, cyclone ash and filter ash [12] [mg/kg]	Mixture of grate fire ash and cyclone ash [12] [mg/kg]	Grate fire ash [12] [mg/kg]	Cyclone ash [12] [mg/kg]	Filter ash [12] [mg/kg]
As	29	5	5	4	7	13
Ba	200	n.a.	n.a.	n.a.	n.a.	n.a.
Cd	0,8	**18**	10	**2**	**30**	**121**
Cr	100	**257**	**255**	**290**	**178**	**283**
Co	20	14	14	15	13	12
Cu	36	**237**	**213**	**228**	**181**	**556**
Hg	0,3	**0,38**	0,03	0	0,1	5
Pb	85	65	32	12	79	**510**
Mo	10	3	3	3	3	6
Ni	35	**46**	**44**	42	**51**	**65**
Sn	20	n.a.	n.a.	n.a.	n.a.	n.a.
Zn	140	**2.094**	1.538	753	3.320	9.466
Br	20	n.a.	n.a.	n.a.	n.a.	n.a.
Cl	200	n.a.	n.a.	**423**	**8.505**	**15.984**
CN free	1	n.a.	n.a.	n.a.	n.a.	n.a.
CN complex	5	n.a.	n.a.	n.a.	n.a.	n.a.
F	175 +	n.a.	n.a.	n.a.	n.a.	n.a.
S total	13Lu 2	n.a.	n.a.	n.a.	n.a.	n.a.

number = value **below** limit value of Milbowa soil quality

number = value **above** limit value of Milbowa soil quality

If we look at the data in Table 6.1, we see that the ashes from the laboratory experiment and the ashes from industrially treated wood cannot readily be used as soil improvers. Ashes from clean reject wood exhibit a considerable spread in amounts of impurities. If the lower limit of concentrations is adopted in this connection, it appears that there is compliance with Milbowa except in the case of copper.

Table 6.1 furthermore reveals that filter ash contains the highest concentrations of impurities. The mixing of the three different ashes which accrue is therefore not an obvious step. The combined processing of cyclone ash and grate fire ash appears attractive, although cadmium, chromium, copper and zinc (and chlorine) are seen to considerably exceed the limit.

From these data it may be concluded that it is only reasonable to investigate the use of ashes from clean reject wood as soil improvers. During such an investigation, the spread in the amounts of impurities will have to be scrutinized.

Grate fire ash and cyclone ash will be more likely to fulfil the requirements imposed than filter ash1).

Viewed economically, the use of the ashes as soil improvers is attractive: dumping costs (NLG 140 to NLG 200/tonnes of ash) and the use of another soil improver are eliminated.

Use as an additive in compost can favourably affect the oxygen content of the compost. The compost becomes drier and also acquires a granular structure. The compost will then be introduced into the soil as a manure. The compost containing ashes will therefore have to be checked against the soil quality limit values. For this purpose, composition data for compost containing ashes as an additive will have to be known. The composition of compost is, however, very diverse and therefore will have to be investigated for each situation.

However, it can be stated that the use of relatively small amounts of ashes compared with the amount of compost will *probably* be possible; the concentration of impurities in the ashes will, after all, be reduced by mixing with compost2).
With the most critical component Cu (see Table 6.1) and a Cu concentration in the compost of 10 mg/kg as a starting point, it can be calculated that approximately 10% of grate fire ash can be added to compost before the Milbowa limit values are exceeded. The other elements will have to be checked in the same way.

Viewed economically, this application will also be attractive because the dumping costs are eliminated and the composting is improved.

6.1.2 Use of grate fire ash for land filling

If a material is used for land filling, it will have to be checked against the Building Materials Order (see Appendix 4)3). Within the framework of this study, the leaching behaviour has been determined experimentally to check the ashes against the Building Materials Order. For this purpose the column test has been carried out up to L/S = 10 on a combination of grate fire ash and cyclone ash from clean reject wood. The analytical results of the column test have been worked out in accordance with the method of calculation in the Building Materials Order. In this calculation, the height of the structure may be varied. Here, the minimum height which is permitted in the Building Materials Order has been increased in the

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1) (Ground) grate fire ashes and cyclone fly ashes are already being used abroad as soil improvers [12].

2) Dilution of waste materials with the objective of reducing the concentration of impurities is not permitted. The addition of ashes to compost is, however, a functional mixing of two substances.

3) The meaning here is land filling without the ashes being mixed with the soil.

calculations (minimum height = 0.2 m). After all, the lower a structure, the lower the expected air-borne pollution and therefore the greater the probability that beneficial use will be permitted.
Table 2 in Appendix 3 reveals that there are six elements which exceed the limit value for beneficial use: chromium, molybdenum, chlorine, fluorine, bromine and sulfate. If we consider category 2 applications1), we see that only the air-borne pollution level due to Br is considerably exceeded. The other levels are only marginally exceeded. If checked against category 1 applications, the levels exceeded are markedly larger.

The combination of grate fire ash and cyclone ash from clean reject wood tested here can therefore not be beneficially used without it having undergone a treatment. The use of only the cleaner grate fire ash from clean reject wood is expected to give a better picture. Grate fire ashes are in fact already in use as filling material abroad [12].

6.2 Beneficial use after treatment

Section 6.1 states that the beneficial use of ashes without them having undergone a treatment will be critical. This section considers the working-up procedures.

Two working-up procedures which may be attractive for the ashes are distinguished [13]:

These two procedures are explained below.

6.2.1 Dry and wet separation

The objective of using a separation step is to separate material into a relatively clean main stream and a small residual stream. In particular, impurities are usually concentrated in the fine fraction and the coarse fraction is then relatively clean. The separation is therefore directed at obtaining an amount of purified material which has to be much greater than the amount of concentrated impurity (residual fraction) and, in addition, have a quality such that beneficial use becomes possible.

An investigation will have to be carried out into whether the ashes from biomass are composed of a relatively clean and relatively contaminated fraction. If this is in fact the case, the following procedures may be suitable:
- systems based on dimensions (sieving curves, vibrating sieves, etc.). This is suitable for separating 500 µm particles and above;

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1) See Chapter 4 for an explanation of category 1 and 2 uses.

- systems based on gravity (upward flow column and settler) can separate particles greater than 50-100 µm;
- systems based on centrifugal forces (hydrocyclone) can process particles greater than 10 to 20 µm.

The suitability of the procedures for ashes is shown qualitatively in Table 6.2.

Table 6.2 Separation procedures for ashes obtained from biomass.

Ash fraction	Particle size	Separation principle		
	µm	Dimension	Gravity	Centrifugal force
Grate fire ash	10 - 30.000	yes	yes	yes
Cyclone ash	2 - 100	no	yes	yes
Filter ash	0.2 - 5	no	no	no

It may be concluded that the grate fire ash can be dispersed into a number of different fractions. Cyclone ash will be capable of being separated into approximately two fractions. No practical separating procedures are available for filter ash.

The costs of separating ashes will be approximately NLG 5 to NLG 100. In view of the current dumping costs (NLG 140 to NLG 200/tonne of ash) this type of procedure may be attractive.

Aspects which deserve greater attention are:
- is there a large coarse fraction which is relatively clean?
- can the relatively coarse clean fraction be used beneficially?
- which disposal possibilities are available for the relatively contaminated fraction?
- what costs are involved in the disposal of the relatively contaminated fraction?
- what are the total process costs?

6.2.2 Washing

Another possibility for improving the quality of the ashes is washing. During washing, impurities are transferred from the ashes to the liquid phase. The washing process can be carried out in three steps:
- washing;
- post-treatment with wash water;
- post-treatment of the ashes (for example, drying).

In Section 6.1, it was concluded that the elements Cr, Mo, Cl, F, Br and SO_4 leach out too much for the material to be beneficially used for land filling. The elements Cd, Cr, Cu, Zn and Cl were found to be critical for using the ashes as soil improvers.

An investigation at TNO-MEP revealed that anions can be washed out satisfactorily. Cations can also be washed out, but acidification of the wash water is then desirable in order to improve the solubility of the elements in water.

The costs of the washing process will be approximately NLG 100 - NLG 200/tonne (dumping costs NLG 140 - NLG 200/tonne). It is attractive to investigate this processing procedure further.
Aspects which deserve greater attention are:

- which type of washing process is the most effective?
- what degree of acidity in the wash water is desirable?
- in what way can the washed ashes be marketed. Is it necessary, for example, to dry the ashes after washing?
- in what way can the wash water be processed?
- what are the total process costs?

6.3 Processing and subsequent beneficial use of the product

Another possibility for processing the ashes is to process the ashes to form a beneficially usable building material. Immobilization procedures can be used for this purpose. Immobilization is a procedure in which impurities are permanently fixed in waste materials. Immobilization procedures can roughly be divided into cold procedures and thermal procedures. In the case of the thermal procedures, a distinction can again be made between sintering procedures and melting procedures. These three types of immobilization procedures are very different in nature and are therefore discussed separately below.

In the case of cold immobilization, the waste material is mixed with chemical stabilizing agents and cement or a mixture of lime and powdered coal fly ash is then generally added. This is possibly followed by compaction and, finally, hardening in order to obtain an immobilized material which retains its shape. In this way, the impurities are trapped in a calcium-silicate matrix and the additives which are added can, in addition, bring about an additional chemical bonding of the impurities.
The cement-like product will have to be checked against the Building Materials Order in order to investigate whether beneficial use is possible. Road building and hydraulic engineering can be thought of in this connection.

The process can be carried out with relatively simple equipment and is therefore not very complicated. However, large-scale use of cold immobilization is not yet being carried out in the Netherlands (but it is abroad). This reticence is due to the lack of clarity in the regulations in the past. The introduction of the Building Materials Order will largely eliminate this lack of clarity.

The costs of immobilization procedures are between NLG 100 and NLG 200 per tonne, depending on the degree of contamination. In view of the current (and future) dumping costs, this procedure appears attractive.

In order to actually be able to assess whether beneficially usable products can be manufactured by means of cold immobilization, immobilization tests will have to be carried out and the immobilized material will have to be tested for leaching behaviour. The results will have to be checked against the Building Materials Order. Questions which deserve further attention are:

– which cold immobilization procedure immobilizes the impurities in the ashes optimally?
– which ashes should act as starting material: grate fire ash, cyclone ash, filter ash, washed ashes or ashes which have previously been treated with separation equipment?
  In the case of direct immobilization of the ashes, the cold immobilization procedure will be more expensive (more impurities) than in the case of the immobilization of ashes which have been washed or separated (fewer impurities). However, a washing or separation process also involves costs;
– can the immobilized material be marketed? What is the profit from the immobilized material?
– can ashes be used directly in a concrete-type application without extra additives being necessary? In that case, we are then no longer talking of immobilization, but of replacement of primary raw materials (filler, sand or gravel) in concrete. From an environmental protection and economic point of view, this will be the most attractive option.
– The investigation has shown that the addition of grate fire ash in road building even increases the wear resistance of roads [5];
– what are the total process costs?

6.3.2 Sintering techniques

In a sintering process, the starting material is heated to just below the melting point. As a result, sintering of the material takes place. However, the crystal structure of the material remains intact. Immobilization of impurities therefore occurs because a physical barrier is formed.

The sintering process as such is already used on a large scale in the Netherlands. It is possible to think of the production of bricks. However, sintering processes specially designed for processing waste materials on a large scale are still being developed. In the short term, the most attractive option is therefore to investigate what possibilities there are for using ashes in existing processes. As a result of the negative value of the ashes, it will probably be economically attractive to use the ashes as starting materials. In any stocktaking of the possibilities, the following points will require attention:

- what amounts of ashes can be added to existing processes without the environmental protection or physical quality of the product being effected?
- what positive contributions can be expected from the ashes (for example, lowering of the melting point as a result of the presence of Ca and K)?
- is there (will there be in the future) sufficient ash for a brick industry?
- which ashes can be used: grate fire ash, cyclone ash, filter ash, washed ashes or ashes which have previously been treated in separating equipment?

6.3.2 Melting procedures

A further type of immobilization procedure is melting. In this procedure, the material is heated above the melting point, as a result of which the crystal structure is broken up. After cooling, a new silicate lattice is produced. This new matrix will be able to absorb the non-volatile heavy metals. This will considerably reduce the availability of impurities for leaching out, as a result of which the product can probably be used beneficially.
Volatile heavy metals still present will not be absorbed in the new matrix, but will be removed via the flue gases. A flue gas purification is therefore necessary in almost every case.
In view of the high temperatures employed and the flue gas purification, the processing is relatively complicated. The process is therefore only beneficial if a relatively large installation can be designed. In view of the current low amount of ashes, it will at present be possible to process the ashes thermally only in combination with other waste materials.

It may be stated that, due to the strong growth in energy production from biomass foreseen, the amount of ashes will increase considerably. It can be estimated that ashes accruing from biomass in 2020 will amount to approximately 65,000 tonnes/year. At a scale level of approximately 5000-10,000 tonnes per year, thermal processing of the ashes alone may be attractive.
No melting installation for immobilizing large flows of waste materials is as yet available in the Netherlands. However, initiatives are being taken to set up such a process. In other words, immobilization by melting ashes (in combination with other waste materials) is not possible in the short term. However, it will probably be possible in the longer term.

In the Netherlands, there are, however, melting processes on a commercial scale for the production of inorganic products. The primary aim of these processes is the production of a product and not waste processing. The cement industry, the glass industry and the rock wool industry may be thought of. In view of the composition of the ashes, they can probably be used as stock material.
From an economic point of view, the addition of ashes to an existing melting process is probably attractive. Dumping costs are eliminated and fewer primary

stock materials are necessary. However, an (additional) flue gas purification installation is necessary.

The following questions deserve closer attention:
- what thermal immobilization processes are being developed at present and what waste materials are being evaluated during the development?
- is it possible to add the ashes in a future melting installation?
- what is the quality of the immobilized material?
- for what quantity of ashes is it worth the effort of setting up a thermal immobilization process for the ashes alone?
- what are the costs of processing?
- is it possible to use ashes in the melting installations of, for example, the cement industry, glass industry or rock wool industry?

6.4 Processing and subsequent dumping of the product

At present, all the ashes are transported to a standard IBC dumping site. There is therefore no point in processing and subsequently dumping the product.

If, however, transporting the ashes to a standard dumping site were to present problems in the future, the procedures explored above may also be attractive in this framework.

From an economic point of view this is the least attractive option since both dumping costs and treatment costs are associated with the disposal.

7. Evaluation

7.1 Quality of the ashes

Three fractions accrue in the combustion of reject wood: grate fire ash, cyclone ash and filter ash. The grate fire ash is the least contaminated and the filter ash the most contaminated. It is therefore probable that the cleaner grate fire ash and cyclone ash can be processed differently from the filter ashes.
The quality of the ash is furthermore considerably dependent on the type of reject wood. The cleaner the stock material, the less contaminated the ashes. The information in the literature relating to the composition of the ashes therefore reveals a considerable spread.

To determine the possibilities for disposing of materials, it is a requirement in the Netherlands that the leaching behaviour, among other things, should be known. The leaching behaviour of unshaped materials has to be determined by the column test. However, no results have been found in the literature for the leaching behaviour of ashes determined by this test. It has therefore been decided that we should carry out the column test ourselves. In the column tests, a combination of grate fire ash and cyclone ash from clean reject wood has been used. This is relatively clean material. Even here, a considerable spread in results can be expected if different ashes are used as starting material.

In view of the considerable spread in the composition and leaching behaviour which may be expected, the characterization of the starting material and the possible spread in the results should be an important point to which attention is paid in investigating the possibilities of processing ashes.

7.2 Cost aspects of current processing

The current dumping costs are around NLG 140 to NLG 200 per tonne. The costs of the alternative processing possibilities will have to be offset against these dumping costs. In doing this, the costs of collecting the ashes will also have to be included. Requests made to several recycling plants for an estimate of the collection costs did not reveal much concrete information. The Dutch policy in regard to the combustion of biomass is based on the fact that it will increase considerably in the coming 20 years. It may therefore be expected that more large-scale installations will be built in the future. This will markedly facilitate the collection of ashes. This aspect has not been explored further within the framework of this study.

7.3 Processing possibilities

The possibilities for treating ashes obtained from biomass which may be attractive have been described above. An examination of the feasibility of this has been made in an environmental protection, economic and technical context. The legal framework is involved in the environmental protection aspects.

In the table below, an evaluation is made of the various processing possibilities. In view of the nature of the ashes, a distinction is made here between grate fire ashes and cyclone ashes, on the one hand, and filter ashes, on the other.

8. Conclusions and recommendations

- The quality of the ashes exhibits a considerable spread. In investigating the processing possibilities, attention will have to be paid to characterizing the ashes.
- The cleaner grate fire ash and cyclone ash can be processed better than the more contaminated filter ash.
- Grate fire and cyclone ash may possibly be used without pretreatment:
    - as a soil improver;
    - as an additive in composting;
    - in road building;
    - in the brick industry;
    - in existing melting processes (cement, glass, rock wool).
- The finer and more contaminated filter ashes may possibly be used without pretreatment:
    - in road building;
    - in the brick industry;
    - in existing melting processes (cement, glass, rock wool).
- Before it is possible to proceed to direct use, questions have to be answered in greater detail relating to:
    - compliance with environmental protection criteria (soil improver, road building, melting processes);
    - the willingness to use ashes in the current process (composting, road building, bricks, melting processes).
- In view of the relatively high current dumping costs (NLG 140 to NLG 200 per tonne) alternative processing possibilities must certainly be said to be economically attractive.
- The costs of collecting the ashes will have to be explored further.
- In the first instance, it is recommended that the use of grate fire and cyclone ashes as soil improvers and as additives in composting be investigated in more detail. In this connection, it should be remarked that these ashes are already being used as soil improvers abroad.

9. Authentication

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

Not applicable

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

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