

# USING METAL-RICH WEEE PLASTICS AS FEEDSTOCK / FUEL SUBSTITUTE FOR AN INTEGRATED METALS SMELTER

November 2006



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**PlasticsEurope**  
Association of Plastics Manufacturers



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## 1. Executive summary

European legislation fixes obligations for end of life management of waste electrical and electronic equipment (WEEE), with ambitious targets, both for equipment reuse or materials recycling, and for energy recovery.

Economic and environmentally appropriate valorisation routes for WEEE materials with high plastics contents therefore have to be identified. These must be adapted to plastics with and without containing flame retardants, which are used in many electrical and electronic products to improve fire safety, either to meet mandatory safety standards or because of manufacturers' voluntary product safety objectives.

Integrated metal smelters represent one recycling route for such WEEE materials: metals can be recovered and recycled, and the plastics content can serve as an energy source and reducing agent.

The European Flame Retardants Association (EFRA), the plastics producing industry federation PlasticsEurope, and Umicore Precious Metals Refining carried out a full scale trial to assess the technical feasibility of including mixed WEEE materials with high plastics contents in the feed to an integrated metals smelter. The trial ran for a total of 8 days, using a sample of 217 tonnes of household WEEE. Impacts on plant performance, metals recovery, emissions and energy balance were assessed.

Results show that including approximately 6% WEEE (mixed metals – plastics materials, approx 3/4 plastics) in the smelter feed at this plant resulted in no operating problems, and that environmental emissions were not affected. One tonne of WEEE plastics enabled a reduction of consumption of nearly 0.6 tonnes of coke and 0.1 tonnes of fuel oil: approximately 2/3 of the plastics' energy content was used to replace consumption of coke and fuel oil (reducing agent and energy source) and approximately 1/3 was recovered as increased steam production.

At this plant, use of plastics rich WEEE at levels significantly higher than 6% of feed would require control and/or plant modifications to increase coke and fuel oil replacement as well as energy recovery in steam. The relatively low levels of flame retardants (FR) present in the typical household WEEE used in this trial posed no problem to use as smelter feed.

## 2. Introduction and objectives

The EU WEEE Directive (Waste Electrical and Electronic Equipment) 2002/96/EC requires Member States to ensure that producers of such equipment achieve ambitious targets both for equipment reuse or materials recycling and for energy recovery as of December 2006. The targets will be reviewed in 2008.

Economic and environmentally appropriate waste valorisation routes for WEEE plastics therefore have to be identified.

A significant part of these plastics from information technology, communication and some consumer sectors contain flame retardants, based on bromine, antimony, phosphorus, nitrogen and/or minerals. Annex II of the EU WEEE Directive specifies that WEEE plastics containing brominated flame retardants need to be identified and separately treated.

Integrated metal smelters equipped with state-of-the-art gas cleaning systems, potentially offer advantages for recycling of WEEE materials containing plastics: the metal content can be recovered for recycling (copper, precious metals used in electronic circuitry, solders ...) and the polymer content can serve as an energy source and reducing agent for the smelter process. Organic contaminants are eliminated in the high temperature smelter process and in the smelter emission controls systems.

Therefore, a full scale trial was carried out at the Umicore integrated metals smelter, Hoboken, Belgium. The objectives were to demonstrate the technical feasibility of including WEEE materials with high plastics content in the smelter feed and to assess the effects on the smelter performance and metals recovery (substitution potential for coke as a reducing agent and fuel oil as an energy source).

## 3. WEEE plastics

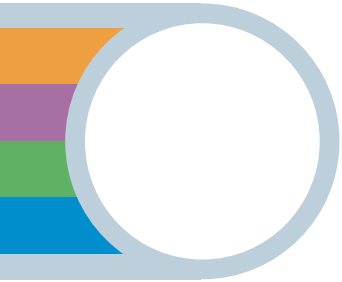


A wide variety of plastics are used in Electrical and electronic equipment (E&E), in order to meet the performance specifications defined by manufacturers and required by consumers.

Flame retardants are often included in WEEE plastics to improve fire safety. The main flame retardants used are magnesium and aluminium hydroxides, brominated flame retardants (in particular, reacted TBBPA and DecaBDE in WEEE), antimony compounds, phosphorus-based flame retardants, melamine compounds.

The type and content of flame retardants found in WEEE plastics varies widely depending on the type of equipment, collection and sorting. The amount and type of flame retardants in the WEEE plastics used in this trial was typical of that collected in The Netherlands .





## 4. The WEEE materials used in the trial

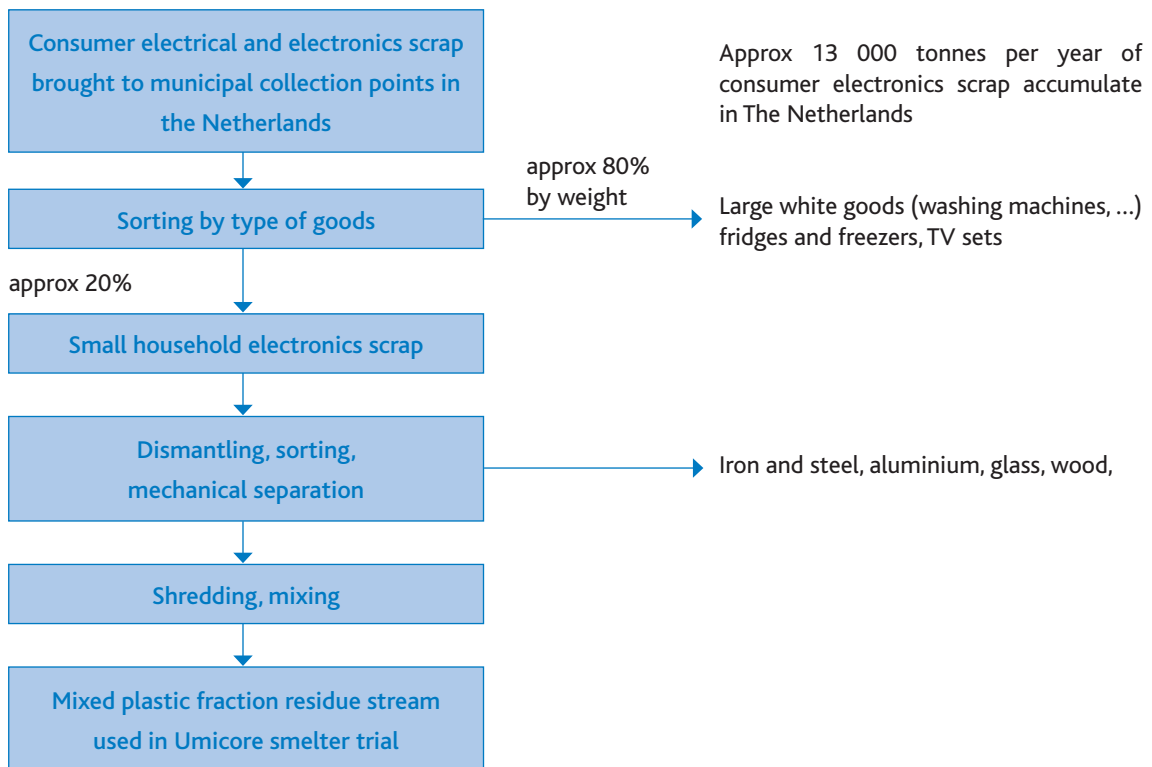
The WEEE (waste electrical and electronic equipment) material used was a plastics rich fraction of consumer electronics scrap, derived from partial dismantling of mixed small household appliances. brown goods (audio ...), grey goods (computers ...), etc.

The WEEE was supplied by a collecting organisation in The Netherlands and was from small household electrical and electronic goods brought voluntarily to municipal collection points by consumers in 2004. Large electrical equipment, white goods and TV sets were collected separately and were not included in the WEEE supplied.

A total sample of 290 tonnes of WEEE materials was provided via the recycling company PHB, consisting mainly of plastics and mixed metals, of which 217 tonnes were used in the trial.

As shown below, the actual plastic content of this WEEE residue is approximately 76%.

### 4.1. Origin and processing of the WEEE material



The 290 tonnes of WEEE delivered were divided in 3 equal lots. From each of these lots a representative 400 kg sample was taken for analysis to establish the elemental composition.

## 4.2. Composition of the WEEE material used in the trial

		% by weight	
Organic content (plastics)	Approx. 76%	Oxygen	8.4 - 13.5 %
		Carbon	58.6 - 63.7 %
		Hydrogen	6.2 - 7.2 %
		Nitrogen *	2 %
Metals	Approx. 10%	<u>Including:</u>	
		Copper (Cu)	3.9 - 6.7 %
		Silver (Ag)	0.01 %
		Lead (Pb)	0.2 - 0.4 %
		Iron (Fe)	0.3 - 1.1 %
		Aluminium (Al) *	2 - 3.4 %
		Antimony (Sb) *	0.1 - 0.25 %
Magnesium (Mg) *	0.14 - 0.28 %		
Other		Halogens	
		Bromine (Br) *	0.2 - 0.24 %
		Chlorine (Cl)	2.2 - 3.2 %
		Phosphorus (P) *	0.05 - 0.2 %
		Inert (eg. silica Si)	Approx 10%
* = elements present in WEEE principally because of flame retardant content			





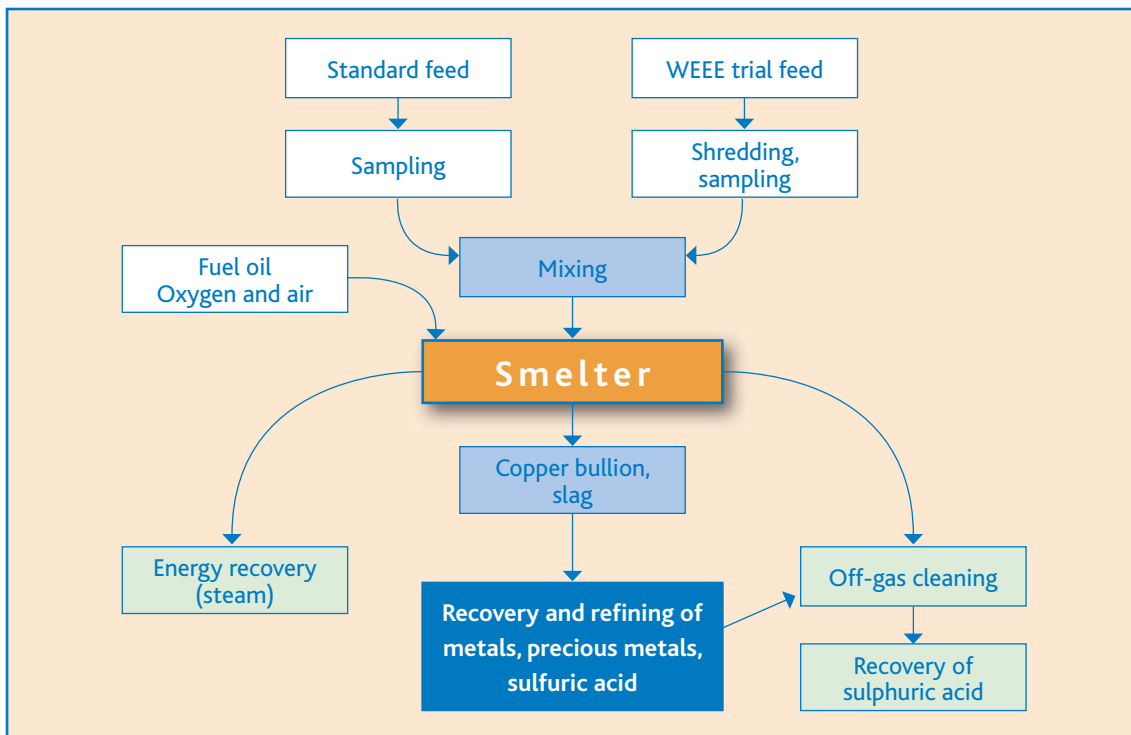
## 5. The Umicore plant at Hoboken

The trial was carried out in 2004 at the Umicore Precious Metals Refining plant, operating at Hoboken near Antwerp, Belgium. This is an integrated metals smelter and refinery. The plant recovers, separates and purifies a wide range of precious metals, special metals, base metals, antimony and sulphur (as sulphuric acid).

Feed materials are various complex industrial by-products (drosses, slags, flue dusts, process sludges, filter cakes, leachates, ...) as well as consumer recyclables such as end-of-life automotive catalysts and printed circuit boards / electronic components. The plant treated some 250,000 tonnes of different materials per year in 2004 (300,000 t/y today), of which electronic scrap is at present up to 10%. These 25 000 tonnes/year of electronic scrap are mainly printed circuit boards, containing on average 25-30% of plastics.

The recycling operations at the plant are based on complex lead / copper / nickel metallurgy and the use of these base metals as collectors for precious and special metals.

### 5.1. Simplified flow chart of the integrated smelter process



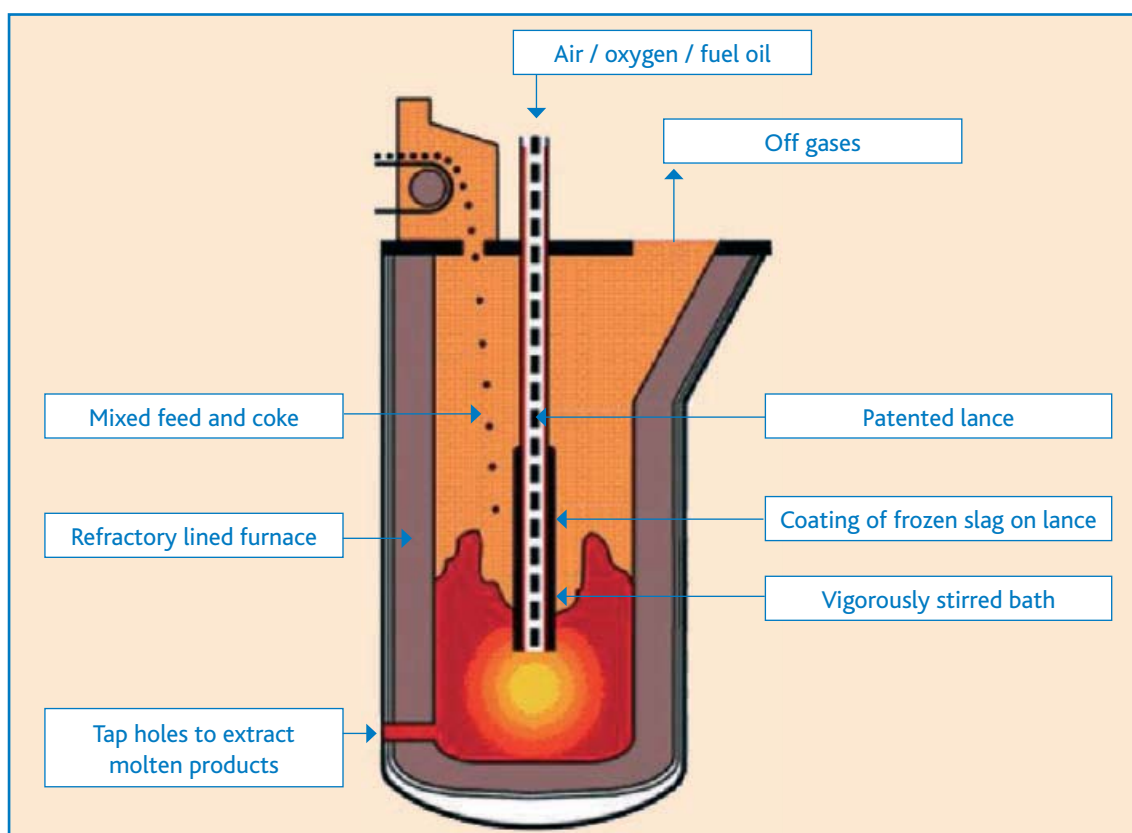
This integrated plant comprises two linked operations:

- the Precious Metals Operation, which includes the main processing steps: smelter, copper leaching and electro-winning, precious metals refinery. The smelter collects precious metals in a copper bullion, while most other metals are concentrated in a lead slag and further treated at the Base Metals Operation. After leaching out the copper in the leaching and electro-winning plant, the precious metals are collected in a residue that is further refined at the precious metals refinery.
- the Base Metals Operation includes a lead blast furnace, the lead refinery and a special metals plant.

The plant was comprehensively refurbished between 1997 and 2003. Around one quarter of the total costs concerned installations for safety and environmental protection, including state-of-the-art air and water treatment facilities.

## 5.2. Diagram of the Hoboken smelter

The core of the plant is the smelter, commissioned in 1997. The smelter uses the IsaSmelt Top Submerged Lance (TSL) combustion technique.



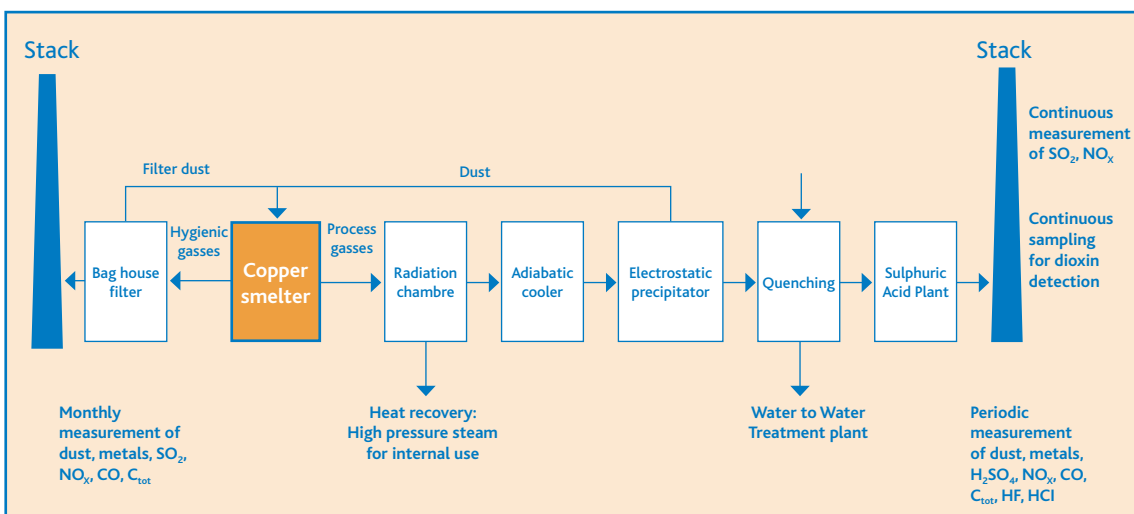


The ISA smelter (see diagram) is an upright tube, approx 15 metres high, with ceramic lining. A concentric lance feeds air, oxygen and fuel, in order to smelt and to reduce the material fed to the furnace, in the molten bath. Coke is added as a reducing agent for the metals. Material is fed to the furnace from the top by means of a metallic feed conveyor. The process gases leave the furnace also by the top where they are collected and sent to the gas-cleaning installation. The smelter offers considerable flexibility and a high process efficiency, which results in maximum metal recovery rates and optimal precious metal yields via different process steps. The process used is able to cope with all forms of feed material, wet or dry, fine or lumpy and all types of materials, metallic, oxidised, hydroxide, sulphide or sulphate, and also with the whole range of metals and plastics present in WEEE.

The smelters' role is to separate lead from copper and precious metals. The smelter operates in a temperature range between 1050 and 1200 °C. During this trial, the temperature was always close to 1200 °C.

### 5.3. Off-gas emission control installations at Umicore's Hoboken site

The Hoboken plant is equipped with an extensive flue gas cleaning system (see diagram), resulting in very low emissions. The following are monitored on a regular basis: dust, metals, dioxins, total organic carbon (TOC), HCl, HF, HBr, NO<sub>x</sub>, and SO<sub>2</sub>.



## 6. Trial run using WEEE in the smelter feed stream

### 6.1. Parameters of trial run and control

In order to measure and assess the impacts of including WEEE plastics in the smelter feed, a trial run with around 6% (by weight) WEEE plastics was compared to a "control" run with feed not containing such materials. For the control run, a feed mix typical of daily operation at the Hoboken plant was used, but specifically excluding electronic scrap (whereas the plant currently regularly includes WEEE in its feed, mainly in the form of printed circuit boards, see above). This control feed mix included around 3.7% (by weight) coke necessary to ensure the reduction of the metal content of the waste stream. This run was carried out over about 3 days of continuous smelter operation.

A transition run was then performed (using the trial run feed as below), in order to ensure that trial run data was fully representative of the trial run conditions and not carry-over from the control run.

For the trial run, the same average typical feed mix was used, but with 6.4% (by weight) WEEE (of which approx 76% plastics, as described above), and only 0.9% (by weight) coke. This run was carried out over about 4 days of continuous operation.

In total, the two runs and the transition run were carried out over about 8 days of continuous smelter operation.

During the whole experiment (control run and trial run), the standard feed composition was changed as little as possible (other than the WEEE content in the trial run). The different waste types mixed in the feed stream were adjusted to maintain a fairly constant average composition although, because of the large volumes treated, the feed composition could not be kept 100% identical.

### 6.2. Specifications of feed mixtures

		Control run	Transition	Trial run
Duration (approx)		3 days	1 day	4 days
Tonnage standard feed used		1 530 tonnes	893 tonnes	2 733 tonnes
<b>Feed composition</b>				
As % of standard feed	WEEE	None	6.4%	
	Coke	3.7%	0.9%	
	Fuel oil	4%	3.3%	
Standard feed : feed mix typical of daily smelter operation at the plant, but specifically excluding electronic scrap				





## 7. Trial results

### 7.1. Energy balance

The energy balance calculation is given below. Energy losses are accounted into the steam energy production figure. This is based on the known energy content of coke, fuel oil and steam production, and the measured changes in energy input (coke, fuel oil) and output (steam production). From these, the useful energy content of the WEEE used in the feed is calculated.

	Inputs			Outputs
	WEEE	Coke	Fuel Oil	Steam production (20°C -> 1180°C)
Energy content (GJ/tonne)		30	43	2.8
<b>Control run</b>				
Tonnes / tonne standard feed		3.7%	4.0%	0.467 tonnes
MJ / tonne standard feed		1102 MJ	1700 MJ	- 1 313 MJ
<b>Trial run</b>				
Tonnes / tonne standard feed	6.4%	0.9%	3.3%	0.658 tonnes
MJ / tonne standard feed	Calculated as: 1629 MJ	272 MJ	1 435 MJ	- 1 847 MJ
MJ / tonne standard feed		Reduction in coke and fuel consumption: 1095 MJ		Increased steam production: - 534 MJ

Note: The detailed calculations are to be seen in the appendix.

From the above assessment of the plant performance data approximately 2/3 of the recovered energy (1095 MJ) resulted in this trial run in reduced coke and fuel consumption (reducing agent, energy resource), and 1/3 in increased steam production (534 MJ). The steam production is used as an energy source for various processes in the Umicore plant.

Observation suggests that this is because the plastic is not all coming into the molten bath zone of the smelter, but a part of it is decomposed by the smelter heat during loading into the top of the smelter, volatilises and burns higher up in the furnace, transferring its energy into steam production.

**It can therefore be concluded, that approximately 2/3 of the energy content of the WEEE plastics included in the smelter feed stream in this trial replaces consumption of virgin coke and fuel oil (reducing agent and energy source) and approximately 1/3 is used in increased steam production.**

## 7.2. Environmental performance

During the trial run, plant emissions measured after the existing off-gas cleaning system for chlorinated dioxins/furans remained well below the legal emission limit of 0.1 ngTEQ/Nm<sup>3</sup>, and no significant difference was observed between the control and trial periods. Brominated dioxin/furan congeners were not detected during the air emission measurements. The overall effects on solid waste production and water emissions have not been measured.

It can be assumed that organic compounds (such as brominated flame retardants TBBA, DecaBDE, organic phosphorus flame retardants, melamine compounds ...) are essentially destructed at the high smelter operating temperature (>1100°C). However, exact destruction efficiency calculations could not be carried out in the industrial operating context of this trial. Bromine from brominated flame retardants will be converted to a large extent to soluble acid (HBr) and transferred to the plant's waste water treatment system.

Other flame retardant compounds: at the Hoboken plant, over 70% of antimony (Sb) in feed is recovered and recycled as a commercial antimony salt (sold for industrial applications); aluminium, magnesium and phosphorus are transferred mainly to slags which are reused in the concrete industry as a substitute for gravel; some phosphorus may be transferred to phosphoric acid in the plant's air scrubbing system.

Reliable and meaningful mass balances could not be measured due to the relatively short term and the industrial scale of this trial as well as the integration of the integrated smelter into the whole plant operations at the Hoboken site.

## 7.3. Smelter operational performance

The trial shows that, in the current smelter configuration, the proportion of WEEE plastics which can be included in the feed stream is limited by the steam production and by the increase in temperature at the top of the furnace.





## 8. Conclusions and recommendations

### 8.1. Technical conclusions

This trial showed that in the Umicore smelter at Hoboken:

- inclusion of approximately 6% plastics rich WEEE (mixed metals – plastics materials, approx 3/4 plastics) in the smelter feed resulted in no operating problems. The process stability and environmental emissions were not affected as far as measured.
- input levels of plastics rich WEEE significantly higher than normally today are limited by steam production capacity and would require control and/or modifications to prevent overheating of the furnace
- in this trial, one tonne of WEEE plastics enabled a reduction of consumption of approximately 0.6 tonnes of coke and 0.1 tonnes of fuel oil: approximately 2/3 of the plastics' energy content was used to replace consumption of coke and fuel oil (reducing agent and energy source) and approximately 1/3 was recovered as increased steam production.
- flame retardants present in the typical household WEEE posed no problem to use as smelter feed within the % limits indicated above
- there was no measurable increase in air emissions from dioxin/furan like compounds from chlorine or bromine containing flame retardants at the levels present in this household WEEE

### 8.2. Recommendations

- Implementation of the EU WEEE Directive (2002/96/CE) will result in considerably increased arisings of collected WEEE-scrap materials.
- Integrated metals smelters can provide an appropriate route for certain plastics and metal rich WEEE residue materials, enabling recovery of different precious and non-ferrous metals, including antimony in flame retardants, and the use of the plastics fraction to replace coke and fuel oil (reducing agent and energy source)..
- The Hoboken smelter plant has the ability to treat WEEE plastic containing fractions in conformity to applicable legislation, and without requiring meticulous sorting or complex pre-processing of WEEE-scrap. It therefore provides an appropriate solution for complex WEEE-scrap fractions, in particular circuit boards and small electronic apparatus such as mobile phones, portable music players, calculators, telephones, modems and computer components....

## 9. Appendix

	Inputs			Outputs
	WEEE	Coke	Fuel Oil	Steam production (20°C -> 1180°C)
Energy content (GJ/tonne)		30	43	2.8
<b>Control run</b>				
Tonnes / tonne standard feed		3.7%	4.0%	0.467 tonnes
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Tonnes / tonne standard feed	6.4%	0.9%	3.3%	0.658 tonnes
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MJ / tonne standard feed		Reduction in coke and fuel consumption: 1095 MJ		Increased steam production: - 534 MJ

From the table above:

One tonne of WEEE plastics input corresponds to a reduction in consumption of 0.57 tonnes of coke and 0.1 tonnes of fuel oil.

*Calculation:*

$$6.4\% \text{ WEEE} \times 76\% \text{ plastics} = 4.9\% \text{ WEEE plastics}$$

$$\text{< --- > } (3.7 - 0.9)\% \text{ coke and } (4.0 - 3.3)\% \text{ fuel oil}$$

The smelter's inherent energy consumption and the energy content of the standard feed input are assumed to be the same for the two runs. Therefore, the energy provided by the WEEE included in the feed of the trial run can be calculated as follows:

*Calculation:*

$$X = \text{MJ energy in WEEE / tonne standard feed}$$

$$X + 272 + 1435 - 1847 = 1102 + 1700 - 1313$$

$$\text{Therefore : } X = 1629 \text{ MJ / tonne standard feed}$$





Given that the WEEE fraction used contained approximately 76% plastics (see composition table, the rest being metals and inerts), this means that its plastic content delivered around 33 MJ of recovered energy per kg plastic content:

*Calculation:*

*6.4% WEEE / tonne standard feed -> 1629 MJ / tonne standard feed*

*(0.76 x 6.4%) tonnes WEEE plastic -> 1629 MJ*

*Therefore : 1 tonne WEEE plastic -> 33 000 MJ*

This amount for the delivered energy from the WEEE plastics in the trial run (33 000 MJ/tonne above) is coherent with the theoretical calorific value of plastics (which ranges from around 25 000 – 45 000 MJ/tonne) and with analysis of samples of the WEEE plastics used which were variable but within this range.

## 10. Acknowledgements

Technical support and assistance: NVMP Stichting Nederlandse Verwijdering Metalektro Producten (Netherlands Association for Disposal of Metaelectro Products) [www.nvmp.nl](http://www.nvmp.nl)

Financial support: IAOIA (International Antimony Oxide Industry Association) [www.iaoia.org](http://www.iaoia.org)

The WEEE used in trial was supplied via the recycling company PHB (Plastic Herverwerking Brakel B.V.) The Netherlands [www.phb-recycling.com](http://www.phb-recycling.com)

Photos: PHB, Umicore





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