

**Municipal solid waste conversion to energy;
a summary of current research and development in
The Netherlands**

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Summary

In this report a review is given of the present situation regarding Research and Development (R&D) in the field of Municipal Solid Waste (MSW) in The Netherlands.

Basis of the Dutch waste policy is the so-called "Motion Lansink" of 1979, where a priority sequence

- prevention
- reuse
- conversion into energy
- landfill

was established.

Since prevention and reuse are difficult subjects with respect to their actual implementation - amongst other things due to many non-technical constraints - these nowadays obtain increased R&D attention. This is relevant in the present context, since by prevention and reuse generally energy is saved.

Further it is intended to increase the amount of MSW incineration with energy recovery considerably, simultaneously decreasing the waste volume to be landfilled.

In The Netherlands, at least 16 research programs exist in the field of waste management; in 1990 some Dfl. 70 mln was utilised through these programs. On behalf of the Ministries of Economic Affairs and of Housing, Physical Planning and Environment, some 20% of this amount is spent through the National Reuse of Waste Research Program and the Program Energy from Waste and Biomass. Nowadays, from the 5 Mt/a of MSW generated in The Netherlands, some 35% is incinerated. It is intended to increase this amount to 50%, approximately, in the year 2000. At present various other (industrial) waste streams are also incinerated; the total amount of waste incinerated is 2.8 Mt/a.

Basic options for conversion of solid waste into energy are

- incineration of untreated waste ("mass incineration") or RDF,
- gasification,
- pyrolysis,
- fermentation of a fraction of MSW in dedicated equipment,
- deposition, followed by extraction and utilisation of landfill gas.

From these, incineration is the most important one. In total, in The Netherlands 10 incineration plants are in operation. In practically all these plants, energy is recovered.

Within a few years source separation of Kitchen, Vegetable and Garden Waste (KVG) will have been introduced all over The Netherlands. Since KVG has a high moisture content, this will increase the calorific value of the remaining waste. The KVG will be either composted or fermented.

Also other fractions, such as paper, glass, aluminum and hazardous household waste, like batteries, are largely separated from the MSW. The remaining waste, the so-called restfraction, is either incinerated directly or after mechanical processing.

In this context, a number of experimental studies have been carried out and some are still in progress in order to optimise MSW processing systems, regarding

energetic as well as economic aspects. Much effort is put into increasing the overall efficiency of electricity generation, which is now some 22.5%. By a set of measures, such as increasing steam temperature, decreasing the air factor and flue gas recirculation this percentage may be increased considerably.

Simultaneously, emission standards, in particular for dioxin and NO_x , will become more stringent after 1993. Adequate flue gas cleaning systems require 9 to 18% of the energy generated; for smaller installations this percentage will even be higher.

A relatively new trend, getting considerable R&D attention in The Netherlands, is the fermentation of KVG and/or the putrescible part of the restfraction.

Fermentation is a straightforward way of producing energy (biogas) from biomass containing a great deal of water. Moreover, after fermentation the KVG can be used as compost.

Though some installations of this kind are being set up at present, the costs are relatively high.

In this context, also more complex processing schemes are being considered, in particular for generating electricity by steam and (bio)gas plants.

Finally, the exploitation of landfill gas should be mentioned. At present, over $50 \times 10^6 \text{ m}^3/\text{a}$ is utilised for various purposes, e.g. for a kiln of a brick factory, a steam boiler of a chemical plant and the furnaces of an aluminum factory. Also part of the gas is supplied to the gasdistribution grid after being upgraded to natural gas quality. Further electricity is generated in gas engines and supplied to the public electricity grid.

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1 Introduction

One of the activities of the International Energy Agency (IEA) Bio-energy Agreement, which started in 1986, covers Municipal Solid Waste (MSW) conversion.

The terms of reference of this activity are:

to establish and organize co-operative research and development between the participating countries in the area of municipal solid waste conversion with emphasis on the technical and environmental aspects of energy recovery.

During the first three year programme, reports describing R&D programmes in the participating countries Canada, Sweden and the UK were prepared. As part of the following 1989 - 91 activity within Task VII of the Agreement, It was agreed that brief reports detailing the recent R&D on Energy from Waste in each of the countries that joined the MSW Conversion Activity would be prepared. This report on MSW-conversion in The Netherlands is therefore one of a series in this context.

1.1 The Netherlands

The Netherlands have a constitutional monarchy with a parliament comprising two legislative houses (First and Second Chamber).

The monetary unit is the Dutch guilder (*f*); 1 US \$ = *f* 1.66 (August 1992).

The total population is 15 million; the total land area nearly 34,000 km². The three most densely populated provinces (out of 12) are North and South Holland and Utrecht (around 6.5 million inhabitants, on 20% of the land area).

The average household size is 2.5 persons. The gross national product (1987) is US \$ 12,000 per capita; the economically active part of the population is 45%.

1.2 Waste Policy in The Netherlands

The Dutch R&D activities in the field of waste, and energy from waste, are rooted in the so-called "Motion Lansink" of 1979, in which the following priority sequence was established.

- prevention,
- reuse,
- conversion into energy,
- landfilling,

This policy, which is well in line with the policy in other EC countries, is illustrated with the "ladder principle" of figure 1 [27].

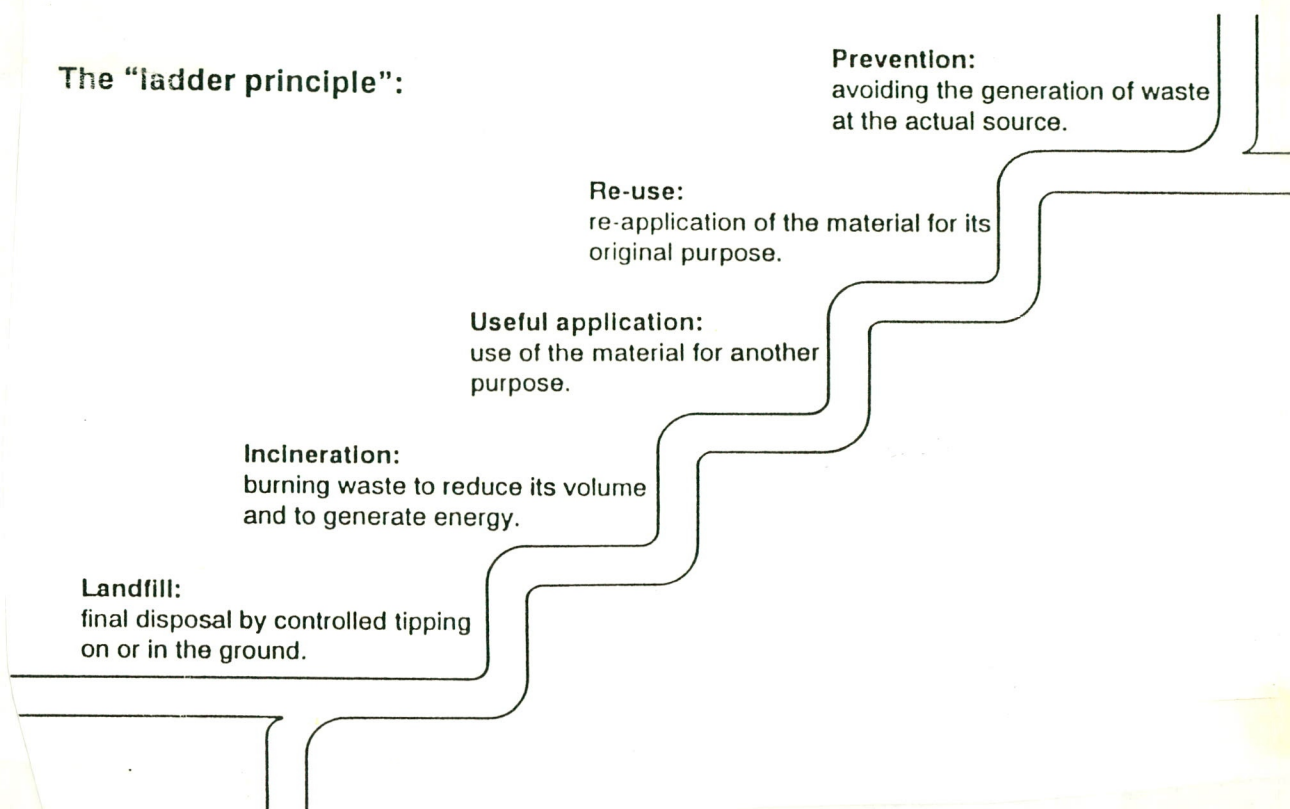


Figure 1 The "ladder principle", constituting the Dutch national waste policy

The road from this basic policy statement of the Parliament to its implementation is a long one. This is mainly caused by the fact that the two options with the highest priority are also the most difficult to realise. Both prevention and reuse require the redesign of many products, and moreover changes in human behaviour. Their implementation is only effectuated as a result of a long-term growing process. However, recycling of some types of wastes, such as paper, organic domestic waste (constituting almost 50% of the total of domestic waste), glass, scrap iron and steel and batteries has already become common practice [27]. Paper from domestic waste is recycled for approximate 30%, glass for approximate 50%; these figures should rise further in future. This recycling does not only imply the preservation of resources, but also the saving of energy. And also by waste prevention energy is saved. For these reasons, in the following two paragraphs, the essential features of prevention and of reuse, respectively, will be treated in short.

1.3 Prevention [34]

Waste prevention can be defined as promoting the generation of less, or less harmful, waste. In this context, we may distinguish four **types of prevention** (roughly speaking in decreasing order of priority):

1. Reducing the harmfulness of waste
2. Prevention of waste that cannot be reused
3. Decrease in diffusion of waste
4. Prevention of waste that can be reused

Measures, promoting each of these types of prevention may be implemented in each link of the **activity chain**:

- A. Exploitation of resources
- B. Manufacturing of products
- C. Trade (wholesale or detail) of products
- D. Consumption or use of products
- E. Disposal of products

In fact, two classes of measures may be distinguished, viz. **policy measures** and **technical measures**. Generally speaking, policy measures are a prerequisite for the implementation of technical measures.

In figure 2, conceivable technical and policy measures are formulated, in general terms (roughly in decreasing order of priority). Thus a basis is formed for the analysis of waste prevention options in any conceivable line of business, for any type of waste.

Of course, this is a generic approach; for the realisation in specific situations, detailed studies are required. Yet, the scheme presented in figure 2 can serve as a basis for selecting cases where the prevention of waste is most relevant.

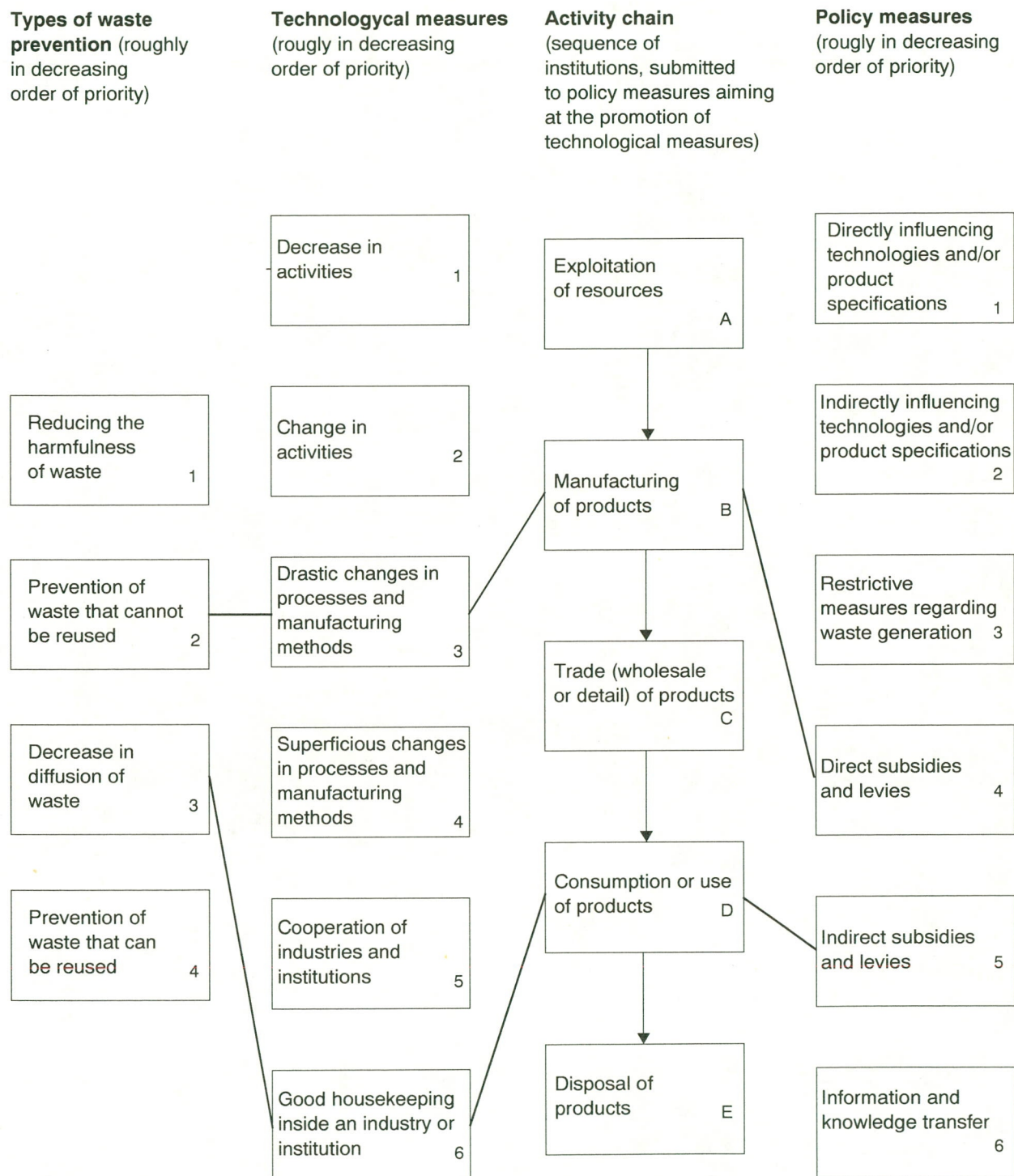


Figure 2 Structural sketch of an approach to the implementation of waste prevention. In specific cases, combinations of elements of the various columns indicate the way in which waste prevention may be implemented, e.g. 36D5, 23B4

1.4 Reuse [35]

As indicated before, the large scale implementation of reuse requires the solution of both non technical and technical problems. In [35], the relation between the various classes of constraints is illustrated like in figure 3.

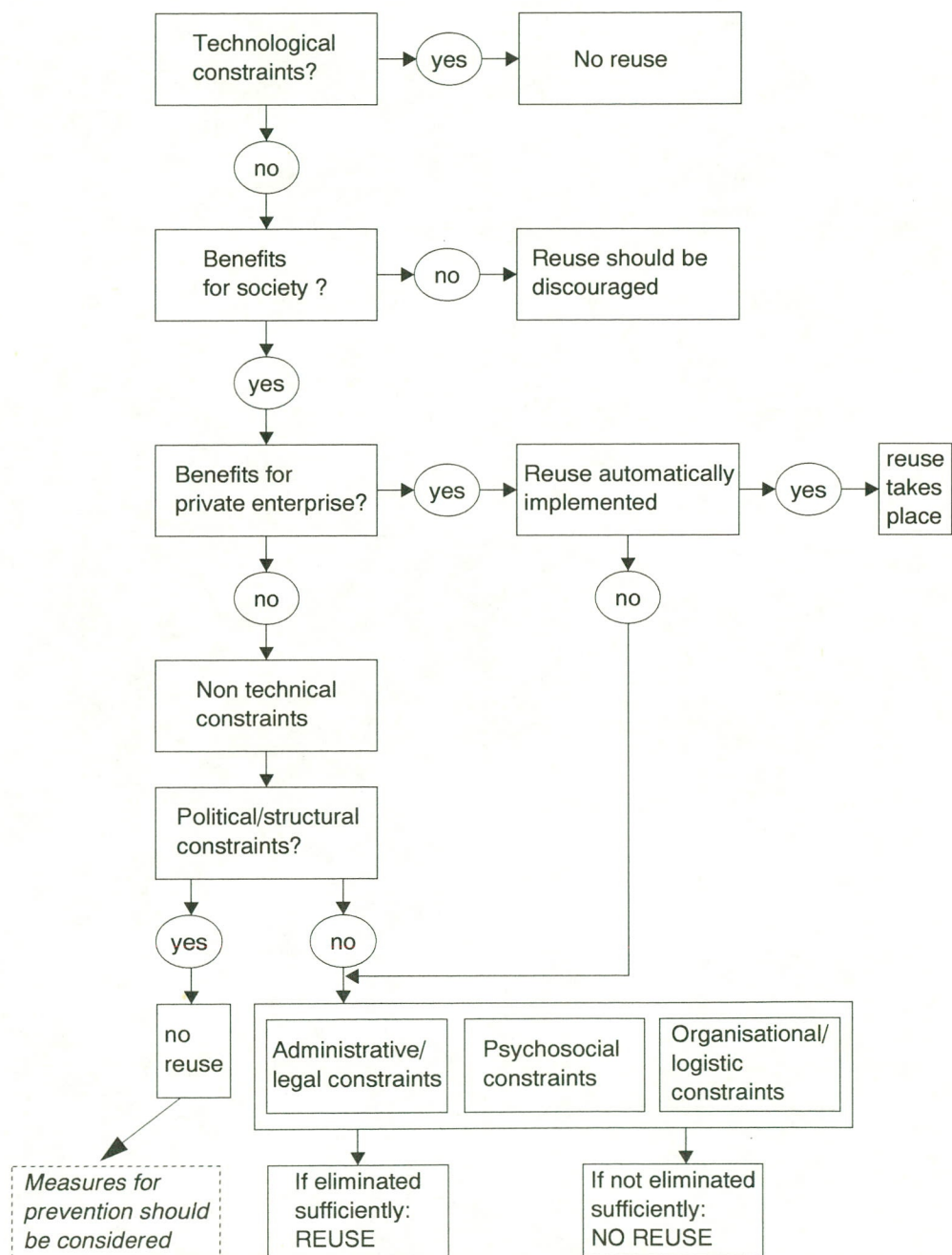


Figure 3 Scheme for identification of constraints in reuse [35]

As shown in table 1, where the energy content of products in the subsequent stages of processing is given, energy saving by reuse is a matter of considerable interest. In general, energy can be saved by the promotion of integrated chain management [33]. This implies that the entire activity chain, from obtaining the resources, through production, utilisation and waste stage, to recycling and reuse or useful application¹⁾ is considered integrally, when certain options have to be assessed (figure 4).

Table 1 Energy characteristics of 22 resources and raw materials (averages as applied in The Netherlands)

Energy content	A:	B:	C:	
Material	Resource energy (GJ/ton)	A + energy for production and transport	B + energy for capital investments	C + energy for manufacturing processes
Metals				
Raw steel		22.6	23.0	23.4
Primary aluminium		189.0	197.8	198.2
Petrochem. resources				
Naphta	42.7	45.7	45.8	45.9
Ethene	42.7	61.2	61.5	61.8
Propene	42.7	61.2	61.5	61.8
Butadiene	42.7	67.2	67.5	67.8
Benzene	42.7	63.6	63.9	64.2
Plastics material				
Polythene (LDPE)	42.7	67.9	68.6	69.3
Polypropene (PP)	42.7	63.9	64.7	65.1
Polyvinylchloride (PVC)	20.7	56.3	61.2	62.0
Polystyrene (PS)	46.4	83.4	83.6	84.6
SBR-rubber	43.3	78	78	79
Paper/cardboard				
Graphic paper	42.8	88.5	93.0	93.4
Packaging paper	46.5	86.5	90.6	91.0
Massive/pliable board	24.5	50.1	52.3	52.7
Corrugated board	12.0	30.3	31.5	31.9
Inert materials				
Portland files		3.65		
Portland cement		4.21	4.43	4.50
Portland flyash cement		3.56	3.75	3.82
Furnaces cement		2.50	2.61	2.68
Packaging glass		9.1	9.5	9.9
Bricks		2.99	3.05	3.10

¹⁾ *Reuse*: usage of a product for the original purpose.
Useful application: usage of a product for a different, lower degree purpose

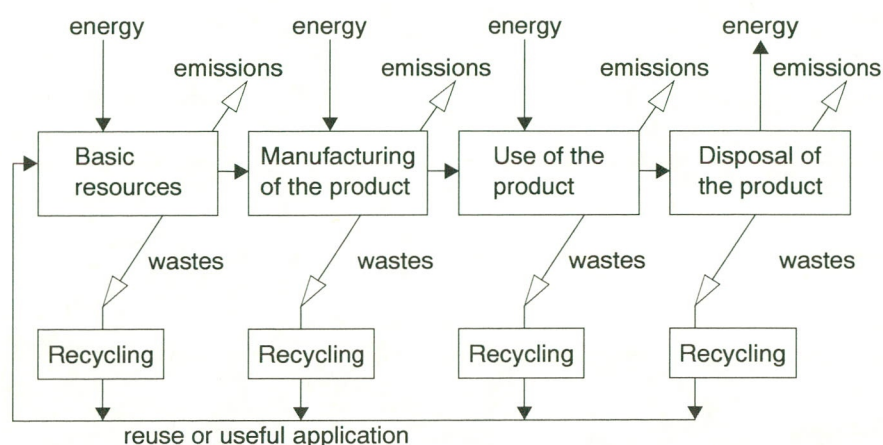


Figure 4 Energy, emissions and wastes in the life-cycle of a product

1.5 Waste streams

In contrast to prevention and reuse, where many non-technical aspects play a part, conversion into energy is mainly (though not entirely) a technological matter, allowing a relatively quick realisation. And, apart from the saving of fossil fuel, the prevention of CO₂ emission from fossil sources is served by producing energy from wastes¹⁾.

On the basis of the Motion Lansink, an integral waste management policy for 29 main waste streams was established in 1988 [1]. These have been totalised into figure 5.

All wastes (manure and dredging spoil excluded)

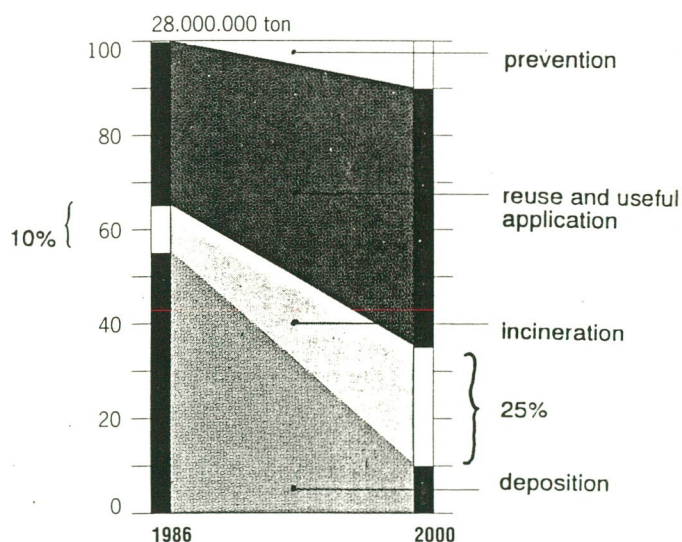


Figure 5 Present policy aim of The Netherlands in the field of waste management (reuse: using the waste for the same purpose; useful application: using it for a different purpose) [1]

¹⁾ This implies the creation of a carbon subcycle, where energy is generated. Thus an equivalent amount of fossil fuel is saved, and the resulting CO₂ is not added into the atmosphere.

In the context of “energy from waste”, the intended increase in incineration capacity from 10% in 1986 to 25% in the year 2000 is of prime importance. The urgency of its implementation is stressed by the fact that the target of reducing the Dutch waste production, as indicated in the National Environmental Policy Plan [2], turns out to be hard to realize. This is clearly demonstrated by the waste stream to landfill, as indicated in figure 6, [3]. From figure 6 it can be seen that the amount of waste disposed of by landfilling, after an initial drop is increasing again; the amount being landfilled in 1990 is approximately equal to that in 1980. Hence the road to the intended target in 2000 has still to be gone entirely. Large efforts have been made to change this trend. With the package covenant, for instance, it is intended to decrease the amount of packaging with 10% in 2000. This requires a great deal of effort from industry, since without extra measures a growth of the quantity of packaging material of 30% was expected.

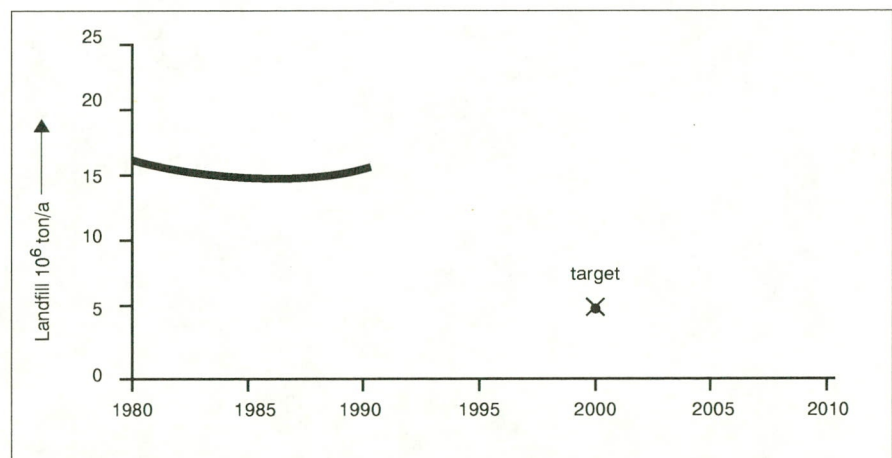


Figure 6 Target and realisation of the waste stream to landfill in The Netherlands [3]

In table 2 [27], a breakdown of the 29 “priority streams” of waste is given, together with the waste production *per capita*. The total of these streams is, however, somewhat more than the 28 mln ton/a indicated in figure 5, since some waste streams indicated in table 2 overlap.

Table 2 Size of annual waste streams in The Netherlands, total and per capita. Streams from which energy can be gained are printed in heavy type [27]

	(* 1000 ton)	(kg/inhab.)
— Batteries	4	0.3
— Blasting grit	100	6.7
— Bulky household waste	700	47
— Car tyres	65	4.3
— Construction and demolition waste	7,500	500
— Dredging spoil	50,500	3,367
— Flyash from coal-fired power plants	530	35
— Glas (non-refillable)	430	29
— Halogenated hydrocarbons	55	3.7
— Hospital waste	150	10
— Household waste	5,000	333
— Jarosite	220	15
— Manure	100,000	6,667
— Office, shop and service waste	1,800	120
— Oxylime sludge	120	8
— Packaging waste	2,000	133
— Paint waste/spray painting waste	20	1.3
— Phosphogypsum	2,100	140
— Plastic waste	540	36
— Polluted soil	500	33
— Scrap in household waste (especially cans)	125	8.3
— Scrap vehicles	500	33
— Sewage sludge	6,000	400
— Shipping waste (chemicals)	160	11
— Shredder waste	100	6.7
— Slag and flyash from incineration of household and commercial waste	750	50
— Street waste, market waste, waste from parks and waterways, dredged slurry and pit mud	1,400	93
— Waste paper/cardboard	2,200	147
— Waste oil	110	7.3

2 Organisation structure of R&D on waste in The Netherlands [28]

In figure 7, the structure of the organisation for the implementation of the Dutch Government policy is shown. The execution of the programs is a task of The Netherlands Agency for Energy and the Environment (NOVEM) which operates in a cooperation with the National Institute of Public Health and Environmental Protection (RIVM). Both these institutions and the programs they manage are financed by the Ministries of Economic Affairs (EA) and the Ministry of Housing, Physical Planning and Environment. EWAB (Energy from Waste and Biomass Program) also is part of NOVEM but is managed by EA only. The contractors for the projects are Research Institutes, Universities, Equipment Manufacturers, Engineering Consultants, and the Municipal Waste Combustion facilities. The activities at the municipal waste facilities are coordinated with the assistance of their branch organisation, the Waste Processing Association (VVAV).

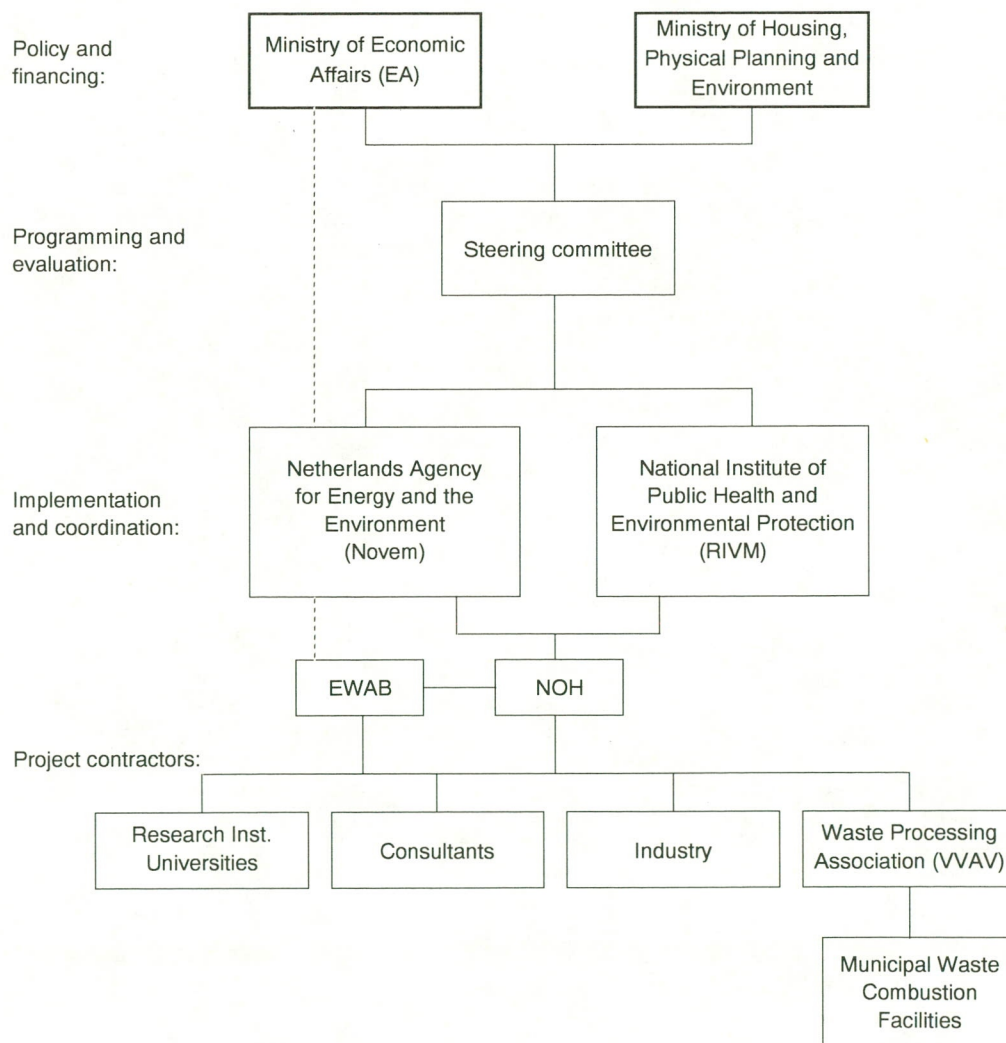


Figure 7 Organisation structure of R&D on waste in The Netherlands

2.1 R&D on energy from waste

The executing organisations NOVEM and RIVM issue and manage a number of research programs on waste on behalf of two Ministries. In total, however, at least 16 research programs in the field of waste exist; in 1990 some Dfl. 70 mln was utilised through these programs together [31].

In table 3, research of efforts and program managing institutions are shown for R&D on the energy containing wastes, as indicated in table 1.

The abbreviations of the institutions in table 3 are in Dutch. Their meaning is explained hereafter.

VROM/DGM/A:	Ministry of Housing, Physical Planning and Environment, Directorate General for Environmental Protection, Directorate of Waste Management Policy
RIVM/LAE:	National Institute of Public Health and Environmental Protection/Laboratory for Waste Materials and Emissions
ITABB:	Interdepartmental Commission on Application of Secondary Materials in the Building Industry
Stim. reg. M.T.:	Environmental Technology Incentive Scheme
NOH:	National Reuse of Waste Research Program
EWAB:	Energy from Waste and Biomass Program
EK:	Tender Scheme Energy Saving by Integral Chain Management
IOP-MT	Innovative Research Program for Environmental Technology (for Universities)
RIZA:	Institute for Inland Water Management and Waste Water Treatment
STOWA:	Foundation for Applied Water Research
DWW:	Road and Hydraulic Engineering Division, Ministry of Transport, Public Works and Water Management
PCLB:	Program Committee on Agricultural Biotechnology
DLO/Mest ¹⁾ :	Ministry of Agriculture, Nature Management and Fisheries, Agricultural Research Department, Manure and Ammonia Research Program

¹⁾ Mest = manure

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As can be seen from table 3, 13 institutions are involved in 13 categories of energy containing wastes. In total, some Dfl. 55 mln/a is spent on R&D on this subject. The efforts differ from Dfl. 0,20 to Dfl. 16,- per ton of waste. The emphasis of the programs lies on waste treatment and disposal, applying more or less conventional technologies.

Practically all programs in the first place finance applied research and, to a lesser extent, feasibility studies. The effort in demonstration projects is limited (EWAB), up to now.

The implementation of the various programs shows a wide variety. In particular, there are differences in the way in which the program and the projects are effectuated, and in the level of the financial support.

In the context of government supported research on "energy from waste", the National Research Program on Reuse of Wastes (NOH) and the Program Energy from Waste and Biomass (EWAB) are most relevant. In 1990, their budgets were Dfl 6 mln and Dfl 7.5 mln in 1990, respectively [31]. By these programs, research is financed (sometimes fully, sometimes partially) on prospective items - particularly on subjects that have a chance on industrial implementation within a reasonable time span [29, 30].

3 Municipal solid waste

The policy with respect to the total waste management, as indicated in paragraph 1 also constitutes the situation regarding Municipal Solid Waste, as well as the R&D in that field. In figure 8, the targets for MSW are indicated. In this context it is obvious that the discrepancy between the policy illustrated in the figures 5 and 8 on the one hand, and the achieved results shown in figure 6 on the other, is a matter of considerable concern, requiring intensification of R&D, not only on technological matters, but also regarding non-technical constraints.

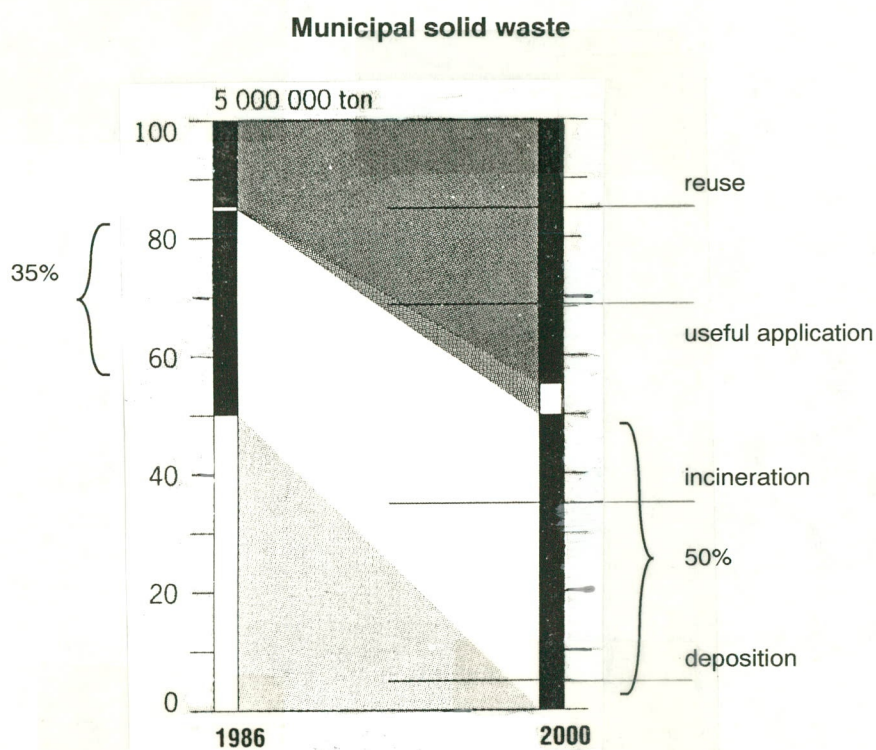


Figure 8 Bar diagram, indicating the policy aims in the field of Municipal Solid Waste in The Netherlands [1]

An analysis of (technical) constraints, implied by the proposed drastic increase in incineration capacity, was made in 1989, and based on this analysis a research and demonstration program was developed [14]. At present, a number of the projects indicated in this program has been carried out; most others have been started up [26].

In the research program, attention is paid to interactions between various phases in the entire chain from acceptance of waste to deposition; efforts are made to arrive at an integral evaluation of technical and non-technical measures and their effects, however emphasis is on technical aspects of the last phases.

One of the results from the analysis [14] is that the total energy production from waste may well be increased from the present 150 MWe up to 400 to 1000 MW, depending on the realised increase in capacity and efficiency.

In the following paragraphs the options available to this end will be elaborated further, together with some of the problems they imply.

4 Energy from MSW

Basic options for conversion of solid waste into energy are

- incineration of untreated waste ("mass incineration") or RDF (after processing),
- gasification,
- pyrolysis,
- fermentation of MSW in dedicated equipment,
- deposition, followed by exploitation of landfill gas.

In the following paragraphs, the state-of-the-art regarding R&D for each of these options will be outlined.

Criteria applied to assess the various alternatives are basically:

- environmental effects:
 - flue gas emissions
 - properties of the residues/products
 - quality of the waste water (if any)
- energy properties:
 - net energy efficiency of the disposal system
 - usefulness of the energy generated (electricity – heat – fuel gas)
- economic aspects

In particular the flue gas emissions obtain a great deal of attention; one of the main topics in this context is prevention and abatement of dioxines. Since 1989 new emission standards apply to waste incineration, the so-called *Richtlijn Verbranden '89* (RV '89); existing installations will have to comply with these standards after 1994. Because of these requirements the various options to improve flue gas cleaning are of great interest.

Another aspect playing a role is the CO₂ production. As indicated before, by utilizing waste for energy production fossil fuel is substituted. Most of the combustible material is of biological (non fossil) origin, so incineration does not add CO₂ to the atmosphere. Apart from the economic benefit, this is another reason to select a disposal scheme that has a high net energy production and therefore a high potential of fossil CO₂ emission prevention.

4.1 Incineration

From all waste available, around 2.6×10^6 tons per year is incinerated in The Netherlands. As indicated in figure 8, the fraction of MSW incinerated is some 35%, or 1.8×10^6 tons/a. In all waste management scenario's considered for predicting the required future developments, the incineration capacity has to increase considerably. Depending on the success of the policy of reducing the waste stream by prevention and reuse, and the application of alternatives like composting or digestion of the organic part, or continuation of landfilling, the capacity has to increase to somewhere between 5 and 7.5×10^6 tons per year around 2000.

Existing Dutch incineration facilities are listed in table 4.

Table 4 Waste incineration installations in The Netherlands

Installation	Nr. of incinerators	Capacity (tons/hour)	Energy recovery	Capacity (tons/year)
Leiden ^{*)}	3	12	no	
Zaanstad ¹⁾	2	18	no	
Alkmaar	3	18	no	123
Leeuwarden ¹⁾	2	12	no	
Amsterdam-Noord	4	68	yes	370
Den Haag	4	52.5	yes	330
AVR	6	126	yes	975
ROTEB	4	50	yes	390
Philips	1	3.5	yes	25
Roosendaal	2	8	yes	35
GEVUDO	3	21	yes, one line	144
AVIRA	3	42	yes, two lines	256
ARN	1	9	yes	68

^{*)} closed in 1990 because of emission levels.

All these incinerators are of the moving or roller grate type; the majority is equipped with a steam boiler for heat recovery. Roosendaal and Avira 3 produce hot water. Furthermore the Roosendaal installation is used for drying of sludge from a sewage water cleaning system; in one of the incinerators of Gevudo sludge is incinerated in the flue gas stream.

At present all installations are equipped with ESPs¹⁾ for particulate control; some have dry sorbent injection for controlling acid emissions; in others a wet flue gas cleaning system is applied.

In 1989, the general concern about a high level of dioxines found near a waste incineration facility led to the establishment of a new set of standards for the flue gas emissions from municipal waste incinerators. This is the Incineration Directive '89, know as RV '89. Table 5 shows the main figures from this standard and for comparison also the EC guideline and the German 17. BIm SchV. Existing flue gas cleaning systems will have to be improved to comply with this standard.

¹⁾ ESP: Electrostatic Precipitator

Table 5 Comparison of emission standards of "Incineration Directive '89" of The Netherlands with those of the EC and Germany

Component	EC mg/m. ³	Maximum emission RV'89 (1-hour average) (mg/m. ³)	Germany 24 hours average (mg/m. ³)
total dust	30	5	10
gaseous anorganic chlorides (as HCl)	50	10	10
gaseous anorganic fluorides (as HF)	2	1	1
CO	100	50	50
gaseous organic compounds (as C)	20	10	20
SO _x (as SO ₂)	300	40	300
NO _x (as NO ₂)		70	200
heavy metals:			
Sb+Pb+Cr+Cu+Mn+V+Sn+As+Co+Ni+Se+Te (total)	1.5	1.0	0.5
Cd	0.1	0.05	0.05
Hg	0.1	0.05	0.05
PCDD's and PCDF's		0.1 ng TEQ/m ₀ ³	0.1 ng TEQ/m ₀ ³

4.1.1 Research and development in The Netherlands

In the past, waste management was mostly handled by the local authorities. However, the increasing scale of the problems, more stringent environmental standards and advanced processing schemes require nowadays cooperation on a higher level.

During the last years there has been close contact between Veabrin (now VVAV), the Dutch Waste Processing Association, and NOVEM/RIVM to assess the possibilities for improving waste incineration in The Netherlands. A large number of studies has been performed and is going on in the framework of the NOH, EWAB and Denox programmes. In 1989 NOVEM/RIVM and Veabrin planned the studies for the period 1989-1992 [14].

Basic for this program were the following needs:

- reduction of flue gas emissions, i.e. dioxines and NO_x.
- optimal utilization of the energy content of the waste, which might at least partly be considered as renewable energy.
- improving combustion conditions to increase capacity; improving availability and decreasing maintenance of the installations.
- improving residue quality with respect to applicability, simultaneously decreasing risks for the environment.

In the program, all steps in waste processing are taken into consideration, ranging from input and acceptance to disposal and reuse of the residues.

As far as the incineration process itself is concerned, a number of different "waste-to-RDF" schemes have been assessed and tested on various scales, including full scale combustion trials. Design and construction of the incinerator and boiler have been studied with regard to maintenance, efficiency, emissions and economical aspects. In the following paragraphs recently finished and current projects will be described.

4.1.2 Mechanical processing of waste to RDF

Recently it has become more and more usual to collect a number of fractions of municipal waste separately. Most relevant in this context is the separation of the so-called GFT-fraction (Kitchen Vegetable and Garden Waste, sometimes called the "green" or "putrescible" fraction) which is intended for the production of compost. In a few years this will be common practice in The Netherlands. This separation at the source can be followed by mechanical processing of the remaining waste, the so-called restfraction, at the waste incineration facility, in order to remove the metals and other inert material from the material to be incinerated. The inert material may then directly be landfilled. This scheme and the designation of the various fractions are presented in figure 9.

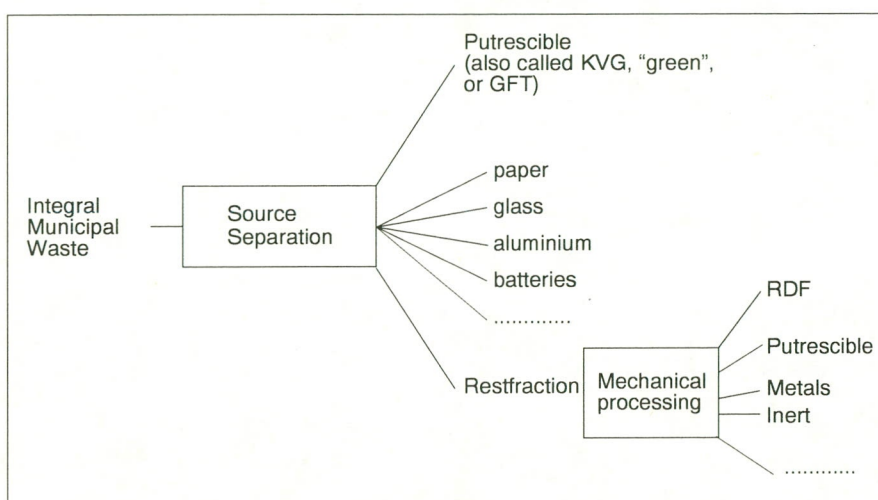


Figure 9 Designation of the various waste fractions as used in this report

A number of studies and experiments have been carried out on the effect of various waste-to-RDF processes and on the combustion characteristics of the product, in combination with the incinerator type.

One of the first tests of this type was carried out at the end of 1988 at the installation of Leeuwarden by Tebodin Consultants [17]. Combustion trials of separately collected waste (without KVG), were compared with similar trials with integral waste. The test runs have been relatively short due to the fact that only a limited amount of separately collected waste was available, so the results are somewhat indicative.

The combustion of the restfraction was faster and the distribution of the material on the grate was more uniformly, so the combustion was also more complete. The integral waste had a higher moisture content than the waste usually burnt in this incinerator, resulting in a poor and unstable combustion process. Pre-heating of the combustion air might have improved the process.

The concentration of heavy metals in slag and fly ash from the combustion of the restfraction were significantly higher; the leaching properties, however, were similar.

No final conclusions could be given regarding the gaseous flue gas emissions like HCl, SO₂, NO_x and CO.

Particulate emissions were very high during incineration of the integral waste; this might be due to the poor combustion conditions. It could be concluded that by the separate collection scheme, and composting of the KVG-fraction, a mass reduction of the combustion residues of 15 - 40% is feasible.

Another project has been carried out by DHV Consultants, using the Philips incinerator, in order to assess incineration of RDF, produced by an installation developed by VAM, in comparison to mass incineration of the restfraction of the source separated MSW [18]. The VAM mechanical processing installation is shown in figure 10.

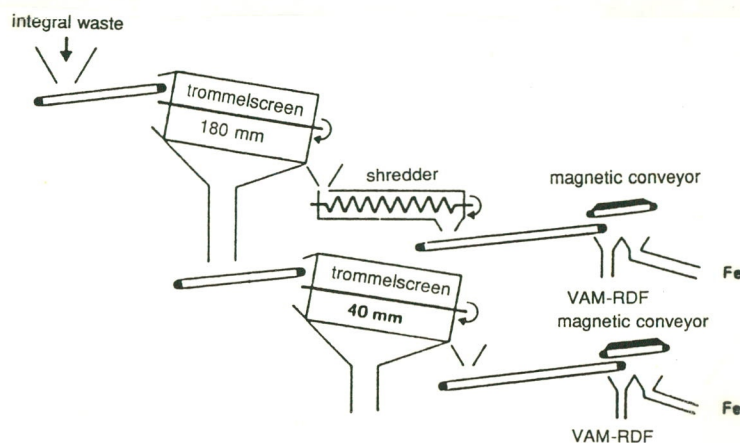


Figure 10 Schematic diagram of the VAM system for RDF production

This processing results into the change of a number of properties. The moisture content, for instance, decreases from 44 to 33%, the LHV¹⁾ of RDF increases from 15 to 20 MJ/kg (dry), the metal content decreases from 10 to 4%. VAM calculated, based on the expected waste composition in the near future, that 56% of the separately collected waste supplied to the mechanical processing unit will be incinerated; the remainder will be directly landfilled. This reduction of the required capacity of the incinerator, resulting in lower investment costs, compensates for the loss of energy recovered (45%) and for the increase in the amount of material to be landfilled. The total costs of disposal are almost equal for both alternatives (Df 100 per ton of waste supplied to VAM for disposal, at a total capacity of 0.9 Mt/a).

The average flue gas emissions, measured before cleaning are lower than during incineration of integral waste. This is partly due to the composition of the waste after being processed to RDF and partly to the improved combustion conditions (more homogeneous and higher temperature).

¹⁾ LHV: Lower Heating Value

A problem that occurred during the test was that the reference-experiment - incinerating the integral waste - could not be conducted properly. Combustion conditions got out of control, finally leading to loss of fire. Due to this, some of the reference parameters, had to be calculated.

Based on these experiments, that were carried out at the Philips incinerator, a full scale installation for producing VAM-RDF and an incinerator will be built.

Long duration combustion experiments with various domestic waste fractions have also been carried out using unit no. 4 of the Waste Incineration Facility in The Hague on three different waste fractions [11]. The fractions used in these experiments were compiled from (household) Municipal Solid Waste. The following fractions were investigated (see figure 11 and 12).

- integral domestic waste.
- the restfraction obtained after separate collection of KVG.
- a fraction obtained after mechanical processing of the restfraction (RDF fraction).

The objective of the experiments was to evaluate the effects on incinerator capacity, energy conservation, quality of combustion and quality as well as and quantity of the emissions, bottom slag and fly ash discharge.

All fractions were derived from household waste, not mixed with other waste streams, which would usually be incinerated together with household waste. The effects of the waste processing observed may therefore have been more pronounced than in actual practice.

The principal results of the experiments are:

- The reductions of incinerator capacities due to combustion of the restfraction and of the RDF fraction are approximately 15% and 35%, respectively (in this specific conventional incinerator).
- There is a decrease in CO emissions due to combustion of the restfraction. A stronger reduction is obtained by combustion of the RDF fraction (see fig. 13).
- There is a positive impact on the thermal efficiency of the incinerator as a result of combustion of the restfraction and the RDF fraction.
- There are various effects on the flue gas emissions. These effects are partly due to the increasing concentration of some components in the waste feed and partly due to the opposite effects of the separation of waste (see figure 13).
- The production of bottom ash in relation to the input during combustion of the restfraction is not influenced. The bottom ash production per ton of input decreases considerably during combustion of the RDF fraction.
- There is a considerably diminished fly ash production due to combustion of the restfraction and the RDF fraction.
- The impact on the quality of the solid waste varies between neutral and negative.

All effects are related to the combustion of integral domestic waste.

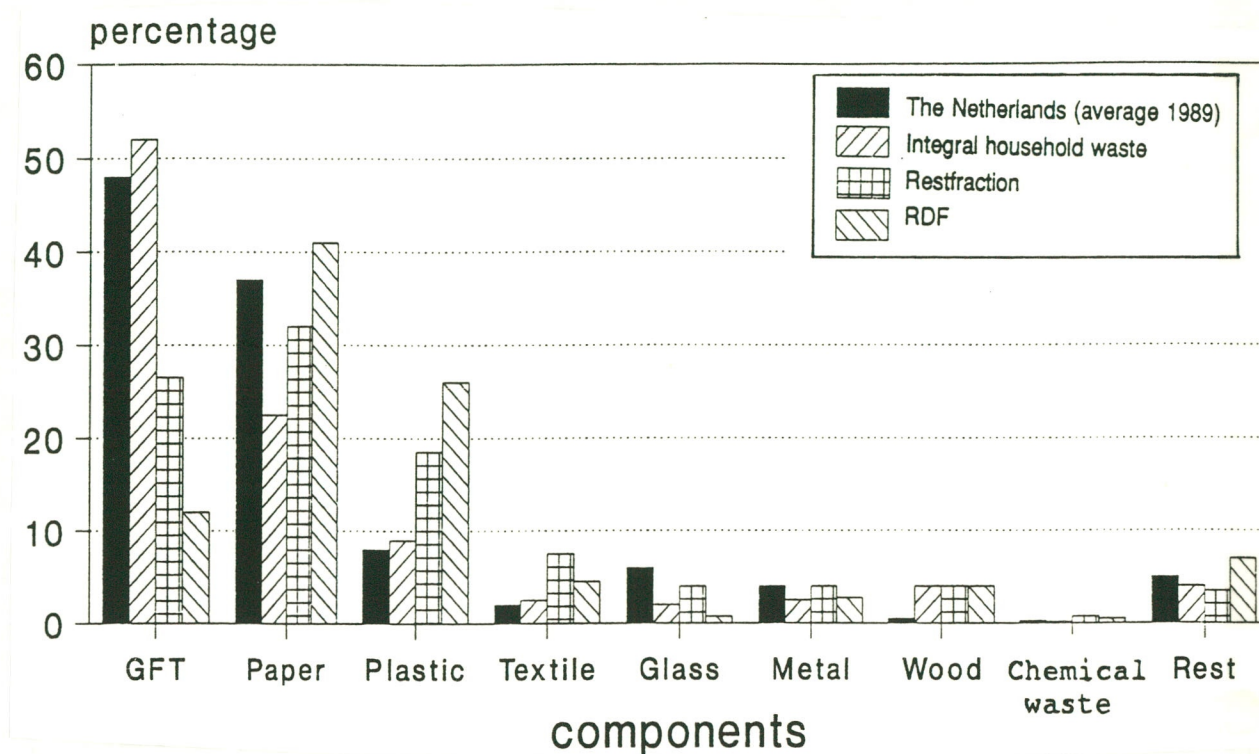


Figure 11 Composition of the three fractions, determined by sorting analyses [11]

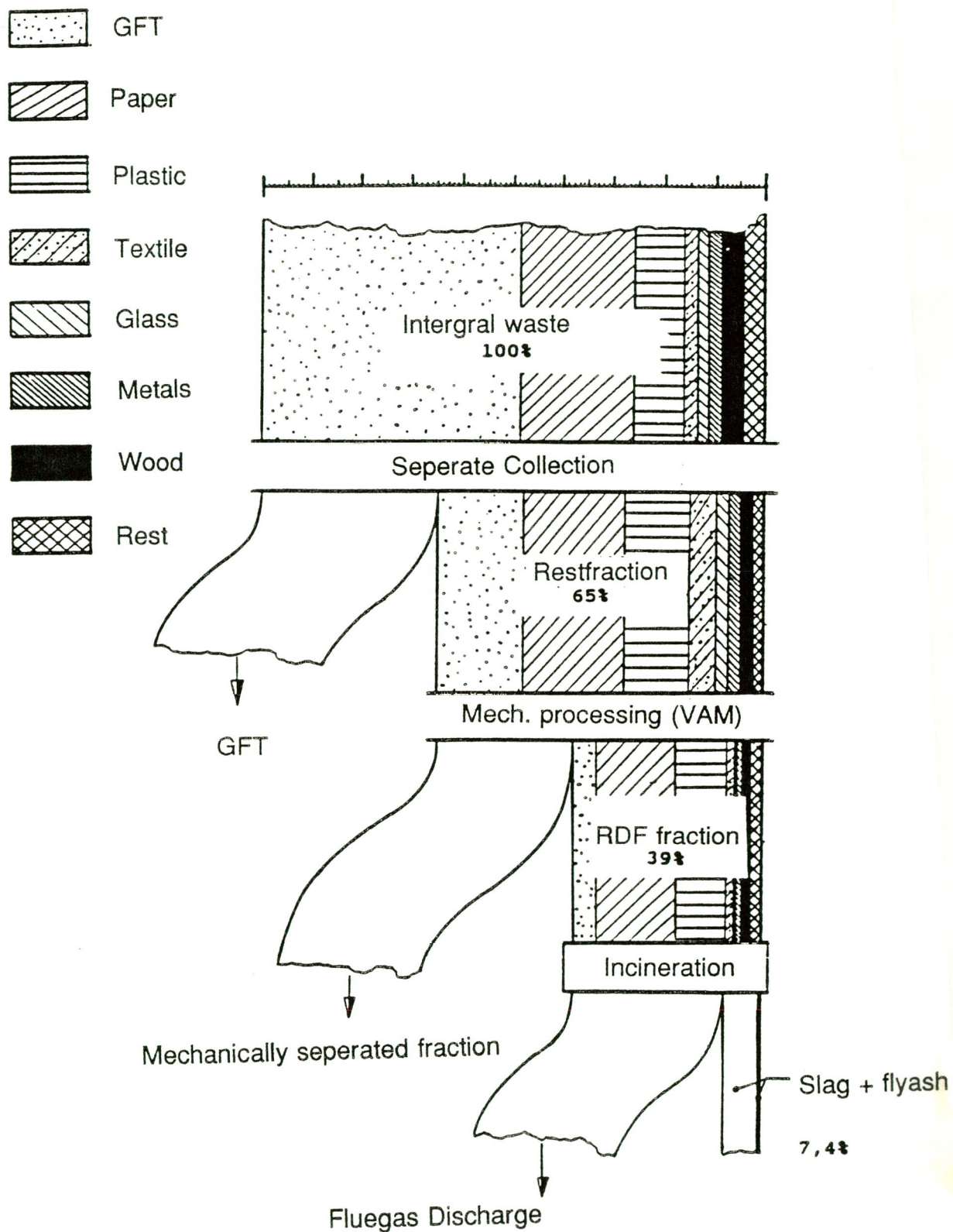


Figure 12 Change in composition of the various fractions by the subsequent steps and the end products [11]

Note: Since the fractions tested are of different origins small differences in composition, independent of the processing do occur

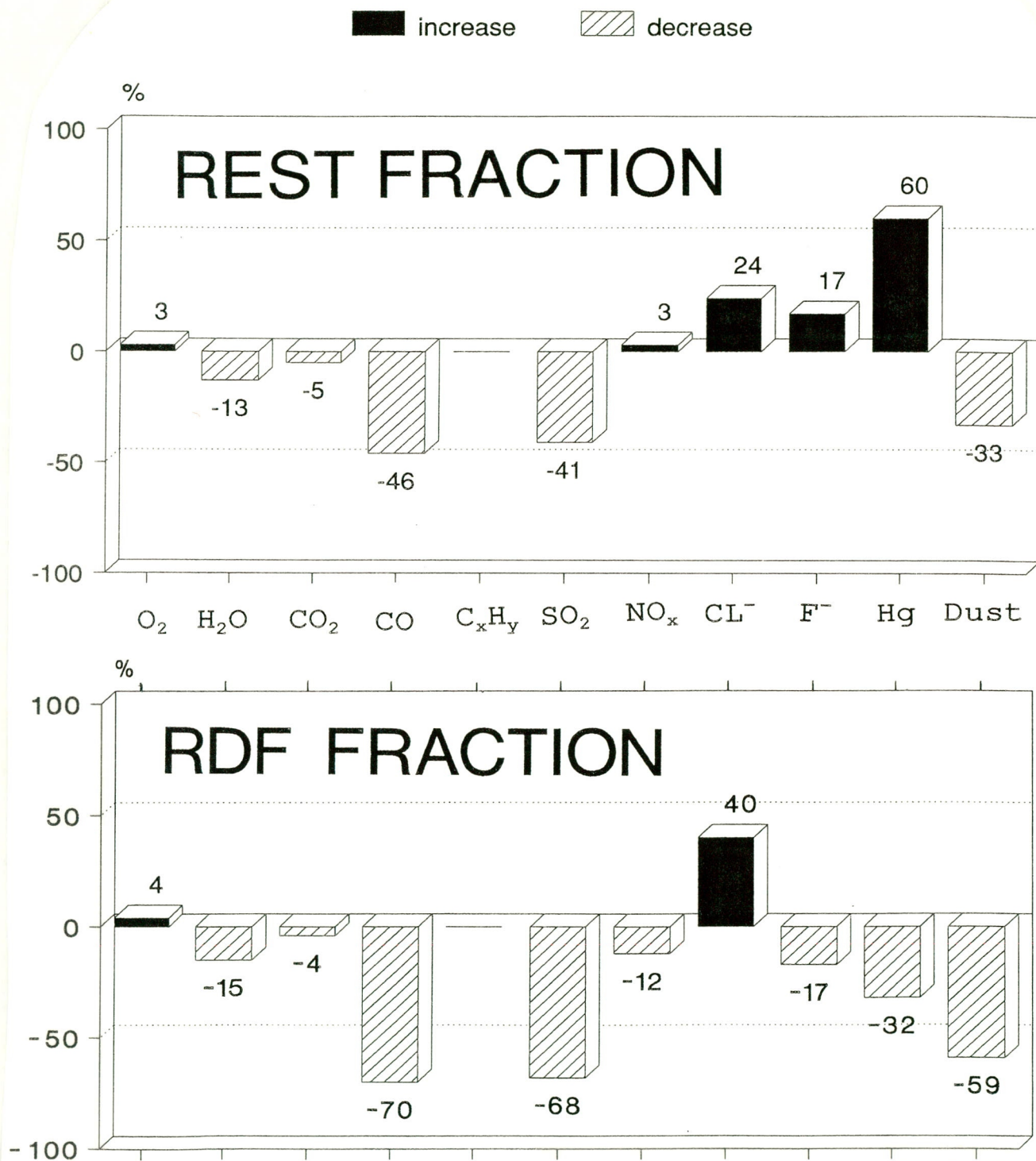


Figure 13 Effect of the processing steps on the concentrations of various components in the flue gas, relative to the reference situation of burning the integral waste

A similar experimental research program has been conducted at the ARN¹⁾ by ARN and TNO [5]. The specific aim of these experiments was to assess the effect of the future change of the waste composition that might be expected as a result of the governmental waste policy. ARN does not operate a mass burn installation but applies a mechanical processing system producing RDF (fluff).

In the first reference experiment the usual mixture of integral MSW, industrial and bulky waste and construction and demolition waste was processed and incinerated.

In the second experiment, only the restfraction of separately collected MSW was processed (resulting in particle size decrease and iron-removal) and incinerated.

In the third experiment three waste streams (restfraction of MSW, industrial and demolition waste) were processed separately and incinerated after mixing (table 6).

Table 6 Results of the ARN combustion trials [5]

Experiment	1	2	3
heating value of waste (MJ/kg)	10.7	14.5	13.3
electricity generation/ton	100%	125%	122%
reuse of waste	100%	1100%	1800%
combustion residues to be landfilled	100%	215%	130%
capacity (ton/hour)	100%	130%	80%
waste to landfill	100%	125%	17%

Experiment 2 as well as 3 shows a considerable increase in specific electricity production, a large increase in reuse of waste and an increase of combustion residues to be landfilled. In a scenario according to experiment 2 the capacity of the installation would increase considerably; however, the part of the waste to be landfilled would increase almost proportionally. Experiment 3 showed a decrease of the total capacity and a decrease of waste to be landfilled.

In the near future the results of the various large scale experiments described here will be compared and evaluated.

Generally it is concluded that incineration of RDF leads to reduced emissions and increased energy output compared to mass incineration [5, 18]. Some theoretical studies have been performed to assess the possibilities for improving RDF quality [12] and the development of dedicated incineration equipment [8].

¹⁾ ARN: Afvalverwerking Regio Nijmegen

4.1.3 Improving energy efficiency of waste incineration

In most existing installations the efficiency of the conversion of waste to electricity is low compared to fossil fuel fired installations. Typical figures for current electricity generating waste incinerators are: steamtemperature 400 °C, pressure 40 bar, air-stoichiometry 2, stack temperature 200 °C, power consumption 15%, efficiency 22.5%.

To improve the economics of the process and also to substitute as much fossil fuel for power generation as possible, optimisation of the energy efficiency is important.

In a study by KEMA [4] various options to increase the output of the process have been assessed.

In the first place it is concluded that, because of the relatively high value of electricity (based on required primary energy) and due to problems in applying all the heat that might be generated, maximising electricity production is preferable. To this end, a number of options is available.

The boiler efficiency can be increased by:

- Increasing the combustion air temperature;
- Decreasing the airfactor to 1.8 or 1.6; This requires a more sophisticated control of the combustion process and in case of the lowest airfactor also mechanical homogenization of the waste;
- Flue gas recirculation, allowing a lower airfactor (1.6) without homogenization of the waste;
- Decreasing the flue gas exit temperature.

By these measures, the electric efficiency rises 1% point. Especially improving the control of the combustion process together with mixing the waste as well as possible with the charging crane, allowing a reduction of the airfactor, is very cost effective. This can also be applied at existing installations.

In case of new installations there are a number of options for increasing the steamcycle efficiency.

- Increasing steamtemperature and pressure up to 520 °C and 80 bar approx. In this way an increase of the electric efficiency of 4% points may be achieved. Especially increasing steamconditions less drastically might be considered.
- Combination of a waste incinerator with a gasturbine waste heat boiler.
By using this combination the moderate temperature of the steam arriving from the waste incinerator can be superheated to around 490 °C. Thus, the efficiency of the waste incinerator is increased with 5% points. The calculated pay back period for the extra investment is around 5 years.
- Combination of a waste incineration and a gas fired boiler.
The efficiency increase with this system is relatively low, 0.9% point, resulting in an unattractive pay back period.
- For older installations, having a high flue gas discharge temperature, say 280 °C, a modification to decrease this temperature to 200 °C, or somewhere in between might be considered. This would lead to an increase of efficiency of 2% points. Depending on specific conditions (spare capacity in parts of the installed heat exchange area or in the steamturbine) a certain investment to decrease this temperature might be profitable.

From these figures it is clear that in case of a new installation, the flue gas discharge temperature should not be higher than 200 °C.

The option of increasing steam conditions in the waste incineration boiler has been subject of a separate study by KEMA [9]. Experiences with these conditions in a number of German installations were assessed.

Special attention has been paid to technical consequences related to the boiler concept, and precautions that have been taken in order to prevent corrosion.

Apparently the reason to choose a high steam temperature (480 °C - 500 °C) in the installations that have been studied was, that they were connected to an external steam system requiring these conditions.

Based on experience from the installations of Dusseldorf, Mannheim, and Oberhausen the following conclusions were drawn:

- A steam temperature of 500 °C is technically feasible.
- The availability of the installations has been developed such that it is at present comparable to "conventional" installations (78% - 85%).
- In the past there have been many corrosion problems in the installations considered, but these problems are not directly related to the steam conditions.
- Careful design of the installation is required to prevent corrosion damage (a.o. prevention of local reducing conditions, temperatures and gas velocities in the proper range, proper surface protection in the high temperature zones, adequate combustion process control).
- At high steam temperature, corrosion problems of the superheater section are more severe. These problems can be handled by selecting the right material and (more) preventive maintenance, increasing the operation costs with 1 DMark/ton, approx.

Of course, the percentage points of efficiency improvement, mentioned in this paragraph, are not entirely cumulative.

4.1.4 Reduction of emissions

As indicated before, after 1993 waste incinerators will have to comply with RV'89. These standards are very stringent, similarly to new standards in a number of other countries, and have a large impact on technological, economical and energy aspects of waste incineration. Not only have new concepts for flue gas cleaning been developed by the international manufactures, but also much effort is put into the improvement of the combustion process to prevent hazardous emissions in the first stage of the process.

A study by KEMA [13] shows that the energy consumption of a flue gas cleaning system, in compliance with RV'89, is between 13.3 and 21.5% of the generated gross power. This would even be higher for a small installation. Energy consumption as well as investment cost might be reduced by applying flue gas recirculation.

One group of flue gas components that receives much attention is that of PCDDs and PCDFs ¹⁾.

Because of the general concern regarding these components the government ordered a large program in which TNO measured dioxine emissions of all Dutch waste incinerators [44]. The dioxine concentrations in flue gas varied

¹⁾ PCDD/F: Polychlorinated Dibenzo-p-Dioxin/Furan

considerably between incinerators, ranging from 2.2 to over 90 ng TEQ/m³ ¹⁾. At one incinerator (Zaanstad) a single extreme concentration was measured (955 ng TEQ/m³). With the requirements of RV'89, MSW incinerators will have to take significant measures to improve process conditions and cleaning of the flue gases.

Because of the stringent NO_x requirement in RV'89 (70 mg/Nm³) there is a need to assess various systems to comply with this standard. For that reason the government (VROM) ²⁾ has founded a program for research and demonstration of NO_x removal from waste incineration. In this program four different Denox systems will be demonstrated and evaluated at five different waste incinerators (Table 7).

Table 7 Denox demonstration projects

Waste incinerators	Systems
AVR/Rotef	SCR (Selective Catalytic Reduction)
VAM	SCR Active Coke
AVI West Amsterdam	SNCR/NH ₃ injection (new inst.)
AVIRA Duiven	SNCR/NH ₃ injection (existing inst.)

4.1.5 Miscellaneous projects

In order to collect and disseminate the scattered know how and experience concerning the waste incineration process, available at operators of installations and manufacturers, Veabrin has compiled a Handbook Quality Control of Waste Incineration ("Handboek Kwaliteitsbeheersing Afvalverbranding") [46].

This handbook covers almost all practical aspects of waste incineration, starting with waste characterisation, continuing with the lay-out of a plant, acceptance of waste, components of the installation, energy utilisation, flue gas cleaning, residues and ending with safety, legal and economical aspects. An English version of the handbook is in preparation.

Another VVAV (Veabrin) project has been an assessment of continuous flue gas emission analysis systems [47], carried out by Haskoning. The results of this study consist of recommendations concerning the design of such a system.

¹⁾ TEQ: Toxic Equivalent

²⁾ VROM: see 2.1

Various quality improvement processes for waste incineration and sewage sludge incineration residues have also been evaluated [48] by Veabrin. Processes considered were:

- sintering (temperature up to 1200 °C),
- melting (temperature 1200 - 2000 °C),
- washing.

The additional costs of these processes imply a major problem; furthermore they require much energy.

Mathematical modelling of the incineration process, aiming at a better understanding of its complex interactions, ultimately resulting into improved process control is subject of an ongoing project by TNO [45]. This study comprises various parts e.g.:

- A parameter study, in which experimental data from incinerator units have been correlated with dioxin emission. A good correlation was found between the dioxin emission and the carbon concentration in the E-filter ash.
- A theoretical modelling based on mass and energy balances, combined with reaction kinetics. This principle has been applied to various parts of the incinerator, e.g. the flue gas cooling zone, the waste layer on the grate and also on the process dynamics of incinerator and boiler.

A more practical approach is applied in a large project aiming at the improvement of the combustion conditions in a large incinerator (at AVR), to decrease the emission of CO, dioxines and hydrocarbons. To this end an elaborate measuring program in the incinerator has been conducted (TNO). Based on the conclusions of the first phase of this project, various major alterations will be made to the installation. In a later stage the results will be verified experimentally.

The moving grate is an important part of a waste incinerator; its proper functioning is crucial for good combustion of the waste. Because of the severe operating conditions it is, however, subject to a high wear rate. At present KEMA is conducting a study to evaluate the various grate types currently in operation, bearing in mind the gradually changing waste composition in The Netherlands and the more stringent emission standards.

The result of this study will be an inventory of practical experiences and recommendations for improvement.

In almost all experimental work on waste incineration it is important to know the calorific value of the waste as accurate (and as fast) as possible. To this end VVAV, together with KEMA, has started a study in order to assess the possibilities for establishing the heating value of waste (streams) in an economically feasible and sufficiently accurate way ("Calorimeter" project).

4.2 Gasification

In the gasification process, biomass and polymers are heated at understoichiometric conditions, with air or oxygen. In the first case a mixture of CO, H₂ and N₂ is produced, in the second case a mixture of CO and H₂. Both can be used as fuel gas; the latter, however, has in principle a higher value as a resource for industrial hydrogen.

After cleaning fuel gas is a versatile energy carrier which has many advantages

over the initial waste. Its composition is more constant, enabling a higher efficiency to be obtained. Also, in this way dioxin production may be avoided.

At present, industrial attention is paid to the gasification of polymer wastes. The implementation of waste gasification in The Netherlands is still in its infancy. Both by NOVEM and in the framework of so-called IOP's (Innovative Research Programs) research on slagging gasification of polymer waste is under preparation (TNO plus University Twente). If the results turn out to be positive, pressurised gasification may be a next step. In these contexts, however, the economics will play a crucial part. Whether or not this technology will ever be applied to MSW, remains to be seen.

4.3 Pyrolysis

Pyrolysis - heating of biomass and polymers without oxygen - leads to the breaking down of large molecules into a not very well defined (nor predictable) mix of gases, fluids and solids. In principle, this mix can be used as a resource, and refined into oil or petrol.

However, both composition and price of the mix obtained gives rise to problems. Though some attention is given to this technology in The Netherlands [16] it is unlikely that it will ever be applied to MSW.

4.4 Fermentation of MSW in dedicated equipment

As indicated in 4.1, separation of KVG from the MSW results into an increase in heat value of the restfraction, since the KVG contains a great deal of water. Nevertheless, KVG does contain energy as well. Composting it aerobically actually implies destruction of this energy: a part of the biomass is gradually oxidised into CO₂ and H₂O and the heat disappears into the air. What remains is compost; this is still for a great deal organic material, which can be utilised for soil improvement. Its value as a nutrient is limited (table 8), [21].

Table 8 Nutrients in KVG-compost in % dry material (approximate values)

Nitrogen (N)	1.5
Phosphate (P ₂ O ₅)	0.7
Potassium (K ₂ O)	1
Calcium (CaO)	4.5
Magnesium (MgO)	1.5
Chloride (Cl)	0.3

The average concentration of heavy metals in KVG-compost is indicated in table 9, together with preliminary standards from the Dutch government. This

implies that on a number of points improvements have to be made in order to comply with future standards in this field.

Table 9 Heavy metals and arsene in KVG-compost, in ppm dry material [21]

	Average heavy metals	Intended standardisation		
		"Clean compost" before 1995	"Compost" after 1995	"Very clean compost"
Lead (Pb)	100	120	100	65
Copper (Cu)	35	90	60	25
Nickel (Ni)	10	20	20	10
Zinc (Zn)	170	280	200	75
Chromium (Cr)	30	70	50	50
Cadmium (Cd)	0.8	1	1	0.7
Mercury (Hg)	-	0.7	0.3	0.2
Arsene (As)	-	15	15	5

Utilising the energy contained in KVG can be realized if (aerobic) composting is replaced by (anaerobic) fermentation. Part of the energy is then preserved by producing biogas, CH₄ (55%) plus CO₂ [19]. In this context table 8 and 9 are relevant as well, since the residue from KVG-fermentation can also be used as compost. And the composition of the compost depends rather on the quality of the KVG than on the production process [37].

In general, fermentation requires more expensive equipment than composting [25]. This is to a certain extent compensated by the value of the biogas, of which 70 to 150 m³/ton KVG is produced [20, 39]. Further, fermentation implies a number of secondary advantages, such as smell reduction [38]. Moreover, (in The Netherlands) subsidies on fermentation equipment help to compensate the extra investment and to restrict the consequences of technical and economic risks. A full review of the various aspects that play a part in decision making concerning fermentation (and of composting) of the biomass fraction of MSW is given in [21]. It is noteworthy, however, that composting of KVG is a proven technology, while its fermentation of KVG is still in its infancy.

In the following paragraph (4.4.1), a number of systems of fermentation will be described. Next (4.4.2) a short review of the situation in The Netherlands regarding MSW fermentation will be presented [37]. And finally (4.4.3) we will deal with the option of integrated fermentation and incineration of waste [36].

4.4.1 Systems for MSW-fermentation

In a recent study of Haskoning, [37, 39], four systems of MSW fermentation are described and compared (as well as four systems for aerobic composting). This paragraph contains a summary of the relevant parts of this study.

Note: It should be noted that more recent experience has learned that for most of these processes, the specific methane yield, as indicated in the study, is overestimated. More realistic figures are typically between 75 and 100 m³/ton (wet) [49].

Anaerobic systems are characterised by bacteriologic conversion of organic material in absence of oxygen. The organic material is transformed into methane (CH_4), carbon dioxide (CO_2) and compost (after aerobic post-treatment). Wet and dry systems may be distinguished. In wet systems (< 20% dry material) conversion generally takes place in two separate reactors, an acidification reactor and a methane reactor, both fed continuously. In dry systems, both processes occur in one reactor; the feeding system may be either batch or continuous.

a. The BIOCEL system

BIOCEL is a dry anaerobic batch processing system. It has been tested on pilot level, in a reactor of 450 m³. The processing time is 2 to 3 weeks at a temperature of 35 °C. No additives are used. The biogasproduction is 70 m³/ton KVG-waste, with 55% methane. The process-control is automated, on the basis of some process parameters. After fermentation the residue is dried thermally; one ton of KVG-waste yields 230 litres of waste water with a high organic content. Post-treatment of the digested material takes place in a closed hall, from which air is extracted and treated with biofilters. Aerobic stabilisation into compost and ammonia emissions while drying of the residue are still investigated.

b. The DRANCO system

DRANCO (DRy, ANaerobic CONversion) is a dry, continuous system. A pilot plant of 45 m³ is tested in Gent, Belgium, since 1984, amongst others on KVG-waste. In a pre-treatment the KVG-waste is mixed with paper and digested material. Conversion takes place in 14 to 18 days at 55 °C, approximately. Biogas production (55% methane) is 130 m³/ton KVG-waste. After fermentation, the residue is dehydrated mechanically and composted aerobically, during one week. All processes take place in closed halls, where air is extracted and treated in a biofilter. The waste water from the mechanical dehydration is purified physicochemically and partially evaporated with waste heat. The remaining waste water, 340 litres per ton KVG-waste, contains a low organic load and can be discharged of into the sewer system.

c. The Valorga system

The Valorga system is also a dry system. It is, however, continuously fed. In France, two plants are in operation: La Buisse (since 1984) and Amiens (since 1988), 16,000 and 110,000 tons/a, respectively. In these plants, the organic fraction of MSW is digested, after separation from the MSW. This separation consists of de-ironing, removal of large items by hand, size reduction, mixing with paper and fermented residue. Conversion takes place in tanks at 37 °C during 18 days. The biogas production (55% methane) may be increased to 130 m³/ton by adding paper to the feed. After fermentation the residue is dehydrated mechanically and stabilised aerobically during 6 hours. The waste water, 340 litre/ton, is cleaned in a centrifuge and discharged of into the sewer system. It is expected to contain a high organic load.

d. *The BTA system*

The BTA system is a wet, continuously operating system, designed for KVG-waste, sewage sludge and manure. An experimental plant (180 t/a) is in operation in Munich since 1986 and since 1991/92 a full scale plant 25,000 t/a in Helsingør, Denmark [49]. Pre-treatment consists of de-ironing, size reduction, mixing with process water, separation of heavy and floating fractions, and heating to 60 to 70 °C. Conversion takes place in two phases: Hydrolysis and acidification in the first reactor and fermentation (methane production) in the second one. The processing time is only three days; biogasproduction is 180 m³/ton with 73% methane¹⁾. The residue is dehydrated mechanically (390 litres of waste water/ton of waste). Post-treatment of the residue has not yet been defined.

It is obvious that any comparison between these systems has a preliminary character, since their development is still in progress.

Nevertheless, in figure 14 a qualitative comparison is presented of a number of relevant aspects of the four systems described here [39]. In figure 15 a cost estimate of the systems is given (together with four aerobic composting systems).

system:

state of the art

capacity

flexibility

space requirement

process control

energy use

energy production

maintenance

labour

quality end product

environmental aspects: air

environmental aspects: water

working conditions

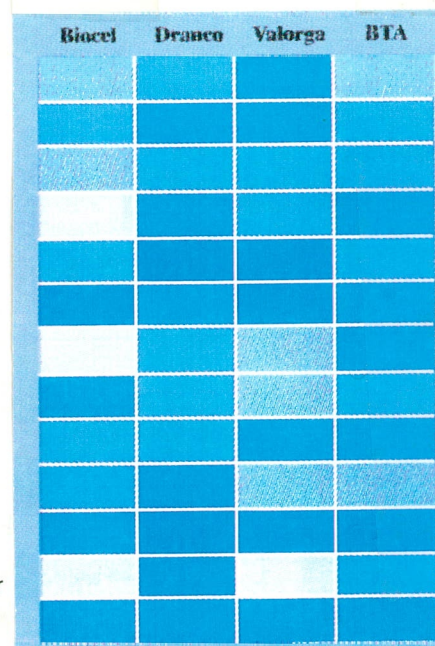


Figure 14 Qualitative comparison of four anaerobic processing systems for KVG-waste (darker means more favourable)

¹⁾ The authors believe that this percentage is unusually high

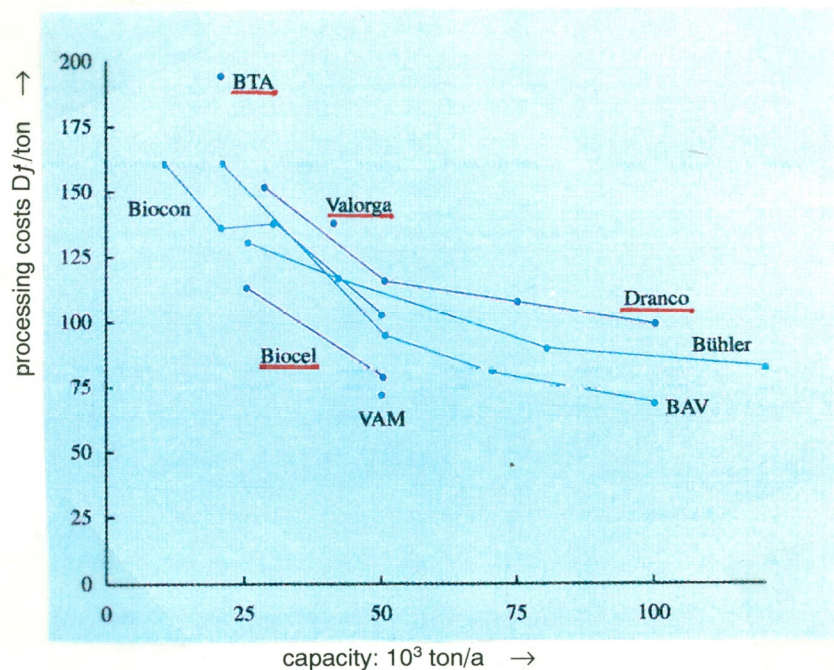


Figure 15 Preliminary cost comparison of four anaerobic and four aerobic processing systems for KVG-waste

4.4.2 Fermentation of KVG-waste in The Netherlands

In The Netherlands, at present four initiatives regarding KVG-fermentation on full scale level are under consideration.

- At *Leiden*, the set up of a 100,000 ton/a plant is studied (PAQUES system), both for separately collected KVG-waste and the organic fraction of MSW separated mechanically [41]. It is intended that KVG and the organic fraction of MSW are processed separately [49].
- At *Tilburg* a VALORGA system will be installed, for processing 40,000 ton/a separately collected KVG-waste [40] plus 6,000 t/a of waste paper [49].
- Near *Rotterdam* (AVR, Botlek), a fermentation plant is studied as well, both for separately collected KVG and for the mechanically separated organic fraction of MSW. Due to financial aspects, however, it is uncertain whether it will be implemented [42].
- In the Province of Flevoland a Biocell-system for processing 25,000 t/a of separately collected KVG has been projected [49].

4.4.3 Integral fermentation and incineration of waste

In [36], a number of suggestions have been elaborated regarding a technological integration of fermentation and incineration of waste. Both separately collected KVG-waste and the residual waste are pre-treated, thus

yielding an inert, a combustible and a digestible fraction, respectively. The digestate from the KVG-digester is stabilised into compost; digestate from the residual waste is combusted together with the other combustible fractions (figure 16). (In both cases combustion of digestate is relevant, since anaerobic bacteria do not convert all organic material into CH_4 and CO_2 . This is in particular the case for wood-like structures, like cellulose and lignine).

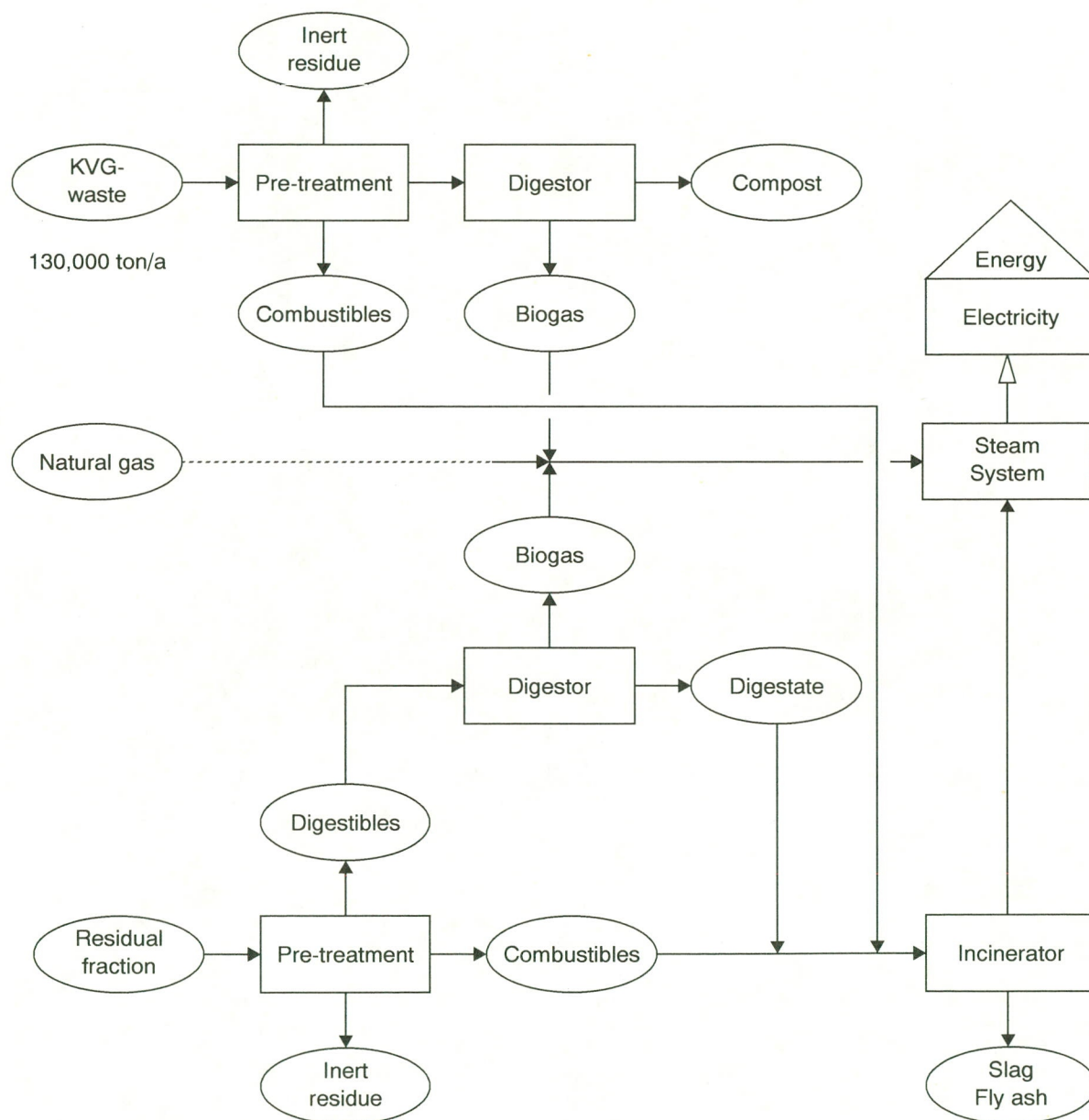


Figure 16 Process scheme for integrated processing of separately collected KVG and residual fraction [36]

The actual integration is effectuated in two ways:

- a. Utilising low grade waste heat from the incinerator for obtaining the required temperature of the fermentation process and for the compensation of heat losses.
- b. Integrated electricity production from waste and biogas incineration.

The basic scheme for the energy production is shown in figure 17.

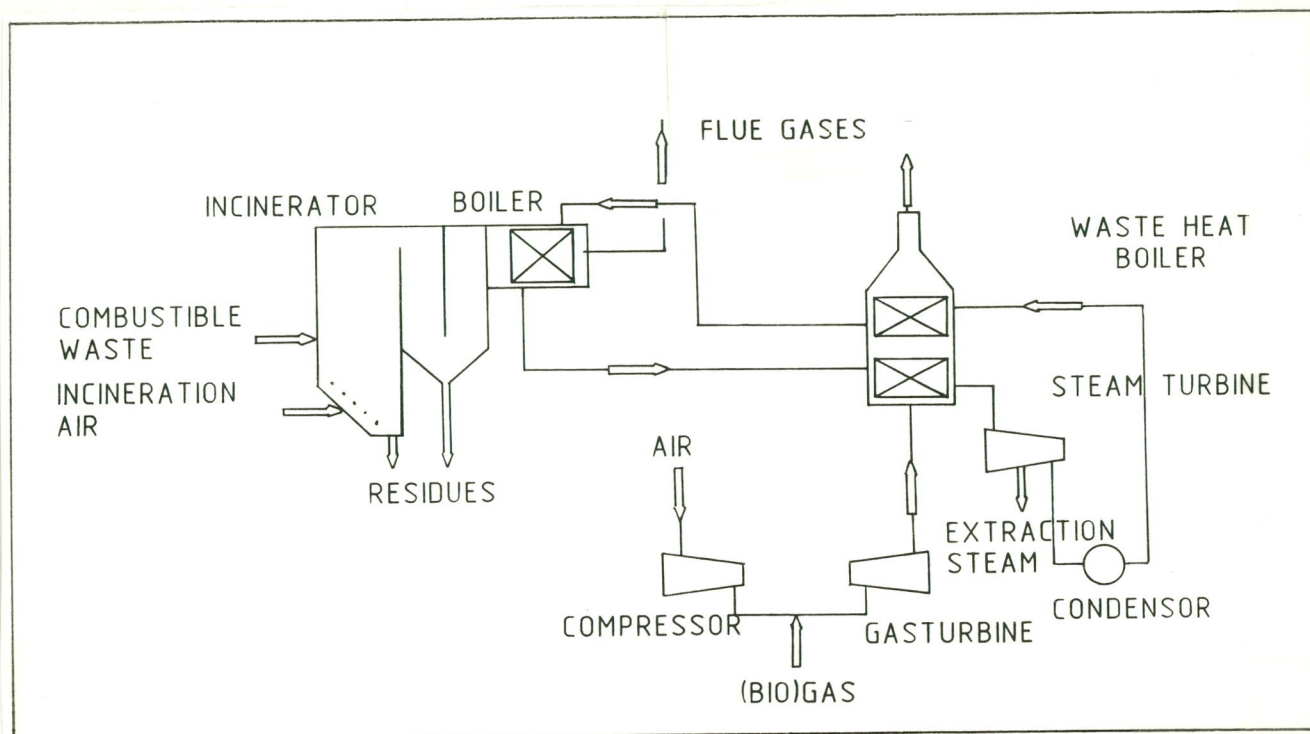


Figure 17 Basic scheme of operation for integrated energy production by combined incineration and fermentation of waste [36]

It is claimed that in this way the efficiency of electricity generation is increased from 18 to 28%; CO₂ reduction may be tripled. The costs are roughly comparable with a conventional reference situation, viz. incineration of integral MSW, followed by flue gas clean up.

4.5 Deposition, followed by exploitation of landfill gas

In the eighties, in The Netherlands some 50% of the MSW was landfilled. The rest was incinerated (35%) or composted (15%) [22]. Most landfill sites are located North, East and South in the country; in the densely populated West the majority of the MSW is incinerated. In the eighties the number of landfill sites decreased, but the remaining ones grew larger. The approximately 60 MSW landfill sites being exploited at present are all above surface level ('landraise'). They vary in height between 5 and 40 meters and in area from 5 to over 100 ha.

Landfill gas (biogas) is generated by spontaneous anaerobic fermentation of the organic fraction of the waste.

The first experiments on extraction of the gas took place at VAM in Wijster in 1979. It appeared that landfill gas extraction led to substantial smell reduction and to a decreasing damage to vegetation. Also safety aspects play a part: some accidents due to landfill gas explosions are known. But in the first place, by extracting and utilising landfill gas fossil energy is saved. Furthermore, CH₄ emission into the atmosphere is prevented, and in fact replaced by CO₂ emission. And the greenhouse effect of one molecule of CO₂ is only 4 to 5% of that of CH₄. In 1982, calculations showed that exploitation of landfill gas was economically attractive at 12 sites; an average production of 150 mln m³/a was forecasted. In 1985 an updated calculation indicated a feasible production of 220 mln m³/a on 26 sites. If landfill gas is gained from all present MSW-sites, a maximum of 660 mln m³/a can be produced.

Nowadays, from 13 sites in total more than 50 mln m³/a is generated (table 10).

Table 10 Landfill gas projects in The Netherlands (status 1990) [50]

Landfill site	Application	Since	Utilisation 10 ⁶ m ³ /a ^{*)}
Wijster	electricity	1983	6.8
	"natural" gas quality	1989	7.1
Amt-Delden	unprocessed gas	1984	5.6
Bavel	unprocessed gas	1984	5.6
	electricity	1991	0.8
Joure	electricity	1984	2.7
Maarsbergen	electricity	1987	0.5
Tilburg	"natural" gas quality	1987	5.0
Nuenen	"natural" gas quality	1990	3.5
Veendam	"natural" gas quality	1990	5.4
Borsele	unprocessed gas	1990	2.3
Linne	electricity	1990	5.0
Hengelo	unprocessed gas	1990	0.2
Emmen	electricity	1991	0.1
Vasse	"natural" gas quality	1991	0.9
Total			51.5

^{*)} Data of 1991

Summarising, 16 mln m³ gas/a is used for electricity generation; the remainder is used for heating purposes, either in upgraded or in unprocessed form.

In general, finding a proper application for landfill gas is relevant, since the energy demand of a landfill site is negligible. In a number of cases the gas is delivered to adjacent industries, e.g. the stove of a brick factory, (Bavel), a steam boiler of a chemical plant (Ambt-Delden) and the ovens of an aluminum factory at Borsele.

Constraints in obtaining suitable customers for the gas are:

- the distance between site and potential customer;
- differences between the quantities produced and required, respectively;
- the time span over which gas delivery can be guaranteed.

In this context it is relevant that investigations have indicated the possibility of accelerated gas recovery by recirculation of percolation water. At present this is, however, economically not attractive [23, 24].

Most disadvantages that count for industrial application do not hold for upgrading the gas and delivering it to the public grid. The sites are almost always located near the grid and the base load of the grid is sufficient to guarantee continuous acceptance of the upgraded landfill gas. The quality must, however, become the same as that of natural gas.

The third basic option is applying the gas for electricity production, either for own or industrial application, or for delivery to the public grid. In Wijster this is done in cogeneration, on behalf of their waste separation and composting plant. From other sites, electricity is sold to the grid.

Figure 18 finally, shows the development of the market value of a landfill gas for the three applications described here.

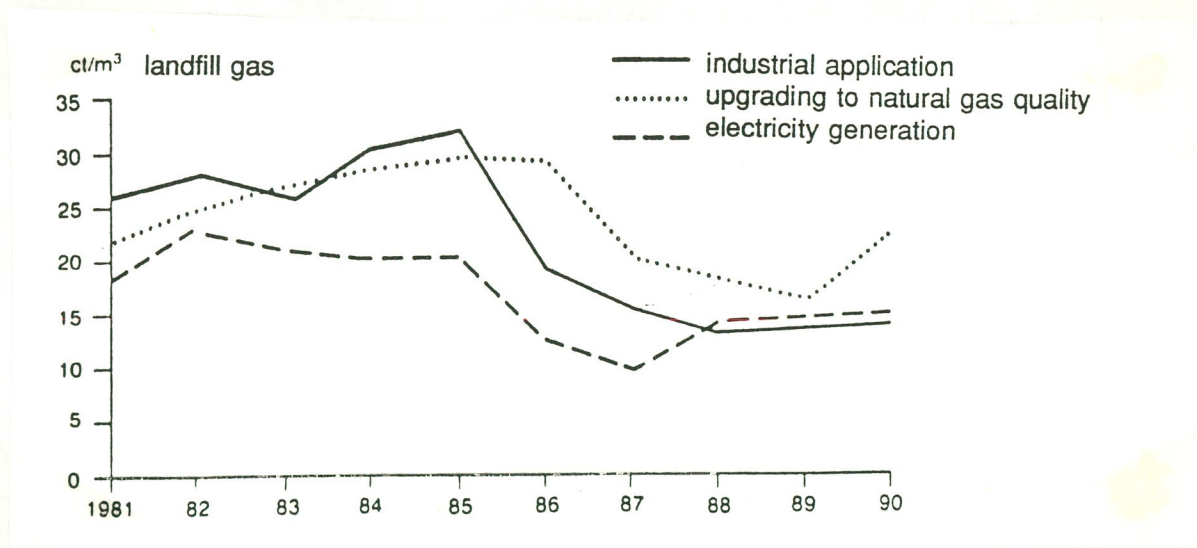


Figure 18 Development of the market value of landfill gas for three applications [22]

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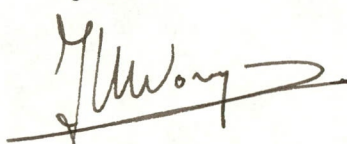
Names of establishments to which part of the research was put out to contract

—

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

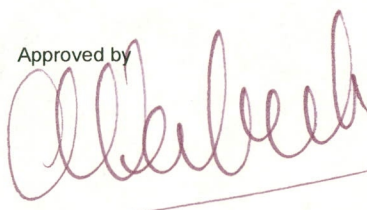
January 1992 - July 1992

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