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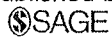
**Co-combustion of shredder residues and municipal solid waste in a Swedish municipal solid waste incinerator**

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What is This?

# Co-combustion of shredder residues and municipal solid waste in a Swedish municipal solid waste incinerator

Incinerating automotive shredder residue (ASR) in order to increase the recovery from end of life vehicles (ELVs) is an attractive option when recycling this material. In this study, incineration combined with energy recovery, was investigated. The incineration experiments, where 20% shredder residue (SR) was burnt with conventional municipal solid waste (MSW), were conducted in a full-scale MSW horizontal grate incinerator. Measurements were made before, during and after the incineration. The results showed some minor increases in the emission levels of raw gases sampled after an electrostatic filter, but almost no significant differences when sampled after a wet scrubber. An increased level of 'non-toxic' metals was detected within the bottom ash. It was concluded that refined SR, in small quantities, is suitable to add to MSW.

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Keywords – (Auto) shredder residue ((A)SR), full-scale incineration, emissions, end-of-life vehicle (ELV), car recycling.

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## Introduction

The aim of this study was to investigate whether there were any differences in the products of the incineration of conventional, pure municipal solid waste (MSW) and those of the same material co-combusted with 20 percent shredder residue (SR). The products examined were flue gas emissions, fly ashes, bottom ashes and process waters. These were analysed for a range of potential by-products before, during and after mixing SR with MSW in a full-scale municipal solid waste incinerator (MSWI).

## Background

In January 1998, legislation was introduced in Sweden making car manufacturers responsible for end-of-life vehicles (ELVs) (SFS 1997:788). The legislation requires that

the recycling goal rises from approximately 75% of the car weight in 1998 to 95 percent by the year 2015. Therefore, new techniques or treatment options must be developed for automotive shredder residue (ASR).

This study was initiated by the Swedish car industry, because of the producers' liability. Due to the relatively low numbers of ELVs in Sweden (maximum 200 000 tonnes per year) and results from a pilot study (Börjeson *et al.* 1998, 2000), it was decided to undertake full-scale studies of shredder residue. The residue was not exclusively material from ELVs, but comprised one third light material from ELVs, one third light material from waste white goods and one third light material from industrial waste other than automotive shredder residue. The material studied is representative of the output from modern Swedish shredder facilities. However, this thesis does contain a discussion of previous studies of pure ASR.

Although there are various options for treating ASR, incineration, combined with energy recovery, is one of the most economic. In Sweden, ELVs account for relatively small amounts of waste, and there are large distances between waste facilities.

#### Recycling of automotive shredder residue

An average car consists of approximately 70–80% metal, 10–20 percent plastic, 5% rubber, 3% glass, plus anti-corrosion substances, paint, noise-reduction material, textiles and fibreboard (Neuendorff 1994). When an end-of-life vehicle is scrapped, it is first delivered to an automobile dismantler, and later shipped to an automotive shredder facility. In the modern shredding processes, metals, comprising about 75–80% of the mixed waste, can be recovered. Of this, the non-ferrous material (NF), comprising about 5%, can be separated out. The remaining 20–25% is referred to as shredder residue or sometimes, less accurately, automotive shredder residue. After shredding, the (A)SR has been, traditionally, deposited in landfills (Peterson 1995).

The (A)SR contains a heterogeneous mixture of both inert and combustible materials, including plastics, such as polypropylene, polyethylene, polyvinyl chloride, acetylene butadiene styrene, polystyrene and polyurethane foam, as well as glass, fabric, wood, rubber, fibres, paper, tar, rust, dirt, sand, gravel, metals, metal oxides, moisture and car fluids (Field & Clark 1991; Jody *et al.* 1992; Jody *et al.* 1996; Lanoir *et al.* 1997; Sendjarevic *et al.* 1997). The metals present tend to be in the form of small pieces or powder, which have not been removed in the shredder processes. About 50 percent of the ASR is combustible (Börjeson *et al.* 2000; Jody *et al.* 1992; Hubble *et al.* 1987; Martin *et al.* 1992).

#### Previously published research

A number of studies of the combustion of ASR have been conducted. However, most of these investigations were undertaken in conditions where it was not possible to sample emissions in flue gases and levels of organic pollutants and metals in bottom ash, fly ash and process water. Most previous studies have been conducted under laboratory conditions. For example, Hubble *et al.* (1987) tested ASR as a fuel for on-site power generation in a rotary kiln test incinerator. They found that the volume of fluff in the ASR was reduced by 80%, and the weight by 55%. Inorganic emissions of nitrogen oxide (NO), carbon

monoxide (CO), hydrocarbons (THC) and sulphur dioxide (SO<sub>2</sub>), were measured, but not organic emissions. However, these authors suggested that polychlorinated dioxins and furans had been produced, since they found chlorine within the shredder fluff.

Ryan *et al.* (1993) simulated open-burning of unadulterated fluff. They measured inorganic flue gases on-line and sampled volatile and semi volatile organics, metal aerosols and particulates. The semi volatile compounds included species such as polyaromatic hydrocarbons, chlorinated aromatics, polychlorinated dibenzodioxins and dibenzofurans. Their results indicated that substantial quantities of air pollutants were emitted.

In contrast, Funcke *et al.* (1998) demonstrated that it was possible to co-combust ASR with MSW, in a MSWI, without producing any significant increase in the emission levels of polychlorinated dibenzodioxins/furans (PCDD/F). In their experiments, the MSW was combined with 20 or 30% ASR. The MSWI, in which the tests are performed, was equipped with an air pollution control system, which comprised a flue gas cooler, a cyclone reactor, the separate addition of activated carbon, a spray absorber, a fabric filter and a catalyst to reduce NO<sub>x</sub>. In these experiments, samples were taken of the raw gas before the cyclone reactor, of the clean gas before the stack and from the boiler ash. The emission levels (1,3–6,5 ng I-TE m<sup>-3</sup> in raw gas) from all the samples were almost the same for the incineration of ASR with MSW and MSW alone.

Zakaria *et al.* (1994) also demonstrated that co-combustion was possible in an MSWI. At the SEMASS Resource Recovery Facility, MSW containing no more than 10 percent ASR is burnt. A mix containing 40 percent ASR, caused problems with bridging and plugging of the conveyer transfer chutes and in the feed system. Problems occurred particularly when higher percentages of ASR were incorporated.

Mark (1998) compared different incineration methods. These included MSW incineration, cement kiln incineration, hazardous waste incineration (HWI), and newer, cost-effective, environmentally sensitive techniques. The results suggested that MSWI of SR was the most appropriate technique. Other advantages of MSWI combined with energy recovery are: that the technique is well known; it is environmentally sound; and it can be performed at a reasonably low cost. In

Sweden there are 22 full-scale incinerators for municipal solid waste, which comply with the requirements for controlled incineration, flue gas cleaning and the ability to handle the residual products.

### Experimental background

A study was conducted to characterise six different sets of shredded waste. These were then combusted in a pilot fluidised bed reactor. The experiment demonstrated that the refined fractions of ASR (i.e. fractions where the metal separation was more efficient than in normal shredder operations, see Fig. 1.) generated energy equating to about 23 MJ kg<sup>-1</sup>. Using shredder residue comprising one third from ELVs, one third from waste white goods and the final third from industrial waste, the heat generated was estimated to be approximately 14 MJ kg<sup>-1</sup> (Börjeson *et al.* 1998, 2000). See Börjeson *et al.* 1998 and 2000 for further details.

Analysis of refined ASR indicated an ash content of 20–27%, which included three fractions each decomposed to a different extent. The mixed SR had an ash content of 52%. This was because the white goods and industrial waste contained larger amounts of metal. Despite the relatively high chlorine content (2.0–2.8%) and levels of PCB (1.1–6.7 µg g<sup>-1</sup>), PCBz, (0.4–2.2 µg g<sup>-1</sup>), PCP, (0.3–1.4 µg g<sup>-1</sup>) and PAH (7.4–11.0 µg g<sup>-1</sup>), it appears that incineration, combined with energy recovery, could be a good way to recycle refined ASR. In SR, the levels were 1.4% chlorine, 12 µg g<sup>-1</sup> PCB, 0.8 µg g<sup>-1</sup> PCBz, 1.1 µg g<sup>-1</sup> PCP and 15 µg g<sup>-1</sup> PAH. For PCDD/F, the amounts in both ASR and SR were below 0.6 ng g<sup>-1</sup>. The amount of bromine, a flame retardant, was very low. The levels of bromine were between 100 and 1000 times lower than the corresponding levels of chlorine. These amounts are even smaller than those usually found in wheat flour. After characterising the material, the co-combustion of 20 percent SR and 80% MSW (Wikström & Marklund 1998b) was assessed in a fluidised bed laboratory reactor (Wikström *et al.* 1998a).

Analysis indicated that there were no significant differences in emission levels between burning ASR and mixed SR. Amounts of organic micro-pollutants, such as polychlorinated dibenzodioxins/furans (PCDD/F), polychlorinated biphenyls (PCBs), polychlorinated benzenes (PCBz), polychlorinated phenols (PCP) and polyaromatic hydrocarbons (PAH), were measured in the flue gases. PCDD/F levels are expressed as

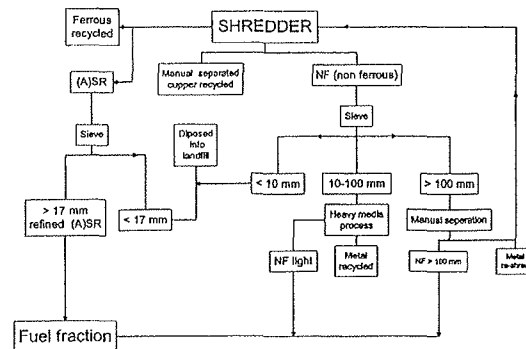


Fig. 1. Schematic figure of the shredding process

International Toxic Equivalents (I-TEQ) (Rappe 1994). Börjeson *et al.* (1998, 2000) described the results and details of these experiments. In fly ash it was not possible to detect any differences between ordinary shredder residue and automotive shredder residue, with respect to organic compounds. Some minor differences in the metal content of the fractions originating from SR and ASR were observed. Higher levels were found in SR.

## Materials and methods

### The shredding process

The shredding process, Fig. 1., is performed in order to recover iron and other metals from end-of-life vehicles, waste white goods and industrial waste. A hammer mill shreds the mixed material into small fragments, of about 1–10 cm. Light fragments (shredder residues), such as fabric, plastic, plastic foam, insulation and paint, are sucked out of the hammer mill and separated in a large cyclone. Heavier fragments, such as iron, steel and other heavy metals, are separated from wood rubber, aluminium and stones in a rotating separation drum using strong airflows. The final fragments to be removed are the non-ferrous materials. After the separation drum, the metals are transported to a vibration conveyor with a magnetic separator, which separates iron and steel from non-ferrous metals.

For the experiments presented here, the shredder residue was sieved in a 17 mm sieve. The larger particles were used in the combustion experiments and the maller particles were disposed of in landfill. The non-ferrous material is usually separated in a heavy-media flotation process, in which the metals are separated according to their density. Energy rich materials, such as

rubber and wood, can be included in the fuel fraction together with the refined shredder residue. However, they were not used in the full-scale combustion experiments.

#### Materials used: MSW and SR

The shredder residue tested, originated from Stena Bilfragmentering in Halmstad, Sweden. As described above, we used SR, a mix of waste from ELVs, industry and white goods. The MSW used was domestic waste, collected from households around Gothenburg, Sweden. The content of typical MSW in Sweden is detailed in Wikström & Marklund 1998b. The precise content of the MSW was not of importance for these studies, so it was not analysed. In the experiments, conventional municipal solid waste was used as the main fuel and SR was added. The mix was 80% MSW and 20% SR.

#### The incineration plant

This waste incineration facility is the country's largest, generating about 1 100 GWh per year, of which 15% is electricity and 85% is heat. The plant used for the experiments (Renova, previously known as GRAAB) had a capacity of 58 MW and a combustion capacity of 22 tonnes per hour. The combustion took place at 850°C. The plant was the horizontal grate type. The line used was one of three, all of which consisted of a incineration oven, a steam boiler, an electro-filter, a flue gas economiser and a condensing device (see Fig. 2.). Both primary and secondary air was added to achieve complete combustion. Re-circulated air was combined with ammonia to reduce the level of nitrous oxides emitted. After heat recovery, the outgoing condensed water is cleaned by neutralisation, flocking, ammonia

stripping, flotation and sand filtration. Normally, the bottom ash weighs about one-fifth of the weight of the input materials (GRAAB 1996).

Two weeks prior to the "real" co-combustion experiments and sampling of flue gases, SR was co-combusted with conventional MSW at the full-scale MSWI in Sävenäs, Gothenburg, in order to check the operational conditions. During this test, key inorganic flue gas parameters, including water (H<sub>2</sub>O), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), sulphur dioxide (SO<sub>2</sub>), ammonia (NH<sub>3</sub>), hydrogen chloride (HCl) and particle content were measured on-line, just before the stack. The addition of SR did not affect handling techniques or the flue gas control. Since the SR had a slightly higher energy content than MSW, it was only possible to incinerate at about 95% of the plant capacity.

#### Sampling of flue gases, ashes and process water

The experiments took place over three days. During the first day, conventional MSW was incinerated. During the second day, 20% refined SR was co-combusted with 80% MSW. On the third day, conventional MSW was once again incinerated, in order to determine whether there were any residual effects.

Flue gases were sampled, simultaneously, at two parallel points. Sampling locations (Fig. 2.) were selected to highlight any differences in flue gas content between the two waste fuels:

- after the electrostatic filter (Point 1, flue gas temperature 250°C); and
- after the wet scrubber, but before the final cleaning (Point 2, flue gas temperature 60°C).

After passing through all the cleaning systems, differences in the combustion products would not have been detectable. Automatic on-line measurements of inorganic parameters were taken after flue gas cleaning, just before the stack. Manual measurements of particles and HCl were made at Point 1.

Samples for the analysis of organic micro-pollutants (PCDD/F, PCB, PCBz, PCP, PAH) in the flue gases were collected over two-hour periods, and samples for particulate and HCl evaluation were collected over one-hour periods. On days 1 and 3, two samples for determining organics and one for particles and HCl were collected. On day 2, three samples for organics and one for particles and HCl were collected. Fly ash, bottom ash

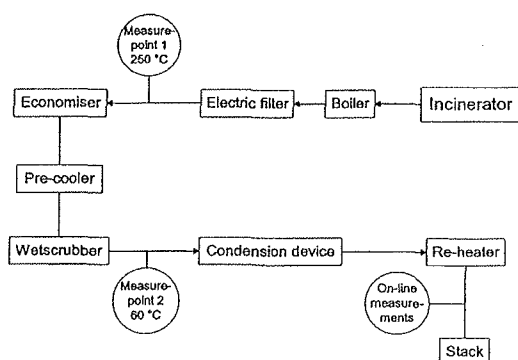


Fig. 2. Schematic figure of the incineration plant

and process water were sampled each day for the determination of organic pollutants and metals.

#### Sampling and clean up methods

The sampling of flue gases, the clean up process and the GC-MS analyses were performed according to Marklund *et al.* (1992). They included a Soxhlet Dean Stark Extraction with toluene. Before the extraction, 13C-internal standards of PCDD/F, PCB, PCBz, PCP and PAH isomers were added. Additional sample preparation varied according to the compounds to be analysed. Samples for PCDD, PCDF and PCB evaluations were passed through three columns: a silica column, a super alumina oxide column and an activated charcoal column. Samples for PCBz and PAH analysis were purified by passing them through a deactivated silica column. After acidification and hexane extraction, the silica column eluates were also used for PCP evaluation. Following preparation, but prior to analysis by GC-MS, recovery standards were added to the samples. PCDD/Fs were measured using HRGC (HP 5890, with a 2330 column) /HRMS (VG 11-250J). Other compounds were measured using HRGC (GC800 with a DB5 column) /LRMS (Fisons MD800).

Particles were sampled isokinetically on a glass fibre filter. The sampling point was after the electrostatic filter, in the flue gases, at Point 1. HCl was collected at the same location as the particles, in a 0.24 mmol HCO<sub>3</sub><sup>-</sup>/CO<sub>3</sub><sup>2-</sup>-solution. The particles were weighed and the HCl (Cl<sup>-</sup>) was measured using a Dionex DX-100 Ion Chromatograph. Other inorganic constituents were measured on-line in the flue gases, just before a muffler tall pipe in the stack.

Samples from the fly ash, the bottom ash and the process water were analysed for organic pollutants and metals. The organic analyses were performed as described above. After drying and dissolving in lithium borate, according to the ASTM D3682 method, the metals and metal oxides were analysed by ICP/AES or

ICP/MS. Leaching tests were also performed on the bottom ash: HNO<sub>3</sub>-extraction for either 2 or 10 hours, was followed by ICP/AES or ICP/MS analysis.

## Results and discussion

### Inorganic compounds and particles in flue gases

On-line measurement of flue gases over the three days indicated that burning SR did not cause any disturbance to the process. The only waste products, measured on-line, that increased on the second day were particles. Just before the stack, the amount increased from 1 mg Nm<sup>-3</sup> to 4 mg Nm<sup>-3</sup>. This is within the range of normal variation in particulate emissions. The maximum permitted level is 20 mg. When the HCl and particles were measured manually at Point 2, the results differed from the on-line measurements (table 1). The difference between the on-line measurements and the manual measurements could be explained by the different locations of the sampling points.

Table 2. Organic emissions in flue gases at measure points 1 and 2 during the three days

		I-TEQ ng Nm <sup>-3</sup>	PCB ng Nm <sup>-3</sup>	PCBz µg Nm <sup>-3</sup>	PCP µg Nm <sup>-3</sup>	PAH µg Nm <sup>-3</sup>
Day 1	Point 1	3.3	35	7.5	6.0	1.5
	Point 1	3.1	94	4.8	5.1	79
	Point 2	1.7	6	8.9	4.0	0.3
	Point 2	3.2	4	15.3	6.6	8.1
Day 2	Point 1	4.9	<140	6.6	na	218
	Point 1	9.0	246	9.6	9.7	4.3
	Point 1	10.9	328	8.5	6.8	4.1
	Point 2	5.1	10	7.1	6.7	1.7
	Point 2	7.0	23	10.8	6.9	6.9
	Point 2	6.7	26	9.9	7.6	7.1
Day 3	Point 1	2.9	79	12.7	4.6	13
	Point 1	4.3	134	7.5	5.0	3.8
	Point 2	2.8	<10	9.1	3.6	10.4
	Point 2	3.8	<10	10.9	4.0	8.2

na=not analysed

I-TEQ=International Toxic Equivalents

Table 1. On-line and manual inorganic measurements at the incineration experiments

	HCl mg Nm <sup>-3</sup>	Manual HCl mg Nm <sup>-3</sup>	Particles mg Nm <sup>-3</sup>	Manual Particles mg Nm <sup>-3</sup>	SO <sub>2</sub> mg Nm <sup>-3</sup>	CO ppm	CO <sub>2</sub> %
Day 1	6	32	1	109	230	52	12
Day 2	6	85	4	104	193	42	11.8
Day 3	5	66	1	36	199	40	11

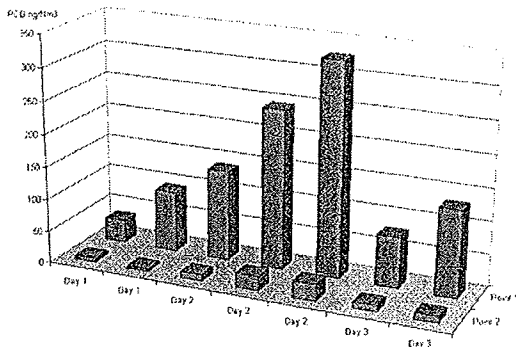


Fig. 3. PCBs in flue gases

#### Organic compounds in flue gases

The results of flue gas emission analysis indicated there were increases in PCB and PCDD/F levels in the flue gases at Point 1 when incinerating refined SR mixed with MSW. In the flue gases at Point 2, only the levels of PCBs increased (Table 2 and Fig. 3.). This demonstrates that the incineration process does not fully destroy the PCBs in the SR. However, most of the PCBs are caught in the wet scrubber, and the total amount of PCB in the emissions is lower than in the fuel.

#### Metals and organic pollutants in ashes and process water

The ashes were also analysed for metals, especially those that can cause environmental problems. The organic micro-pollutants PCDD/F, PCB, PCBz, PCP and PAH were examined in both ash and process water (Tables 3 and 4).

In the ashes, especially the bottom ash, the metal levels increased on the second day. Metals such as Fe, Cu, Zn, Ni and Pb increased about 2–3-fold when SR was co-combusted with MSW. However, levels of more

Table 3. Metals in ashes during the three incineration days

Element	Day	Bottom ash mg kg <sup>-1</sup>	Fly ash mg kg <sup>-1</sup>
Copper	1	1,500	1,500
	2	7,940	3,900
	3	408	1,620
Lead	1	408	7,930
	2	1,100	10,700
	3	1,320	4,510
Zinc	1	3,020	28,800
	2	7,250	62,000
	3	3,410	24,100
Nickel	1	94	106
	2	213	183
	3	79	137
Cadmium	1	3.4	268
	2	5.8	347
	3	2.8	129
Mercury	1	<0.194	<0.19
	2	1.22	0.21
	3	0.47	1.3
Iron*		%	%
	1	10.4	33.8
	2	4.14	3.6
3	13.9	4.6	

\*As iron oxide, Fe<sub>2</sub>O<sub>3</sub>

environmentally damaging metals, including Cd and Hg, did not increase significantly on the second day. Of the organic micro-pollutants in the ashes, only the level of PCB in the bottom ash increased significantly (up to 4–5 times) on the second day. Residual effects were recorded

Table 4. Organic compounds in ashes and process water

		I-TEQ ng g <sup>-1</sup> (ng L <sup>-1</sup> )	PCB ng g <sup>-1</sup> (ng L <sup>-1</sup> )	PCBz µg g <sup>-1</sup> (ng L <sup>-1</sup> )	PCP µg g <sup>-1</sup> (ng L <sup>-1</sup> )	PAH µg g <sup>-1</sup> (ng L <sup>-1</sup> )
Fly ash	Day 1	3.8	6.9-10.6	0.55	0.96	3.7
	Day 2	2.0	7.4-11.6	0.4	0.35	1.6
	Day 3	1.3	11.0	0.24	0.06	1.7
Bottom ash	Day 1	<0.01	90	0.024	0.004	0.6
	Day 2	0.011	435	0.023	0.19	5.6
	Day 3	<0.01	233	0.024	0.012	2.2
Process water	Day 1	30.6	68	2,030	29	19,800
	Day 2	13.7	38	460	8.3	2,430
	Day 3	18.0	33	1,300	11.7	8,780

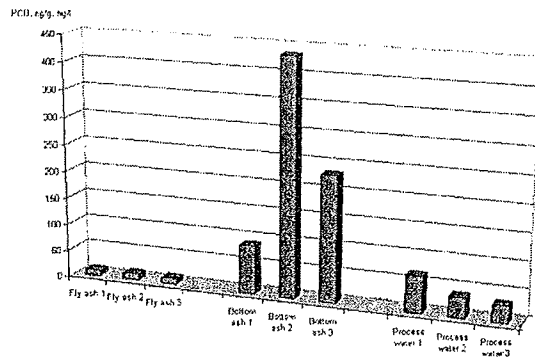


Fig. 4. PCBs in fly ashes, bottom ashes and process water

in the bottom ash on the third day. When analysing the bottom ash, some unburned plastic was visible in the ash, which may explain some of the increased levels of PCB. In addition, there was a minor residual amount of PCB in the fly ash on the third day. There was no significant increase in other organic micro-pollutants in the ashes on the third day compared with the first.

In process water, there were no differences between the first and the second days. Fig. 4. shows the PCB-levels in the ashes and the process water and table 4 contains the results of the micro-pollutant analysis. A leaching test, performed on the bottom ash, revealed no significant variation between the days.

## Conclusions

The results of this study demonstrate the potential for incineration, combined with energy recovery, for (A)SR in Swedish, full-scale MSWI. The results also show that 20% refined SR can be effectively added to MSW. Because SR is heterogeneous and complex, high proportions should not be mixed with MSW. This avoids the emission of large amounts of potentially harmful by-products.

In flue gases, sampled after electrostatic filtration, a minor increase in emissions was detected, but after passing through a wet scrubber, the difference was very small. The emissions measured at the second sampling point indicate that, after the full cleaning process, the gases were unchanged throughout the experiments. The

most critical of the measured organic micro-pollutants in flue gases were PCBs. These increased 3–5-fold in the flue gases at both the first and second sampling points on the second day. In the bottom ash, a 5-fold increase in PCB was noted when SR was burnt with MSW. However, this level of PCB is much lower than in the fuel.

The amount of various metals in the bottom ash also increased on the second day, from 18% to 23 % of input weight. This is probably the most significant problem. To solve it, shredder plants would have to develop refining processes targeted specifically at this type of material. In this experiment the only pre-treatment was to sieve the SR through a 17 mm mesh, to reduce the amount of inert material in the fuel fraction. There are probably other techniques that could improve the refining process.

The cost of SR incineration with energy recovery in Sweden will vary between municipalities, according to charges levied, at the MSWIs, for handling this type of waste

## Potential for energy recovery in Sweden – a future vision?

As mentioned in the introduction, the refined fraction of ASR, with a minor NF component, can generate energy totalling 17–26 MJ kg<sup>-1</sup> (mean 23 MJ kg<sup>-1</sup>) (Börjeson *et al.* 1998). For mixed SR, which is normally shredded, the energy values vary between 13 and 16 MJ kg<sup>-1</sup>. The total amount of ASR produced in Sweden is around 30–45 000 tonnes year<sup>-1</sup>. Refined ASR (i.e. roughly equivalent to the fuel fraction described above) amounts to about 20 000 tonnes year<sup>-1</sup>. In Sweden, the total mixed SR amounts to about 100 000 tonnes equivalent to about 50 000 tonnes of refined mixed SR.

Assuming that incinerating the ASR is realistic, since the legislation for producer responsibility was introduced, then ASR could produce 20 000 x 23 GJ = 460 000 GJ year<sup>-1</sup> (about 130 GWh). If all of the refined SR was incinerated, the energy in this material would be approximately 50 000 x 15 = 750 000 GJ year<sup>-1</sup> (about 210 GWh). The total amount of energy used in Sweden is about 400 TWh, of which one tenth originates from MSWIs. Excluding the costs of transporting material, rough calculations suggest that ASR could contribute 0.03%, and SR 0.05%, of total Swedish energy requirements.



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