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AMSTERDAM WASTE FIRED POWER PLANT©, FIRST YEAR OPERATING EXPERIENCE

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Abstract

Mid 2007 the Amsterdam Waste and Energy Company (AEB) commenced initial operations of their new Waste Fired Power Plant© (WFPP). The unit processes 530,000 metric tons of unsorted municipal solid waste producing electricity with a net efficiency of 30%. (Picture 1)The major contributor to the efficiency increase from the conventional 22% to 30% is a new and patented technology, whereby steam from the high pressure turbine is reheated by steam, rather than flue gas, before entering the low pressure turbine. The WFPP facility has operated successfully throughout 2008 and to this date.

Also, for a period of nearly three years, AEB operated a commercial scale pilot plant, with a maximum capacity of 50 tons per hour, to develop the necessary process steps, to recover ferrous, non-ferrous, as well as precious metals from the bottom ash. In this recycling process, heavy metals and other toxicants are removed from the ash, rendering it suitable as a raw material for use in building materials, leaving less than 5% material to be landfilled.

The operating results of both experiences are presented in this paper.

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Picture 1

Introduction

As a brief introduction, AEB is a Public Utility Company and is 100% owned by the City of Amsterdam. Amsterdam's waste management started back in 1882 and the first waste to energy was inaugurated in 1919. AEB is a self sustaining operation with a mission for optimal environmental performance, creating maximum benefit to the citizens, and nurturing home-grown R&D.

The following is a summary of salient details:

- World's largest WtE facility; 1,500,000 MTPA
- WFPP® most efficient facility; 30% (850 kWh/MT MSW)
- Amongst the world's cleanest, emissions< 20% EPA limits
- Overall solids recycling rate 95% :
- Zero liquids discharge is an option
- Avoided CO2; 600,000 MTPA
- Turnover € 200 million
- Lowest tipping fees in the Netherlands; €75/MT average

Picture 2

The City of Amsterdam has developed an ecological concept for the port district in which the WFPP is located, that is called EcoPoort®. (Picture 2) The objective is to create a sustainable environment, maximizing synergies between adjacent industries and neighboring residential areas. Minimizing the negative impact on the environment is one of the most important priorities to which the City applies the Best Practical Environmental Options or BPEO philosophy.

The WFPP was designed for maximum output while minimizing the negative environmental impact. This was done by means of nearly thirty innovative and novel designs, most of which were developed in house over the years. This paper addresses the following two major technologies:

- High-efficiency W2E concept; Waste Fired Power Plant
  - Reheater concept to increase electric efficiency.
  - Flue-gas recirculation; lower emissions, increased efficiency
  - Use of WWTP bio-exhaust gas for improved drying and fuel efficiency
- Bottom Ash Recycling Pilot Unit
  - Dry separation
  - Wet non-ferrous separation from bottom ash

Waste Fired Power Plant

The following is the realization timeline for the Waste Fired Power Plant

Start of construction	Jan 2004
Hot commissioning	19 March, 2007
100% Load 2 boilers	mid April, 2007
Turbine online	mid June, 2007
Handover	1st August, 2007
Troubleshooting	balance 2007
Operational optimization	2008

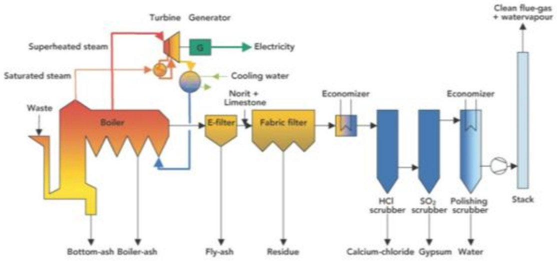


Diagram 1

A simplified block flow diagram (diagram1) of the total system is shown here. The basic design concept is very similar to other modern WtE facilities. Application of the best available technologies to ensure high environmental standards, resulting stackgas performance at 20% of EPA limits as well as high energy and material recycling efficiencies. The investment in fluegas cleaning amounts to almost 50% of the total investment. In addition plant design is extremely robust ensuring high availability and long plant life.

The following diagram (diagram 2) summarizes the efficiency concept for the production of electricity and recycling of products from the bottom ash per metric ton of waste. Electricity output is net, exclusive of the parasitic load and based on a LHV value on the MSW of 10 gigajoules/MT, or a HHV of about 11.Major products recovered from the bottom ash are ferrous and non-ferrous metals, including gold and silver, and products for the building industry.

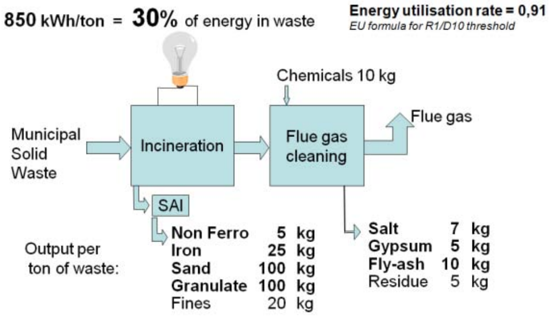


Diagram 2

High Electric Efficiency 30%

The exceptionally high electric efficiency of the WFPP® of 30% net, is accomplished through re-heating by steam rather than fluegas. (Diagram 3) The latter is not possible in WtE mainly be cause of the corrosive environment of the flue gas. Important parameters include:

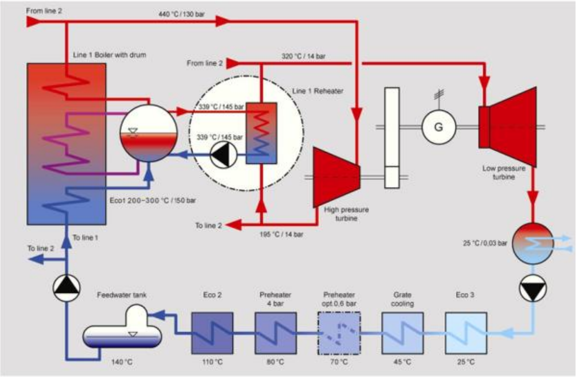


Diagram 3

- Steam temperature/pressure @ 440^{0}C and 130 bar
- Reheating the steam between the HP and LP turbines from 195^{0}C and 14 bar to 320^{0}C at a 14 bar pressure
- Low back pressure 0.03 bar at 25^{0}C
- Low excess air, 6% dry
- Heat recovery from a number of sources including fluegas and grate cooling to preheat boiler feed water.

A comparison between the electric efficiencies of a conventional WtE facility having a net efficiency of 22% and that of the WFPP® with 30% efficiency is shown in the T-S diagram (diagram 4). The surface enclosed by the black lines represents 22% efficiency and that by the red lines 30%. The rising slanted red line in the superheating area depicts the steam reheating step.

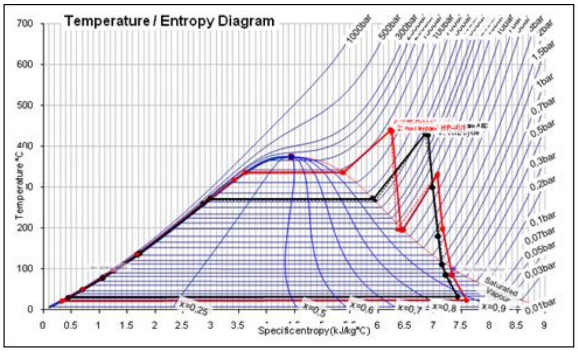


Diagram 4

Since comparing surfaces is somewhat difficult, a representation of the difference in efficiency the T-S diagram on the right may make it easier. One can compare the total length of the backward slanted black and red lines. They have a 22:30 ratio. What this means in total energy can be seen on the following graph (diagram 5)

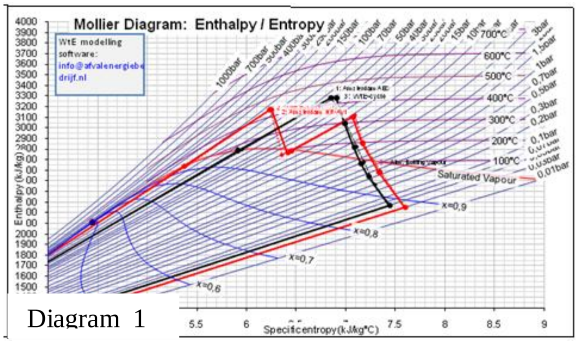


Diagram 5

AEB has developed very detailed modeling tools to optimize the steam/water cycle of a WtE facility using the steam reheat technology. These tools can be made available to third parties with an interest in evaluating the reheat option.

A comparison of the electric energy and heat produced by the different conventional and high efficiency or optimized WtE facilities, as well as with a modern landfill. (Diagram 6)

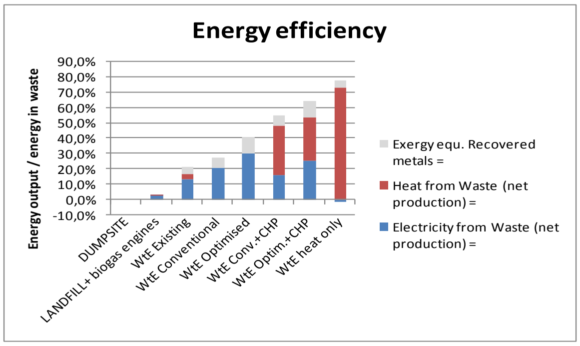


Diagram 6

The "WtE Existing" bar represents the average WtE facility in the Netherlands at about 15% electric efficiency, which is not unlike the average in Western Europe. The "WtE Conventional" bar represents a more modern plant with 22% efficiency. WtE Optimized is our WFPP at 30%.

The red surfaces show the amount of energy recovered if the plant also delivers hot water or low pressure steam or just water and/or steam.

Although one may argue about the amount of energy recovered from a modern landfill with methane recovery, it is significantly less than any WtE facility. The efficiency of methane recovery is only about 50 to 75% and recovery is usually abandoned after 10 years or so, because the methane volume drops below the economic recovery level. Methane production however continues for another 50 years or more.

Since there is a large difference in the value of electricity and that of low pressure steam or hot water, a better comparison of the energy efficiencies is to comparing Exergies.

Exergy is defined as the energy available to do useful work. The bar chart (diagram 7) clearly shows the superiority of the Waste Fired Power Plant design, with and without the production of heat.

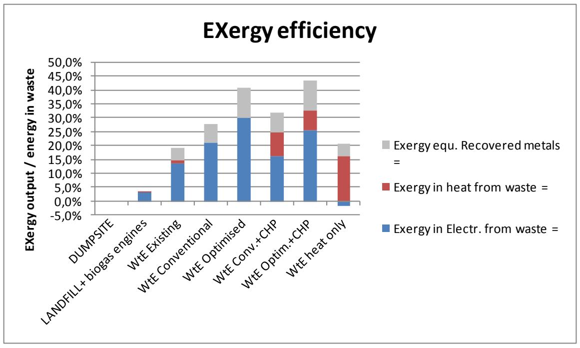


Diagram 7

The gray surfaces by the way represent the energy recovered by the recycling of metals from the bottom ash, a subject I shall be speaking about shortly.

This table (table 1) provides a summary of the results of the test runs as measured by the suppliers of the equipment as well as by testing authority. It shows that in all instances and for both lines of the WFPP, the results exceed the guaranteed minimums, and that the plant was able to meet guaranteed efficiencies operating at 110% of the designed capacity.

	100% Load		110% Load		Units
Date	24-7-2007		25-7-2007		
Timespan	16:00 - 22:00		8.00 - 14:00		
Duration	6		6		h
Net Goal	≥30		>30		%
Measuring company	Supplier	KEMA (Tüv)	Supplier	KEMA (Tüv)	
Boiler efficiency (Thermal)	85,2	85,5±1	85,8	85,5±1	%
Net electr. Efficiency	30,5	30,6±1,6	30,8	30,9±1,6	%
	* Design	* Measured	* Design	* Measured	

Table 1

Additional details of the operational parameters during the test run for both production lines are included in this table. (Table 2) Worth noting is the very high boiler efficiency of 85.2%, due in part to a fluegas recycle rate of about 25% and the installation of ample economizer capacity.

	Guaranteed value	Guarantee measurement		Units
		boiler 35	boiler 36	
Waste Throughput	33,6	34,89	34,94	Mg/h
Calorific value	10	9,94	10,26	MJ/kg
Steam production	28,4	28,46	28,52	kg/s
=	102	102	103	Mg/h
Boiler outlet temperature	180°constant	177,35 - 183,75		°C
Boiler efficiency	85	85,2		%
850°C residence time	>2	5		s
Power from waste	93,3	96,9	97,07	MW
Thermal boiler load	102,7	103,63	102,93	MW
Own consumption	< 850	498		kW

Table 2

More details are shown in the third table. (Table 3) In addition to efficiency data, this table includes data on the stack gas composition. All date confirms that all guarantees were met or exceeded.

	Guaranteed value	Guarantee measurement		Units
		boiler 35	boiler 36	
Control range Steam flow	2	-0,72 / +1,18	-1,57 / 0,75	%
Control range Steam temp	4	3,87	1,92	±K
O2-concentration (boiler outlet)	6,5	6,0 - 6,73	ø<6,5	%
CO (boiler outlet)	≤30	6		mg/m3
NOx (boiler outlet)	70	66 - 68		mg/m3
NH3 (boiler outlet)	≤5	3		mg/m3
TOC in bottomash	≤1,5	0,1 - 0,66		%

Table 3

Unfortunately, the WFPP experienced some unexpected and avoidable difficulties during start-up and subsequent operation of the plant. Although all of these have been addressed and most of them resolved, it negatively affected plant operation for several months as will be seen from the following figures. Some of the more important issues were:

- Turbine-Generator foundation; broken shaft
- Emergency condenser; pipe rupture
- Steam valves; actuator malfunctions
- Flue gas cleaning; blow down treatment
- Plant Control Software; unnecessary shutdowns
- Fly Ash Handling; dust control
- Cooling Water System; water hammer

The most critical issue was the inadequate design of foundations of the turbine and the generator. In the unstable soil of the “low Countries” they set unevenly, causing the turbine shaft to break. This event, now corrected, interrupted power generation for several months.

Water hammer and the pipe rupture were problems limiting plant capacity for a considerable time. Other issues listed caused frequent but short term shutdowns.

In spite of these interruptions, the plant operated satisfactorily as can be seen from the following chart (diagram.8). It shows actual plant operating results for steam production in the period from August 2007 through March 2008. It is evident that the process design fundamentals are sound, and that without avoidable interruptions the plant meets the guaranteed production levels.

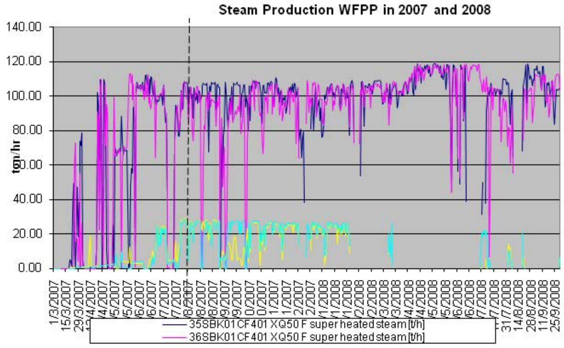


Diagram 8

The net electric efficiency for the first half year of operation after transfer of the plant are shown in the next graph(diagram 9) results for the best day of the month with values ranging from 30.6% to 31.7%, well above the 30% guaranteed value

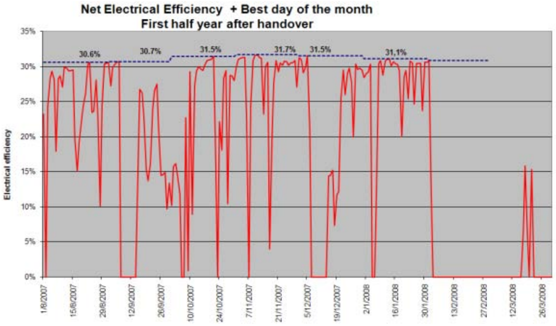


Diagram 9

Operational data taken at a later date, during the month of November 2007, point to a much improved situation. The following graph (diagram 10) shows actual and uncorrected values for boiler and electrical efficiencies, and a much more stable operation than in the early days after the test run.

Boiler and Plant net Efficiencies with uncorrected values (November 2007)

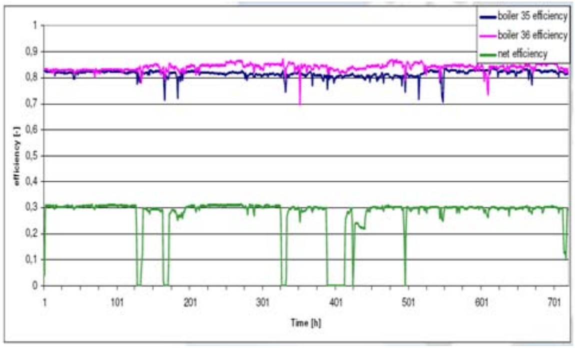


Diagram 10

Bottom Ash Recycling

Let us now turn our attention to bottom ash recycling. Every ton of MSW produces about one quarter ton of ash. If untreated this means millions and millions of tons of MSW to be transported and landfilled, polluting air soil and water and taking up millions of acres of valuable land. AEB's bottom ash treatment recovers most of the valuable metals and other materials, reducing landfill required to about 2%.

Picture 3

The unit shown (picture 3) is a commercial size pilot plant with a maximum capacity of 50 MTPH. Tests have been completed and designs for a full size plant are well under way.

The almost complete recovery of all solids after combustion is also a major factor in the overall economics of waste management in which the avoided landfill cost plays a major role.

In the previous energy and exergy evaluations we have seen that the recovery of metals is a major contributor to the overall efficiency. It is worth mentioning that an increase in energy efficiency causes a reduction in Greenhouse Gasses.

The bottom and fly ash from the different sections of the plant have greatly different compositions. They are therefore recovered separately are treated independently as can be seen from the following block flow diagram. (Diagram 11)

Amsterdam bottom ash contains 13% ferrous and 2.2% non-ferrous metals. The non-ferrous metals fraction also contains precious metals; approximately 3000 ppm of silver and 100 ppm of gold .The residue (ash), approximately 80%, can be used as a secondary building product (road filler, concrete, asphalt, lime sand stone), after removal of heavy metals to pass strict Dutch leaching tests. AEB did select wet separation since bench scale test showed better performance in the recovery of metals.

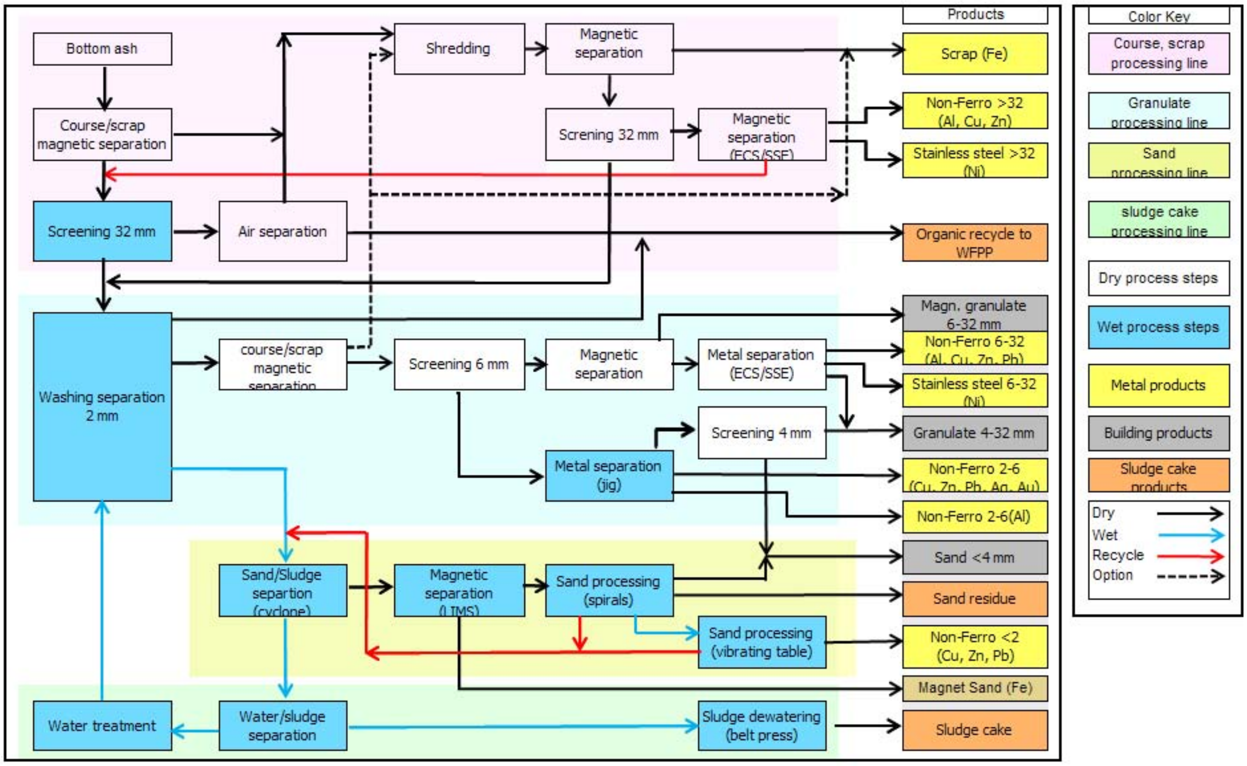


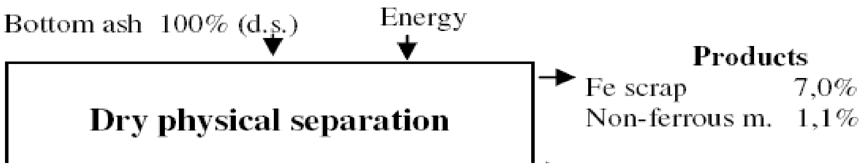
Diagram 11

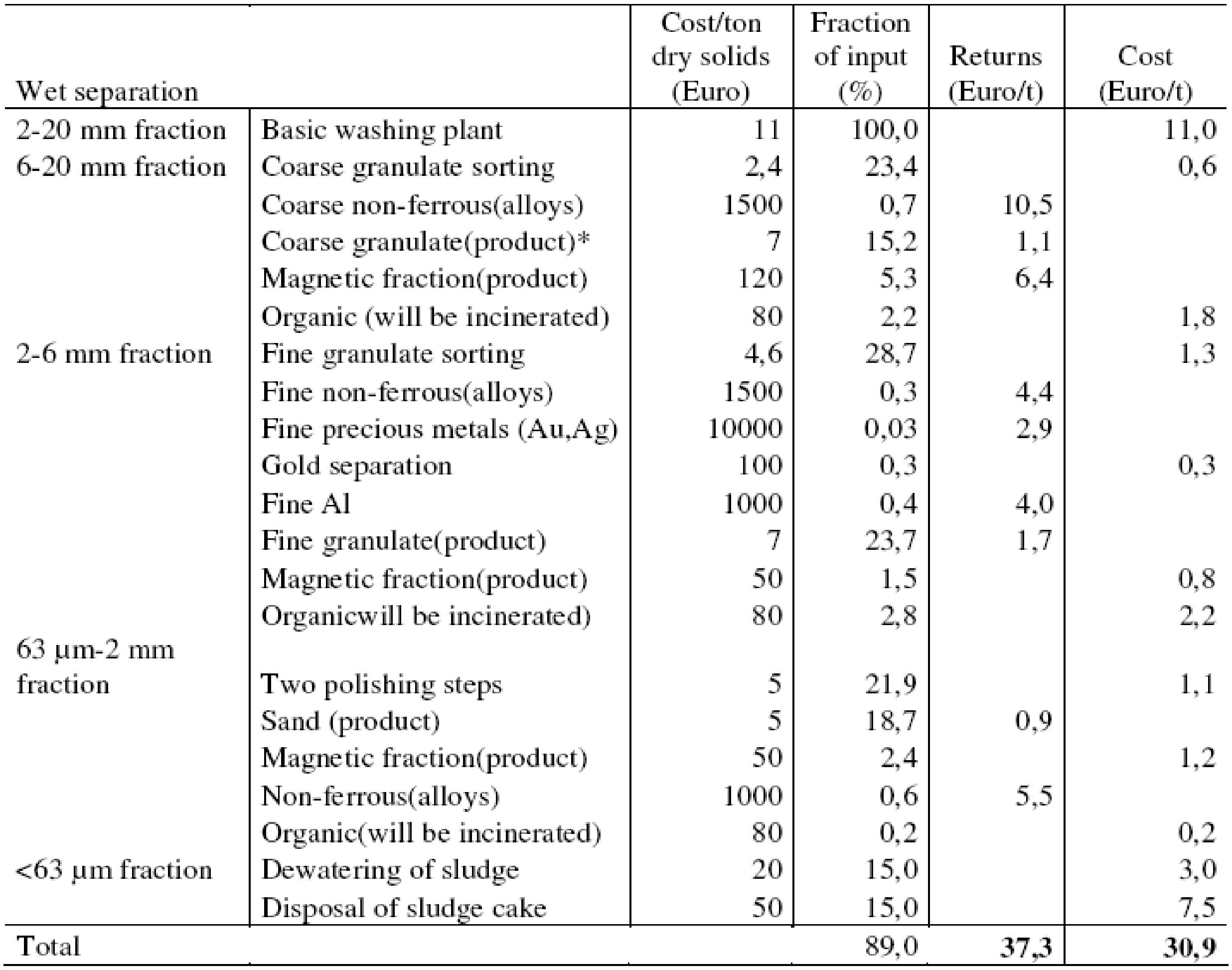
Following dry separation, the ash separated according to size and density of the particles, the non-ferrous fractions are removed by eddy current separation, density separation and jigging. The resulting fractions are the coarse non-ferrous (6-20 mm), fine non-ferrous (2-6 mm) and the very fine non-ferrous (<2 mm) products. The 2-6 mm aluminum scrap is separated from the heavy non-ferrous by density separation. Values of the different products, intermediate product and waste streams are shown in the table. (Table 4).

Although organic material after dry and wet separation are shown as waste, which is correct considering this process only, these stream are fed back to the grate for combustion, thus recycled.

In addition to the metals, three different building products are produced. The first is a 6-20 mm granulate, the second is a 2-6 mm granulate and the last one is the sand (100 µm-2 mm). All three products are sold to building companies as raw material for building products. Summarizing the results of the process, per 1000 kilograms of MSW the following materials are expected to be produced in the commercial bottom ash treatment plant being designed.

- Sand 85 kg bricks
- Granulate 110 kg concrete
- Iron 25 kg trade
- Metals Non-Ferrous 5 kg trade
- fly-ash 11 kg filler in asphalt
- $CaCl_2$-salt 7 kg industry, road
- Gypsum 5 kg construction
- Residue (gas cleaning) 2 kg disposal or vitrification





Wet separation		Cost/ton dry solids (Euro)	Fraction of input (%)	Returns (Euro/t)	Cost (Euro/t)
2-20 mm fraction	Basic washing plant	11	100,0		11,0
6-20 mm fraction	Coarse granulate sorting	2,4	23,4		0,6
	Coarse non-ferrous(alloys)	1500	0,7	10,5	
	Coarse granulate(product)*	7	15,2	1,1	
	Magnetic fraction(product)	120	5,3	6,4	
	Organic (will be incinerated)	80	2,2		1,8
2-6 mm fraction	Fine granulate sorting	4,6	28,7		1,3
	Fine non-ferrous(alloys)	1500	0,3	4,4	
	Fine precious metals (Au,Ag)	10000	0,03	2,9	
	Gold separation	100	0,3		0,3
	Fine Al	1000	0,4	4,0	
	Fine granulate(product)	7	23,7	1,7	
	Magnetic fraction(product)	50	1,5		0,8
	Organicwill be incinerated)	80	2,8		2,2
63 µm-2 mm fraction	Two polishing steps	5	21,9		1,1
	Sand (product)	5	18,7	0,9	
	Magnetic fraction(product)	50	2,4		1,2
	Non-ferrous(alloys)	1000	0,6	5,5	
	Organic(will be incinerated)	80	0,2		0,2
<63 µm fraction	Dewatering of sludge	20	15,0		3,0
	Disposal of sludge cake	50	15,0		7,5
Total			89,0	**37,3**	**30,9**

Table 4

A summary of the estimated and allocated cost of production for the different material fractions in the bottom ash shows a total cost of 30.9 Euro per ton of material versus a commercial value of 37.3 Euro, or in US currency $40 versus $48. While this difference is important, it pales by comparison to the savings in the avoided cost of landfilling this material, which in many instances would exceed $100 per ton.

These are some samples of the materials recycled from Amsterdam's municipal solid waste. It might be surprising to learn that the silver content; in the Ditch waste equals 10% of the Dutch silver consumption. Equally surprising was for us to find out that the copper content in the bottom ash is higher than Chilean ore. Some of the products are shown here.

This is sample of a mix of non-ferrous metals (picture 4)

Picture 4

Gravel for concrete (picture 5)

Picture 5

Sandstone brick (picture 6)

Picture 6

And some of the coins we find (picture 7)

Picture 7

Economics

Apart from environmental considerations, there are good economic reasons for AEB's decision to design and build the plant using Best Available Technologies. This include our choice of the extensive flue gas cleaning technology, not discussed today but an important factor in the overall economics.

This graph (diagram 12) summarizes the economic impact of our design concepts. The gray and blue areas represent income from tipping fees and electricity sales at conventional levels.

By proposing the cleanest and most efficient designs possible we reduced the permitting time to less than one year. Not s single voice of opposition was raised by nearby residents or NGO's. Resultant savings in cost and time are shown in yellow.

Green represents the additional income from electricity sales by raising the efficiency from 22 to 30%.

Since about half of the MSW is biogenic, half of the electricity produced can be considered renewable and in many countries is sold at higher prices than conventional electricity.

In some countries, such as Holland, green fees or subsidies are paid when producing renewable energy. This income is represented by the dark green area.

Lastly building a plant robustly designed will extend its life well beyond the normal 30 years or so, with great economic benefits in the years that follow.

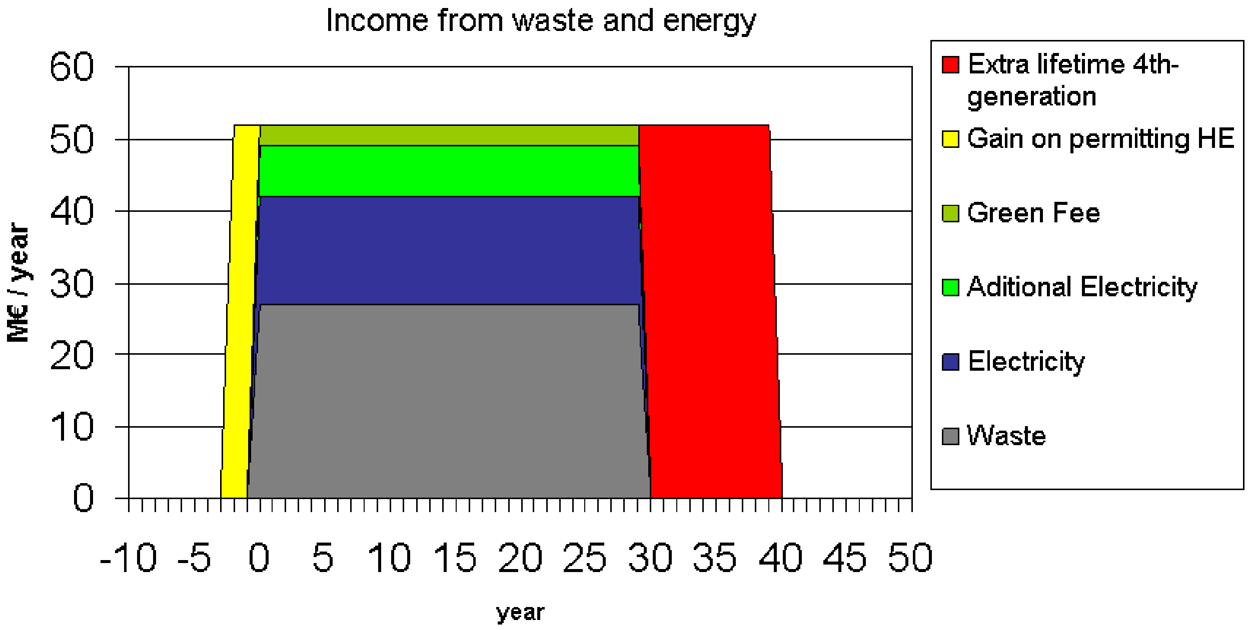


Diagram 12

In closing, the contributions of the following persons to this paper are gratefully acknowledged:

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