



# **Background Study on the Content of Shredder Residue**

**Final Report (Public Version)**

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# 1. Executive Summary

## 1.1 Introduction

Metal shredders are a critical element of Canada's recycling industry. There are approximately two dozen metal shredders in Canada that aggregate metals, shred and separate the metals, and route the materials to downstream recyclers. These businesses play a key role in managing end-of-life vehicles (ELV) as one of their primary feedstocks. While the metals separated from these processes are recycled or utilized for various purposes, the shredder residue<sup>1</sup> is typically sent for disposal at landfills. Generally speaking, shredder residue is not economically valuable, and contains a mix of plastics, foam, rubber, and other non-metallic fractions. These materials, in turn, can contain additives such as plasticizers, flame-retardants and other chemicals that are identified under Canada's Chemical Management Plan or substances that can be found on Schedule 1 of the *Canadian Environmental Protection Act* (CEPA 1999).

In order to enhance its understanding of shredder residues, Environment Canada is conducting a background study on the content of shredder residues in Canada. The objectives of this study were to: (i) characterize the main materials found in shredder residue and identify potential variability across facilities in Canada; (ii) identify and describe the different pathways and technologies for disposal and management of shredder residue; (iii) provide data (from existing studies) describing some of the chemicals, including Chemical Management Plan substances found in shredder residue; and (iv) identify and conclude on information gaps relating to the composition of shredder residue.

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<sup>1</sup> There are two types of residue discussed in this report – auto shredder residue (ASR) and shredder residue (SR). Auto shredder residue is the residue that is left after end-of-life vehicles are shredded, while shredder residue is the residue that is left after other metal waste (e.g. white goods, other metal scrap) is shredded. In practice however, all shredders shred both end-of-life vehicles and other metal scrap. Therefore ASR in this report is typically referring to the residue that is left over after end-of-life vehicles and other metal scrap is shredded. Oftentimes the terms shredder residue (SR) and auto shredder residue (ASR) are used interchangeably in the report. Unless otherwise stated, it should be assumed that the shredder residue originated from a mixture of end-of-life vehicles and other metal scrap

## 1.2 Profile of the Shredder Industry in Canada

There is estimated to be over 1,800 ELV processors in Canada, but only approximately 25 shredding facilities. The following table shows all of the shredders that were identified in Canada and their locations.

**Table 1: Identification of Canadian Shredding Operations**

Province	Shredder	Location
British Columbia	Richmond Steel Recycling	Richmond, BC
	Schnitzer	Surrey, BC
Alberta	Navajo Metals	Calgary, AB
	GenAlta Recycling Inc.	Sherwood Park, AB
	Calgary Metals	Calgary, AB
Saskatchewan	Wheat City Metals	Regina, SK
Manitoba	Gerdau Ameristeel Corp.	Selkirk, MB
	General Scrap	Winnipeg, MB
Ontario	Triple M Metal	Brampton, ON
	Triple M Metal	Sault Ste. Marie, ON
	Triple M Metal	Hamilton, ON
	Triple M Metals	Hamilton, ON
	Scrapmen	Hamilton, ON
	Kimco Steel Sales Ltd.	Kingston, ON
	Bakermat	Ottawa, ON
	Glenview Iron and Metal	Smith's Falls, ON
	Lakehead Scrap Metals	Thunder Bay, ON
	Gerdau Ameristeel	Whitby, ON
Quebec	American Iron & Metal Co.	Laval, QC
	American Iron & Metal Co.	Montreal, QC
	American Iron & Metal Co.	Levis, QC
	ArcelorMittal	Contrecoeur, QC
	ArcelorMittal	La Prairie, QC
	Les Industries Associées de l'Acier Ltée	Sainte-Catharine, QC
	Les Entrepôts de Metaux	Longueuil, QC
New Brunswick	American Iron & Metal Co.	Saint John, NB

Sources: Recycling Today, 2012 Auto Shredder Map and List; websites of the above companies; Cheminfo Services.

### 1.3 Material Composition and Concentration of Specific Substances in Shredder Residue

Auto shredder residue (ASR) is a highly heterogeneous mixture<sup>2</sup> of residual ferrous and non-ferrous metals, plastics, rubber, textile and fibre material, wood, and glass. The exact composition and physical properties of ASR depend mainly on the depollution operations conducted on vehicles<sup>3</sup>, the specific shredder input (e.g. vehicles, white goods and ferrous waste combination<sup>4</sup>), shredder equipment utilized, and post-shredder separation processes. The heterogeneity of the material, with varying levels of contamination (e.g. chlorine, heavy metals, polychlorinated dibenzodioxins/polychlorinated dibenzofurans (PCDD/PCDFs), moisture content, ash content and calorific value, represents a considerable challenge to select or design an appropriate post-shredder treatment process for ASR.<sup>5</sup>

The table below summarizes the material composition of ASR from a wide range of articles/reports that have analyzed this issue. The table demonstrates that the composition of ASR can differ considerably depending on the applied shredding and post-shredding process, especially as far as the major fractions of metals, rubber, plastics and textiles are concerned. This is mainly due to differences in processing and sorting efficiency. However it should be noted that the various articles cited do not use the same classifications, for instance foam (PUR – polyurethane) is sometimes mentioned separately, but is usually included in the plastic fraction. Another example is that “wire” is sometimes mentioned separately, but is usually included in the residual metal fraction or the non-ferrous fraction.<sup>6</sup> Therefore some of the variability in the material composition of ASR, as outlined in the table below, is attributed to varying classification structures utilized by different authors.

Summarizing the material composition of ASR from the table below, plastics generally represent 20-45% of this material, metals 5-20%, rubber 5-25%, foam 0-15%, wood/cardboard 0-5%, textiles/fibres 5-30%, glass 0-20% and miscellaneous/undetermined materials 5-35%. However the most important conclusion that can be drawn from this table is the significant differences that are observed in the material composition of ASR from one sample to the next.

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<sup>2</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>3</sup> Ibid.

<sup>4</sup> Ibid.

<sup>5</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>6</sup> Ibid.

**Table 2: Material Composition of Auto Shredder Residue, as Outlined in the Literature (weight %)**

Reference→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Avg.
<b>Material</b>																			
Metal				0.8-1.6%					6.4%	6%						11%	1%	8%	5.6%
Ferrous	8%	3.1-3.7%	3%			12.0%		11%				2.2%	8.1%	13%	11.4%				8.0%
Aluminum		1.5-2%			16%									3%					6.9%
Non-ferrous	4%	0.45-0.7%			6.7%									1%					3.1%
Wire	5% (harness)		5%	4.2-5.1%		1.7%	3%	1%				3.5%	2.1%						3.2%
Rubber	7%	9.5-14.5%	18%	5.9-8.1%	12.4%	8.9%	21% (elastomers)	13%	2.7%	38%	20%	9.4%	5.3%	23%		14%	7%	20%	14%
Plastics	33%	35.6-44.2%	33%	20.6-23.6%	39.8%	14.2%	41%	37%	21.9%	20%	20%	29.3%	19.3%	22%	42.6%	48%	37%	19-35%	30.4%
Foam (PUR)	16%		15%	5.5-15.9%		6.2%		11%	7.0%	4.5%		5.0%	2.2%	7%					9.0%
Wood+ cardboard	3%		3%			5.1%			4.4%	10%		1%	2.2%	4%				2-5%	4.0%
Dirt+non-combustibles									8.6%										8.6%
Textile/Fibres	15%		7%	30.8-31.2%		16.4%	10%	9%	4.1%	5%	25%	3.7%	45.1%	6%	33.5%	13%	10%	10-40%	16.2%
Glass	7%	14.5-17.5%		8.7-16.8%	11.7%	1.5%	16%		2.0%				3.5%	13%	1.7%				8.5%
Others	2%	21.3-31.8%	16%	6-8%	13.4%	34% (<40mm)	9%	18% (<5.6mm)	42.9%	16.5%	35% (inerts)	30.1% (<5 mm) 16.2% (non-detect)	12.2%	8%	10.7% (miscellaneous)	14% (fines – paint, glass, sand)	45%	15% (unknown, oils)	10.1%

Sources:

- <sup>1</sup> Kanari, N., et. al. (2003), *End-of-Life Vehicle Recycling in the European Union*, published in JOM.
- <sup>2</sup> Ferrao, P., et. al. (2006), *Strategies for Meeting EU End-of-Life Vehicle Reuse/Recovery Targets*, published in the Journal of Industrial Ecology.
- <sup>3</sup> Ambrose, C.A., et. al. (2002), *Diversions from Landfill: Quality Products from Valuable Plastics*, published in *Resources, Conservation and Recycling*.
- <sup>4</sup> Kim, K.H., et. al. (2004), *Management Status of End-of-Life Vehicles and Characteristics of Automobile Shredder Residues in Korea*, published in *Waste Management*.
- <sup>5</sup> OVAM (2008), *Validatie van de recyclagepercentages voor afgedankte voertuigen bij shredder-en flottatiebedrijven*.
- <sup>6</sup> Pineau, J.L., et. al. (2005), *Representativeness of an Automobile Shredder Residue Sample for a Verification Analysis*, published in *Waste Management*.
- <sup>7</sup> Mirabile, D., et. al. (2002), *Thermal Valorisation of Automobile Shredder Residue: Injection in Blast Furnace*, published in *Waste Management*.
- <sup>8</sup> Hwang, I.H., et. al. (2008), *Pretreatment of Automobile Shredder Residue (ASR) for Fuel Utilization*, published in *Chemosphere*.
- <sup>9</sup> Saxena, S.C. et. al. (1995), *Combustion and Co-combustion of Auto Fluff*, published in *Energy*.
- <sup>10</sup> Zolezzi, M. et. al. (2004), *Conventional and Fast Pyrolysis of Automobile Shredder Residue (ASR)*, published in *Waste Management*.

- <sup>11</sup> Galvagno, S., et. al. (2001), *Pyrolysis Process for Treatment of Automobile Shredder Residue: Preliminary Experimental Results*, published in Energy Conservation and Management.
- <sup>12</sup> Osada, M., et. al., (2008), *Brominated Flame Retardants and Heavy Metals in Automobile Shredder Residue (ASR) and their Behaviour in the Melting Process*, published in the Journal of Material Cycles and Waste Management.
- <sup>13</sup> Das, S., et. al., (1995) *Automobile Recycling in the United States: Energy Impacts and Waste Generation*, published in Resource Conservation and Recycling.
- <sup>14</sup> Fabrizi, L., et. al. (2003), *Wire Separation from Automotive Shredder Residue*, published in Physical Separation in Science and Engineering.
- <sup>15</sup> Hwang, I.H., et. al. (2007), *Characterization of Char Derived from Various Types of Solid Wastes from the Standpoint of Fuel Recovery and Pretreatment Before Landfilling*, published in Waste Management.
- <sup>16</sup> Ciacci, L., et. al. (2010), *A Comparison Among Different Automotive Shredder Residue Treatment Processes*, published in the International Journal of Life Cycle Assessment.
- <sup>17</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.
- <sup>18</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.
- Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

### 1.3.1 Estimate of the Amount of Certain Substances Present in ASR Generated Annually in Canada

The table below provides a list of the substances for which ASR concentrations were identified, and estimates of the quantity of these substances contained in ASR generated annually in Canada (one group of estimates is based on 200 kilograms of ASR per vehicle, while the other group of estimates is based on 280 kilograms of ASR per vehicle). Please note that these figures are gross estimates, and that the three parameters upon which the calculations are based are all approximations. In addition, please note that we have not provided estimates in the table below of the quantity of organotin species present in ASR, even though concentration data for these species was identified in the literature. This is attributed to the fact that the organotin concentration data for ASR is only available from one study and it is believed that there is an error with respect to the specification of units in that article.

**Table 3: Estimated Quantity of Specified Substances Contained in ASR Generated Annually in Canada**

Substance	Assumed Concentration in ASR (kg/tonne) or (wt%)	Estimated Quantity Contained in ASR Generated Annually in Canada Assuming 200 kg of ASR per Vehicle (tonnes)	Estimated Quantity Contained in ASR Generated Annually in Canada Assuming 280 kg of ASR per Vehicle (tonnes)
<b>Metals</b>			
Aluminum	6.5%	20,800	29,120
Arsenic	0.01	1.9	2.69
Cadmium	0.03	8.0	11.2
Chromium	0.3	96.0	134.4
Copper	30	9,600	13,440
Iron	11%	35,200	49,280
Mercury	0.00025	0.08	0.11
Nickel	0.33	104	145.6
Lead	4.0	1,280	1,792
Tin	0.04%	128	179.2
Selenium	0.0003	0.1	0.13
Antimony	0.11	33.6	47.04

Substance	Assumed Concentration in ASR (kg/tonne) or (wt%)	Estimated Quantity Contained in ASR Generated Annually in Canada Assuming 200 kg of ASR per Vehicle (tonnes)	Estimated Quantity Contained in ASR Generated Annually in Canada Assuming 280 kg of ASR per Vehicle (tonnes)
Titanium	0.9%	2,880	4,032
Zinc	12.0	3,840	5,376
Calcium	6%	19,200	26,880
Potassium	0.53%	1,696	2,374.4
Sodium	1.89%	6,048	8,467.2
Phosphorous	0.7%	2,240	3,136
Silicon	13%	41,600	58,240
Cobalt	0.01	3.8	5.38
<b><u>Chlorinated Substances</u></b>			
PCDDs/PCDFs*	1.50E-07	4.80E-05	6.72E-05
CoPCBs*	3.00E-08	9.60E-06	1.34E-05
MoBrPCDDs/PCDFs	7.00E-06	2.24E-03	3.14E-03
Polychlorinated Biphenyls	5.00E-03	1.6	2.24
Polychlorinated Naphthalenes	3.00E-05	0.01	0.01
Polychlorinated Benzenes	1.00E-03	0.32	0.45
Polychlorinated Phenols	8.00E-04	0.26	0.36
<b><u>Brominated Substances</u></b>			
PBDDs/PBDFs	0.00004	0.01280	0.01792
Brominated diphenyl ethers	0.16	51.20	71.68
Tetrabromobisphenol A	0.00055	0.18	0.25
Hexabromocyclododecane	0.003	0.96	1.34
Tribromophenol	0.000120	0.03840	0.05376
<b><u>Polycyclic Aromatic Hydrocarbons</u></b>	0.01	4.16	5.82
<b><u>Phthalates (DEHP)</u></b>	5.5	1,760	2,464
<b><u>Minerals/Oils</u></b>			
Mineral Oils	22.5	7,200	10,080
Benzene	0.000003	0.00096	0.001344
Hydrocarbons	6.6	2,112	2,956.8

## 1.4 Potential Technologies/Applications for the Beneficial Use of Shredder Residue

Even though it contains valuable material as plastics, copper wires and up to 5% of remaining metals, ASR is usually landfilled. This is mainly a consequence of the high pollutant content as well as of the lack of cost-effective sorting technologies, suitable for the separation of valuable materials from the ASR.<sup>7</sup> There are several factors that contribute to the desire to manage ASR in a manner other than landfills, for instance:<sup>8</sup> (i) the amount of material that is generated annually; (ii) the recyclable materials content (such as plastics and metals); (iii) the high heat value of ASR (more than 13 MJ/kg); and (iv) its potential hazardousness due to the presence of oils, hydrocarbons, PCBs and heavy metals. Post-shredder technologies are innovative processes dealing with the residual material, specifically ASR. Post-shredder technologies can be distinguished into two main categories: (i) those based on physical and mechanical sorting of the waste into different fractions that can be recycled and sold; and (ii) those based on the thermal treatment of the waste to recover chemical building blocks or fuel for energy production.<sup>9</sup> It has been suggested that a net environmental performance improvement appears to be ensured by those scenarios which include the application of post-shredder technologies.<sup>10</sup>

Within the main body of the report, the range of post-shredder technologies/options for ASR are discussed across the following categories:

- physical and mechanical upgrading of ASR;
- ASR direct to energy processes;
- thermochemical treatment of ASR to produce fuels; and
- incorporation of ASR into manufactured products.

## 1.5 Discussion of the Potential for Future Sampling of SR by Environment Canada

### 1.5.1 Sampling Standards

There were no standard test methodologies specific to auto shredder residue in the U.S. or Canada identified through Internet literature research or industry interviews.

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<sup>7</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>8</sup> Ibid.

<sup>9</sup> Ibid.

<sup>10</sup> Ciacci, L., et. al. (2010), *A Comparison Among Different Automotive Shredder Residue Treatment Processes*, published in the International Journal of Life Cycle Assessment.

In the U.S., individual state environmental agencies are free to choose methods that are deemed appropriate and or may elect to specify no testing method for ASR. Many states do not specify a test method and place the onus on the individual shredders to select a method deemed appropriate for the given parameter and to perform the tests themselves. These tests are intended to ensure that the waste being sent to standard landfills does not contain contaminants above the federal threshold for “toxic” waste as specified in the regulation 40 CFR 261. Some laboratories or experts have developed testing procedures for ASR such as W. Z. Baumgartner & Associates Inc., based in Franklin, TN. Baumgartner and Associates have performed extensive work in the auto shredder industry including multiple projects with Argonne National Laboratory. They have written testing procedures that have been adopted by states such as Arizona, Minnesota, Wisconsin, Massachusetts, Kentucky, and Pennsylvania.<sup>11</sup>

## 1.6 Conclusions

A total of between 320,000-448,000 tonnes of ASR is generated annually in Canada and even more shredder residue will be generated, once white goods and other general metal scrap is taken into consideration. This residue is generated at approximately 25 different shredding facilities in Canada. There will be a wide range of CMP substances that will be contained in this shredder residue, due to the numerous chemicals that are used in the production of vehicles and other metal products. There is continual development of post-shredder technologies to utilize this shredder residue in value-added applications and to consequently divert it away from landfills.

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<sup>11</sup> Interview with W. Z. Baumgartner & Associates, December, 2013.

## 2. Introduction

### 2.1 Background

Metal shredders are a critical element of Canada's recycling industry. There are approximately two dozen metal shredders in Canada that aggregate metals, shred and separate the metals, and route the materials to downstream recyclers. These businesses play a key role in managing end-of-life vehicles (ELV) as one of their primary feedstocks. While the metals separated from these processes are recycled or utilized for various purposes, the shredder residue is typically sent for disposal at landfills, contributing significantly to the amount of waste disposed in Canada's landfills each year. Generally speaking, shredder residue is not economically valuable, and contains a mix of plastics, foam, rubber, and other non-metallic fractions. These materials, in turn, can contain additives such as plasticizers, flame-retardants and other chemicals that are identified under Canada's Chemical Management Plan or substances that can be found on Schedule 1 of the *Canadian Environmental Protection Act* (CEPA 1999).

In order to enhance its understanding of shredder residues, Environment Canada is conducting a background study on the content of shredder residues in Canada. Environment Canada has identified a need to enhance its understanding of exactly what types of materials are present in shredder residue, in particular within automobile shredder residues and what specific chemical substances may be present within these materials, in order to further explore management options for shredder residue.

### 2.2 Objectives

The objectives of this study were to: (i) characterize the main materials found in shredder residue and identify potential variability across facilities in Canada; (ii) identify and describe the different pathways and technologies for disposal and management of shredder residue; (iii) provide data (from existing studies) describing some of the chemicals, including Chemical Management Plan substances found in shredder residue; and (iv) identify and conclude on information gaps relating to the composition of shredder residue.

### 2.3 Methodology

There were two broad components to the methodology that was employed during the study. Initially a broad literature search and review was conducted in order to identify past journal articles and reports that have been completed on shredder residue. Particular

emphasis was paid to locating past literature sources that provided information on the material/chemical composition of shredder residue as well as alternative technologies/options to the use of shredder residue beyond landfilling. Most of the identified journal articles were obtained and a wide selection of publications was reviewed in order to locate and then subsequently incorporate relevant information into the final report. There were other aspects of the literature search and review as well, for instance reviewing the websites of all shredders in Canada.

The second broad methodological component employed during the study was interviews. In total approximately 20 interviews were conducted during the study in order to collect specific information that could not be obtained through the publicly available literature. Among those organizations that were interviewed were approximately 15 shredders (representing approximately 20 of the 26 shredders in Canada). Attempts were made to interview all shredders in Canada in order to obtain information on the distribution of feedstock into their shredder, the location of other shredders in their Province, the fate of the shredder residue that they generate at their facility and their willingness to supply shredder residue for testing by Environment Canada in the future. There were also a handful of miscellaneous other interviews conducted during the study, for instance organizations with knowledge of shredder residue testing protocols.

## 2.4 Structure of this Report

There are six additional chapters in this report. Chapter 3 provides a profile of the shredder industry in Canada. Chapter 4 provides a detailed analysis of the material composition and concentration of specific substances in shredder residue. For instance it summarizes much of the available literature indicating how much plastic, foam, metals, rubber, etc. is present in shredder residue as well as the actual concentration of individual substances (e.g. metals, chlorine, bromine, etc.). Chapter 5 summarizes available information located during the study on the potential for leaching of chemical substances from shredder residue disposed of in landfills. The results from the key studies identified during the project are summarized in this chapter.

Chapter 6 describes the range of technologies/applications for the beneficial use of shredder residue. Within this chapter, the range of post-shredder technologies/options for shredder residue are discussed across the following categories: (i) physical and mechanical upgrading of ASR; (ii) ASR direct to energy processes; (iii) thermochemical treatment of ASR to produce fuels; and (iv) incorporation of ASR into manufactured products.

Chapter 7 provides a discussion of the potential for future sampling of shredder residue by Environment Canada. It discusses the availability of testing protocols for shredder residue as well as laboratories in Canada that could conduct this testing. Some information is provided on shredders in Canada that would be amenable to help



Environment Canada in this potential next phase. Chapter 8 provides the bibliography for the study, identifying those past literature sources that were consulted during the preparation of this report.

### 3. Profile of the Shredder Industry in Canada

There is estimated to be over 1,800 ELV processors in Canada, but only approximately 25 shredding facilities (which shred ELVs as well as other metal scrap). The following table shows all of the shredders that were identified in Canada and their locations.

**Table 4: Identification of Canadian Shredding Operations**

Province	Shredder	Location
British Columbia	Richmond Steel Recycling	Richmond, BC
	Schnitzer	Surrey, BC
Alberta	Navajo Metals	Calgary, AB
	GenAlta Recycling Inc.	Sherwood Park, AB
	Calgary Metals	Calgary, AB
Saskatchewan	Wheat City Metals	Regina, SK
Manitoba	Gerdau Ameristeel Corp.	Selkirk, MB
	General Scrap	Winnipeg, MB
Ontario	Triple M Metal	Brampton, ON
	Triple M Metal	Sault Ste. Marie, ON
	Triple M Metal	Hamilton, ON
	Triple M Metals	Hamilton, ON
	Scrapmen	Hamilton, ON
	Kimco Steel Sales Ltd.	Kingston, ON
	Bakermet	Ottawa, ON
	Glenview Iron and Metal	Smith's Falls, ON
	Lakehead Scrap Metals	Thunder Bay, ON
	Gerdau Ameristeel	Whitby, ON
Quebec	American Iron & Metal Co.	Laval, QC
	American Iron & Metal Co.	Montreal, QC
	American Iron & Metal Co.	Levis, QC
	ArcelorMittal	Contrecoeur, QC
	ArcelorMittal	La Prairie, QC
	Les Industries Associées de l'Acier Ltée	Sainte-Catharine, QC
	Les Enterpots de Metaux	Longueuil, QC
New Brunswick	American Iron & Metal Co.	Saint John, NB

Sources: Recycling Today, 2012 Auto Shredder Map and List; websites of the above companies; Cheminfo Services.

## 4. Material Composition and Concentration of Specific Substances in Shredder Residue

### 4.1 Introduction

End-of-life vehicles (ELVs) are rich in valuable materials, such as metals, and possess a high calorific potential due to their high content of combustibles such as plastics.<sup>12</sup> In order to capture the economic value of these materials and to reduce the amount of automotive shredder residue (ASR) produced as well as the content of contaminants within ASR, depollution and dismantling processes are the first necessary steps for ELVs.<sup>13</sup>

Before dismantling, the potentially hazardous and toxic parts are removed from the ELV – termed depollution. Depollution is focused on approximately 3% of the weight of ELVs, and addresses the parts that contain toxics or hazardous materials.<sup>14</sup> This consists of the removal of batteries, fluids (e.g. fuel, antifreeze, engine oil and brake fluid), heavy metal containing components, or potentially explosive elements (e.g. airbags). Fluids are generally reprocessed apart or sold as combustibles.<sup>15/16</sup>

Subsequently the dismantling process encompasses the removal of valuable parts and materials which can be re-used or recycled (e.g., glass, metallic components containing aluminum, magnesium, copper, rubber and plastic elements). Generally, the weight percentage of removed parts depends on vehicle age and condition, operational processes employed at dismantling plants, market value of the removed parts and on the labour costs to remove these parts. It has been estimated that the weight percentage removed from an ELV ranges from 9% for old ELVs to 47% for new (premature, e.g., damaged) ones, resulting in an average value of approximately 30%.<sup>17</sup> A large difference exists between for instance European countries, where only about 5–10% of an ELV's mass is

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<sup>12</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

<sup>13</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>14</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>15</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>16</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>17</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

removed during dismantling, and South Korea, where up to 35% of an ELV's mass is removed during this stage.<sup>18</sup>

After these operations, what remains from an ELV is sent to be mechanically shredded into smaller pieces in order to recover different materials in a shredding plant.<sup>19/20</sup>

## 4.2 European and Japanese Directives on Recycling/Recovery of ELVs

Outlined in this section is a description of European and Japanese directives for the recycling/recovery of ELVs. Both of these regions are far more advanced in establishing regional/national regulations that mandate ELV recycling/recovery than North American countries, where Canada and the U.S. do not have comprehensive national requirements established.

European Directive 2000/53/CE (Directive on End-of-Life Vehicles) has required since January 2006 that for all ELVs, the reuse and recovery of ELVs must meet a minimum of 85% by an average weight per vehicle and year. Within the same deadline the reuse and recycling must meet a minimum of 80% by an average weight per vehicle and year. For vehicles produced before January 1980, Member States may establish lower targets, but not lower than 75% for reuse and recovery and not lower than 70% for reuse and recycling.<sup>21</sup>

Furthermore the Directive requires that by January 1<sup>st</sup>, 2015, a minimum of 95% (in average weight per vehicle and year) of ELVs must be reused or recovered (including energy recovery), and that at least 85% must be reused or recycled, so as to reduce the disposal of this waste in landfills.<sup>22</sup> As such, only 5% of the weight of ELVs may be landfilled, and only 10% may be incinerated.<sup>23</sup> As a consequence of meeting these targets

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<sup>18</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>19</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>20</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>21</sup> Gonzalez-Fernandez, O., et. al., *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution.

<sup>22</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

<sup>23</sup> Fiore, S., et. al. (2012), *Automobile Shredder Residues in Italy: Characterization and Valorization Opportunities*, published in Waste Management.

the ASR must be subjected to some form of recovery, since it constitutes more than 20% of the car mass.<sup>24</sup>

Besides setting targets, Directive 2000/53/EC aims at preventing waste from vehicles, by requiring that Member States encourage vehicle manufacturers, in liaison with their material and component manufacturers to: (i) limit the use of hazardous substances in vehicles, so as to prevent their release into the environment, to make recycling easier, and to avoid the need to dispose of hazardous waste; (ii) design and produce vehicles which facilitate dismantling, re-use and recycling; and (iii) increase the use of recycled materials in new vehicles. The Directive furthermore requires that components of vehicles, sold after July 1<sup>st</sup>, 2003, no longer contain mercury, chromium, cadmium or lead (with a few exceptions, listed in Annex II of the Directive).<sup>25</sup>

A separate instrument, European Directive 1999/31/CE, states that wastes having a lower heating value (LHV) higher than 13 MJ/kg cannot be landfilled. Therefore ASR, characterized by a LHV higher than 13 MJ/kg cannot be forwarded to any landfill without further treatment designed to lower combustible components.<sup>26</sup>

In Japan recycling of ELVs is considered a priority area, and a law on automotive recycling was implemented in 2004. Consequently, most car producers have branches in the recycling business and develop easy-to-recycle cars. Targets for recycling (including thermal recovery) of ASR were set at 50% by 2010 and at 70% by 2015, corresponding to an overall recycling rate of ELVs of about 95% by 2015, analogous to Europe, when the fraction represented by ASR in the total mass of ELVs is considered.<sup>27</sup>

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<sup>24</sup> Cossu, R. & Lai, T. (2013), *Washing Treatment of Automotive Shredder Residue*, published in Waste Management.

<sup>25</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>26</sup> Fiore, S., et. al. (2012), *Automobile Shredder Residues in Italy: Characterization and Valorization Opportunities*, published in Waste Management.

<sup>27</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

## 4.3 Description of the Shredding Process and Automotive Shredder Residue

### 4.3.1 Description of the Shredding Process

The main objective at a shredder plant is to recover as many metals as possible (ferrous and non-ferrous).<sup>28</sup> A typical shredder plant utilizes several process steps, the first of which is a hammer mill that reduces ELVs into small pieces.<sup>29</sup> The larger of these hammer mills can contain 10 hammers or more, and each of these hammers can be 300 pounds or more in weight. Shredders of this size are capable of reducing a vehicle into fist-sized pieces of scrap in less than a minute.<sup>30</sup> After the vehicle hulk is mechanically reduced in size, steps and technologies applied by vehicle recycling facilities tend to vary.

Most often ferrous metals are then removed from this waste stream by a series of mechanical and magnetic separation processes. Purities of more than 99% can be reached using a magnetic drum, rendering this waste stream very suitable for recycling. The removed ferrous metal fraction of an ELV can amount to up to 65% of the original ELV's mass.<sup>31</sup>

The ferrous metals are not always removed first, however. Sometimes, air clarifiers or air-flow separators are used to remove a light fraction of ASR, which consists primarily of low density plastic pieces.<sup>32</sup> This light ASR fraction also typically contains materials such as glass, wood, sand, dust, fine metallic particles and foams.<sup>33</sup> If the light ASR fraction is not removed before ferrous metals, then this step is carried out later in the process.

Non-ferrous metals are then separated from the remaining heavier elements of the ASR such as heavy plastics and rubber by processes such as induction (which includes technologies such as sink-floating or eddy current separators).<sup>34</sup>

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<sup>28</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

<sup>29</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>30</sup> Steel Pacific Recycling (February 18, 2008), *Backgrounder*.

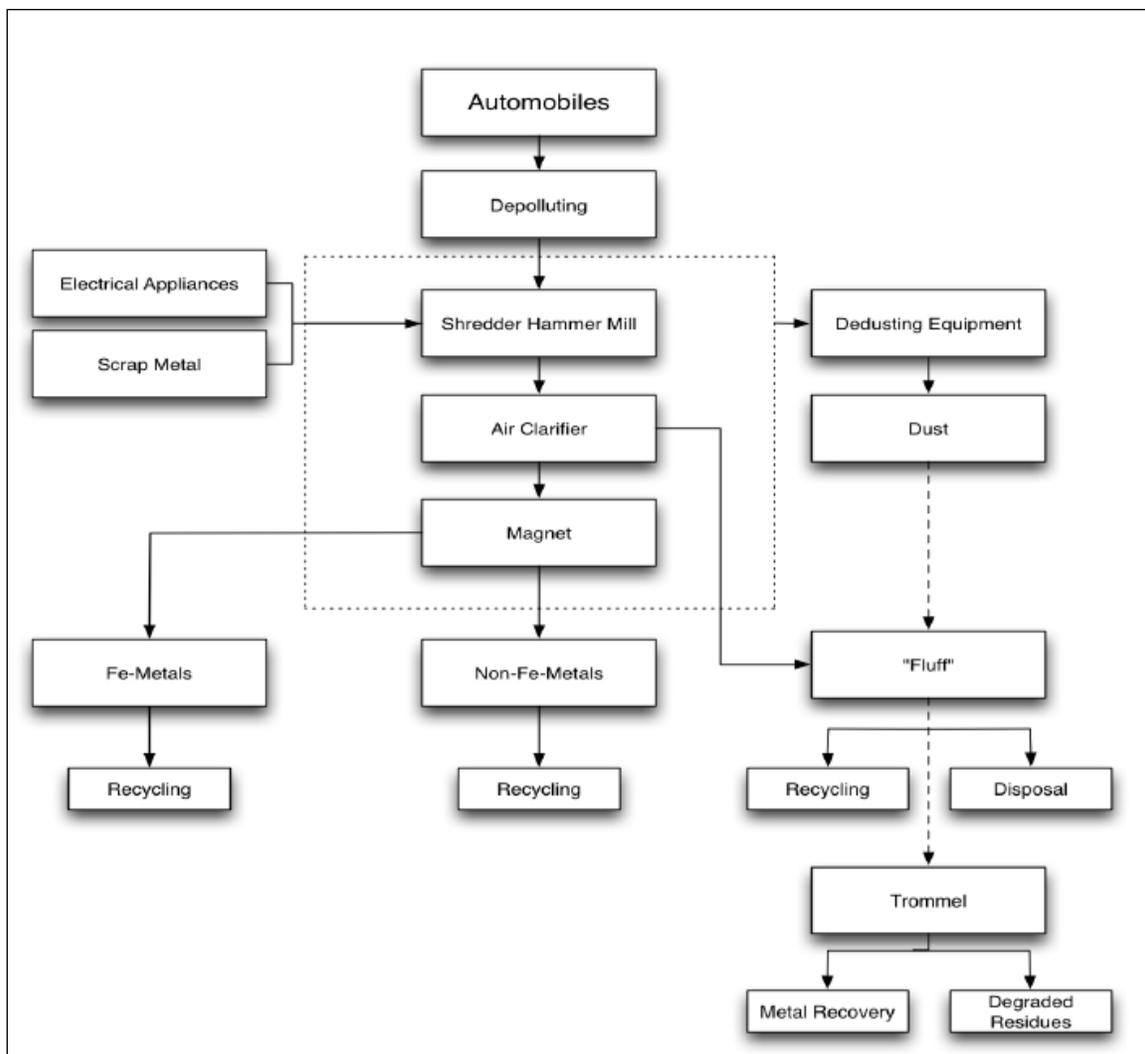
<sup>31</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>32</sup> Gonzalez-Fernandez, O., et. al., *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution.

<sup>33</sup> Ibid.

<sup>34</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

The order these technologies are applied in (or the actual technologies applied) vary substantially from facility to facility. The diagram below, for example, was published by the United Nations Environment Programme and shows a different process than is described by some of the other sources consulted for this project.



**Figure 1: Automotive Shredder Process Flow Diagram**

Source: UNEP, (2010), *Stockholm Convention on Persistent Organic Pollutants Supporting Document for the Draft Technical Paper Developed in Accordance With the Work Programmes on New Persistent Organic Pollutants as Adopted by the Conference of the Parties.*

In North America, light and heavy fractions of ASR are of little value, and are usually used for landfill cover. However, in some countries, certain plastic fractions (including for example polypropylene, polystyrene and acrylonitrile butadiene styrene) are removed

from ASR by applying physical or mechanical separation techniques, exploiting differences in density, solubility or melting point.<sup>35</sup> These plastics can then be recycled.

#### 4.3.2 Description of Automotive Shredder Residue

Automobile shredder residue is the residual fraction of a vehicle obtained after the depollution, dismantling, shredding and metal separation steps (also named “car fluff”).<sup>36</sup> Most authors have indicated that ASR represents in the vicinity of 15-30% of the weight of an ELV.<sup>37/38/39/40</sup> As an example, an Italian facility shredded approximately 250,000 tons of cars per year, producing 180,000 ton of ferrous material, 6,000 tons of non-ferrous metals and 64,000 tons of light and heavy fluff. On a vehicle mass balance basis, this was estimated at 69.5% recovered from ferrous and non-ferrous metals, 0.5% from tires, bumpers and tanks, while the remaining ASR (i.e. 30%) was routed to landfill.<sup>41</sup>

ASR can be classified into:<sup>42</sup>

- light fluff - fraction generated during shredding of the hulk and separated using air classification (approximately 75% of the total ASR and 10–24% of the total ELV);
- heavy fluff - fraction remaining after metal separation from the shredded heavy fraction (approximately 25% of the total ASR and 2–8% of the total ELV); and
- a soil/sand fraction is sometimes reported separately, but is usually included as part of the heavy ASR (approximately 0–2.5% of the total ELV).

ASR is also frequently classified based on its particle size.<sup>43</sup> This typically is defined as either being within the fine fraction (0-20 mm) or the coarse fraction (i.e.  $\geq 20$ mm) of ASR.

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<sup>35</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>36</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>37</sup> Ciacci, L., et. al. (2010), *A Comparison Among Different Automotive Shredder Residue Treatment Processes*, published in the International Journal of Life Cycle Assessment.

<sup>38</sup> Fiore, S., et. al. (2012), *Automobile Shredder Residues in Italy: Characterization and Valorization Opportunities*, published in Waste Management.

<sup>39</sup> Cossu, R. & Lai, T. (2013), *Washing Treatment of Automotive Shredder Residue*, published in Waste Management.

<sup>40</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>41</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>42</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>43</sup> Ibid.

Overall, ASR has the following characteristics: (i) it has a high calorie and ash content; (ii) it contains many fine particles of diameter 5 mm or smaller as well as considerable crushed waste of diameter 50 mm or larger, resulting in a low bulk specific gravity; and (iii) it contains large amounts of heavy metals, brominated flame retardants and chlorine. Due to these characteristics, ASR is considered to be a type of waste that is very difficult to treat.<sup>44</sup> However, the total loss on ignition (LOI) accounts for 25-42% of the gross ASR mass. This implies that 60-75% of ASR is not decomposed or burnt (inorganic and residual ashes). As such, ASR has potential value as a raw material in incineration or waste-to-energy plants.<sup>45</sup> Unfortunately due to its highly heterogeneous nature and the fact that it is often classified as hazardous material, ASR is typically most often disposed of in dedicated and appropriate hazardous waste landfill sites.<sup>46</sup> The classification of ASR as hazardous waste in Canada varies from province to province. For instance, it has been reported that ASR is classified as non-hazardous solid waste in Ontario, but hazardous waste in Quebec.<sup>47</sup>

Finally it should be noted that shredders often not only process ELVs, but ELVs together with other consumer products such as white goods and other metallic manufacturing and construction waste. In such cases the more general term “shredder residue (SR)” is used to describe the product of the shredding process.<sup>48</sup>

### 4.3.3 Trends in the Generation of ASR

The composition of ELVs change as the weight of non-ferrous metals and plastics increases at the expense of ferrous metals (i.e. lightweighting to increase fuel efficiency and reduce greenhouse gas emissions). It has been estimated that the trend over the next 5 years (from 2010) in terms of new automobile production is an increase of plastics (about 15%) and non-ferrous metals (about 10%), resulting in a reduction of 8% in weight of ferrous metals.<sup>49</sup> As a result, the quantity of ASR is likely to grow in the future.<sup>50</sup>

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<sup>44</sup> Osada, M., et. al. (2008), *Brominated Flame Retardants and Heavy Metals in Automobile Shredder Residue (ASR) and their Behavior in the Melting Process*, published in the Journal of Material Cycles and Waste Management.

<sup>45</sup> Gonzalez-Fernandez, O., et. al., *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution.

<sup>46</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>47</sup> Accessed at the following website: [www.greenvehicledisposal.com/about/what-is-an-end-of-life-vehicle/](http://www.greenvehicledisposal.com/about/what-is-an-end-of-life-vehicle/)

<sup>48</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>49</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>50</sup> Ciacci, L., et. al. (2010), *A Comparison Among Different Automotive Shredder Residue Treatment Processes*, published in the International Journal of Life Cycle Assessment.

## 4.4 Material Composition of Automotive Shredder Residue

ASR is a highly heterogeneous mixture<sup>51</sup> of residual ferrous and non-ferrous metals, plastics, rubber, textile and fibre material, wood, and glass. The exact composition and physical properties of ASR depend mainly on the depollution operations conducted on vehicles<sup>52</sup>, the specific shredder input (e.g. vehicles, white goods and ferrous waste combination<sup>53</sup>), shredder equipment utilized, and post-shredder separation processes. The heterogeneity of the material, with varying levels of contamination (e.g. chlorine, heavy metals, PCDD/PCDFs), moisture content, ash content and calorific value, represents a considerable challenge to select or design an appropriate post-shredder treatment process for ASR.<sup>54</sup>

The table below summarizes the material composition of ASR from a wide range of articles/reports that have analyzed this issue. The table demonstrates that the composition of ASR can differ considerably depending on the applied shredding and post-shredding process, especially as far as the major fractions of metals, rubber, plastics and textiles are concerned. This is mainly due to differences in processing and sorting efficiency. However it should be noted that the various articles cited do not use the same classifications, for instance foam (PUR – polyurethane) is sometimes mentioned separately, but is usually included in the plastic fraction. Another example is that “wire” is sometimes mentioned separately, but is usually included in the residual metal fraction or the non-ferrous fraction.<sup>55</sup> Therefore some of the variability in the material composition of ASR, as outlined in the table below, is attributed to varying classification structures utilized by different authors.

Summarizing the material composition of ASR from the table below, plastics generally represent 20-45% of this material, metals 5-20%, rubber 5-25%, foam 0-15%, wood/cardboard 0-5%, textiles/fibres 5-30%, glass 0-20% and miscellaneous/undetermined materials 5-35%. However the most important conclusion that can be drawn from this table is the significant differences that are observed in the material composition of ASR from one sample to the next.

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<sup>51</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>52</sup> Ibid.

<sup>53</sup> Ibid.

<sup>54</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>55</sup> Ibid.

**Table 5: Material Composition of Auto Shredder Residue, as Outlined in the Literature (weight %)**

Reference→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Avg.
<b>Material</b>																			
Metal				0.8-1.6%					6.4%	6%						11%	1%	8%	5.6%
Ferrous	8%	3.1-3.7%	3%			12.0%		11%				2.2%	8.1%	13%	11.4%				8.0%
Aluminum		1.5-2%			16%									3%					6.9%
Non-ferrous	4%	0.45-0.7%			6.7%									1%					3.1%
Wire	5% (harness)		5%	4.2-5.1%		1.7%	3%	1%				3.5%	2.1%						3.2%
Rubber	7%	9.5-14.5%	18%	5.9-8.1%	12.4%	8.9%	21% (elastomers)	13%	2.7%	38%	20%	9.4%	5.3%	23%		14%	7%	20%	14%
Plastics	33%	35.6-44.2%	33%	20.6-23.6%	39.8%	14.2%	41%	37%	21.9%	20%	20%	29.3%	19.3%	22%	42.6%	48%	37%	19-35%	30.4%
Foam (PUR)	16%		15%	5.5-15.9%		6.2%		11%	7.0%	4.5%		5.0%	2.2%	7%					9.0%
Wood+ cardboard	3%		3%			5.1%			4.4%	10%		1%	2.2%	4%				2-5%	4.0%
Dirt+non-combustibles									8.6%										8.6%
Textile/Fibres	15%		7%	30.8-31.2%		16.4%	10%	9%	4.1%	5%	25%	3.7%	45.1%	6%	33.5%	13%	10%	10-40%	16.2%
Glass	7%	14.5-17.5%		8.7-16.8%	11.7%	1.5%	16%		2.0%				3.5%	13%	1.7%				8.5%
Others	2%	21.3-31.8%	16%	6-8%	13.4%	34% (<40mm)	9%	18% (<5.6mm)	42.9%	16.5%	35% (inerts)	30.1% (<5 mm) 16.2% (non-detect)	12.2%	8%	10.7% (miscellaneous)	14% (fines – paint, glass, sand)	45%	15% (unknown, oils)	10.1%

Sources:

- <sup>1</sup> Kanari, N., et. al. (2003), *End-of-Life Vehicle Recycling in the European Union*, published in JOM.
- <sup>2</sup> Ferrao, P., et. al. (2006), *Strategies for Meeting EU End-of-Life Vehicle Reuse/Recovery Targets*, published in the Journal of Industrial Ecology.
- <sup>3</sup> Ambrose, C.A., et. al. (2002), *Diversions from Landfill: Quality Products from Valuable Plastics*, published in *Resources, Conservation and Recycling*.
- <sup>4</sup> Kim, K.H., et. al. (2004), *Management Status of End-of-Life Vehicles and Characteristics of Automobile Shredder Residues in Korea*, published in *Waste Management*.
- <sup>5</sup> OVAM (2008), *Validatie van de recyclagepercentages voor afgedankte voertuigen bij shredder-en flottatiebedrijven*.
- <sup>6</sup> Pineau, J.L., et. al. (2005), *Representativeness of an Automobile Shredder Residue Sample for a Verification Analysis*, published in *Waste Management*.
- <sup>7</sup> Mirabile, D., et. al. (2002), *Thermal Valorisation of Automobile Shredder Residue: Injection in Blast Furnace*, published in *Waste Management*.
- <sup>8</sup> Hwang, I.H., et. al. (2008), *Pretreatment of Automobile Shredder Residue (ASR) for Fuel Utilization*, published in *Chemosphere*.
- <sup>9</sup> Saxena, S.C. et. al. (1995), *Combustion and Co-combustion of Auto Fluff*, published in *Energy*.
- <sup>10</sup> Zolezzi, M. et. al. (2004), *Conventional and Fast Pyrolysis of Automobile Shredder Residue (ASR)*, published in *Waste Management*.

- <sup>11</sup> Galvagno, S., et. al. (2001), *Pyrolysis Process for Treatment of Automobile Shredder Residue: Preliminary Experimental Results*, published in Energy Conservation and Management.
- <sup>12</sup> Osada, M., et. al., (2008), *Brominated Flame Retardants and Heavy Metals in Automobile Shredder Residue (ASR) and their Behaviour in the Melting Process*, published in the Journal of Material Cycles and Waste Management.
- <sup>13</sup> Das, S., et. al., (1995) *Automobile Recycling in the United States: Energy Impacts and Waste Generation*, published in Resource Conservation and Recycling.
- <sup>14</sup> Fabrizi, L., et. al. (2003), *Wire Separation from Automotive Shredder Residue*, published in Physical Separation in Science and Engineering.
- <sup>15</sup> Hwang, I.H., et. al. (2007), *Characterization of Char Derived from Various Types of Solid Wastes from the Standpoint of Fuel Recovery and Pretreatment Before Landfilling*, published in Waste Management.
- <sup>16</sup> Ciacci, L., et. al. (2010), *A Comparison Among Different Automotive Shredder Residue Treatment Processes*, published in the International Journal of Life Cycle Assessment.
- <sup>17</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.
- <sup>18</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.
- Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

Approximately 70% (by weight) of ASR is made of combustible materials (e.g. rubber, plastic, textiles, polyurethane foam, wood and paper) and this fraction has a Lower Heating Value (LHV) of approximately 15–30 MJ/kg, depending on the relative abundance of the described components.<sup>56</sup> This makes ASR suitable for energy recovery as a refuse derived fuel.<sup>57</sup>

Specifically in terms of polymers, there have been 27 different types of plastics encountered in ASR, although the majority of the plastic components are made of polypropylene, polyurethane, polyvinyl chloride, acrylonitrile butadiene styrene, poly-methyl-methacrylate and polyethylene terephthalate.<sup>58</sup> Outlined in the table below is an allocation of ASR into different types of plastic, metals, fines, textiles and rubber, based on a hypothetical 1 tonne of ASR. This allocation provides a greater level of detail with respect to the specific types of plastics, metals, rubber, etc. that is found in ASR. In this particular case, plastics were estimated to represent 48% of ASR, metals and alloys 11%, rubber 14%, textiles 13% and fines 14%. With respect to plastics, polyurethane, polypropylene and polyvinyl chloride represent 67% of the total plastic content, while 100% of the rubber fraction was ethylene-propylene-diene monomer. Aluminum dominates the metal component of the ASR, estimated at 64% of total metals content.

**Table 6: Material and Main Fractions Assumed for 1 Tonne of ASR (kilograms)**

Plastics		Metals and Alloys		Fines		Textiles		Rubber	
ABS	33.6	Aluminum	70.0	Paints	56.0	Natural	65.0	EPDM	140.0
PP	86.4	Copper	4.4	Glass	42.0	Synthetic	65.0		
PE	19.2	Steel	5.9	Sand	42.0				
PUR	168.0	Iron Scrap	26.5						
PVC	67.2	Lead	0.4						
PA	28.8	Brass	2.8						
Other	76.8								
<b>Total</b>	<b>480.0</b>		<b>110.0</b>		<b>140.0</b>		<b>130.0</b>		<b>140.0</b>

Note: ABS = acrylonitrile-butadiene-styrene; PP = polypropylene; PE = polyethylene; PUR = polyurethane; PVC = polyvinyl chloride; PA = polyamide (nylon); EPDM = ethylene-propylene diene monomer.

Source: Ciacci, L., et. al. (2010), *A Comparison Among Different Automotive Shredder Residue Treatment Processes*, published in the International Journal of Life Cycle Assessment.

<sup>56</sup> Fiore, S., et. al. (2012), *Automobile Shredder Residues in Italy: Characterization and Valorization Opportunities*, published in Waste Management.

<sup>57</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

<sup>58</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

#### 4.4.1 Material Composition of ASR - Light Fluff and Heavy Fluff

Apart from analyzing the material composition of ASR as a whole, there are different segmentations that are presented in the literature to provide more detailed insight into the components of ASR and how they may vary across certain parameters. There are two main segmentations that are provided in the literature, specifically how the material composition of ASR varies across: (i) light fluff and heavy fluff (this section); and (ii) the particle size (in millimeters) of ASR (next section).

Outlined in the two tables below is a summary of information in the literature on the material composition of light fluff and heavy fluff. Light and heavy fluff are both characterized by a high content of combustibles such as plastics (38 MJ/kg), rubber (23 MJ/kg) and textiles (17 MJ/kg). Heavy fluff contains more rubber, plastic and wood, while light fluff contains more textiles and low density plastics (i.e. polyurethane foam). Heavy fluff is generally characterized by a higher ash content than light fluff. Light fluff can contain up to 70% of ‘fine’ sized material.<sup>59</sup>

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<sup>59</sup> Ibid.

**Table 7: Material Composition of ASR – Light Fluff**  
(weight %)

Component	1	2	3	4	5	6	Average of Studies 1-4
Metals	1-1.7%	8.8%	2.5%	3.7%	0.3%		4.1%
Wire	2.9-3%	4.7%	1%	2.2%		0.5%	2.7%
Rubber	3.8-4%	2.6%	3%	8.8%	10.3%	4.1%	4.6%
Textile	37.5-39.6%	36.1%	32.5%	26.2%	8.3%	7.9%	15.6%
PUR Foam	6.6-20.6%	35.3%	8%			3.8%	29.0%
Plastic	16.1-24.1%	11.7%	9%	46.1%	11.0%	8.7%	21.7%
Wood	0.03-0.4%		1%	2.7%	0.6%		1.3%
Paper	0.8-1.0%			0.8%			0.9%
Soil/sand	6.4-21.6%			4.3%			9.2%
Glass	0%		43% (minerals)				21.5%
Other	2.7-6.2%	0.8%		5.2%	69.5% (<10 mm)	75% (fines)	3.5%

Note: There can be wide ranges in the stated percentage contents across the different studies for various reasons. For instance, references 5 and 6 have lumped much of the material into the “Other” category instead of assigning it to the actual component categories. This results in their stated percentages for textiles, PUR foam, soil/sand, etc. being much lower than that stated in the other studies. Other reasons for the wide disparity include the measurement techniques that were employed as well as the material composition that was shredded, leading to the light fluff.

Sources:

<sup>1</sup> Kim, K.H., et. al. (2004), *Management Status of End-of-Life Vehicles and Characteristics of Automobile Shredder Residues in Korea*, published in Waste Management.

<sup>2</sup> Lanoir, D., et. al. (1997), *Physical and Chemical Characterization of Automotive Shredder Residues*, published in Waste Management.

<sup>3</sup> Hjelmar, O., et. al. (2009), *Treatment Methods for Waste to be Landfilled*, prepared for the Nordic Council of Ministers.

<sup>4</sup> Cho, S-J., et. al. (2010), *Studies on Gasification and Melting Characteristics of Automobile Shredder Residue*, published in Environmental Engineering Science.

<sup>5</sup> Lin, K.-S., et. al. (2010), *Catalytic Gasification of Automotive Shredder Residues with Hydrogen Generation*, published in the Journal of Power Sources.

<sup>6</sup> de Marco, I., et. al., *Recycling Polymeric Wastes by Means of Pyrolysis*, published in the Journal of Chemical Technology and Biotechnology.

Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals’ Valorisation*, published in the Journal of Hazardous Materials.

**Table 8: Material Composition of ASR – Heavy Fluff**  
(weight %)

Component	1	2	3	4	Average
Metals	0.2-1.4%	5%	0.7%		2.2%
Wire	7.0-12.7%	3%		0.7%	4.5%
Rubber	14.1-17.3%	55%	43.7%	44.8%	39.8%
Textile	7.7-11.6%	3%	10.5%	10.5%	8.4%
PUR Foam	0.9-2.8%			3.3%	2.6%
Plastic	23.8-30.9%	19%	32.6%	29%	27.0%
Wood	0.06-0.7%	7%	4.7%	5.6%	4.4%
Paper	1-2.5%				1.8%
Soil/sand	7.6-12.3%	8% (minerals)			9.0%
Glass	8.3-11.0%				9.7%
Other	4.6-14.0%		7.8%	6.1% (fines)	7.7%

Sources:

<sup>1</sup> Kim, K.H., et. al. (2004), *Management Status of End-of-Life Vehicles and Characteristics of Automobile Shredder Residues in Korea*, published in Waste Management.

<sup>2</sup> Hjelmar, O., et. al. (2009), *Treatment Methods for Waste to be Landfilled*, prepared for the Nordic Council of Ministers.

<sup>3</sup> Lin, K.-S., et. al. (2010), *Catalytic Gasification of Automotive Shredder Residues with Hydrogen Generation*, published in the Journal of Power Sources.

<sup>4</sup> de Marco, I., et. al., *Recycling Polymeric Wastes by Means of Pyrolysis*, published in the Journal of Chemical Technology and Biotechnology.

Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

#### 4.4.2 Material Composition of ASR - Particle Size Distribution

Although the coarse fraction of ASR can be defined as the fraction of particles exceeding either 2 or even 20 mm, roughly about 50% of the ASR exceeds 20 mm (coarse fraction), while the other half is expected to be the smaller (fines) fraction. Generally, a small fraction of ASR (2%) is larger than 100 mm and typically consists of large pieces of foam, rubber or plastics that have not been broken-up during the shredding process.<sup>60</sup> The presence or absence of this size fraction in ASR can be related to the effectiveness of the hammer mill used during the shredding process.<sup>61</sup>

**Table 9: ASR Particle Size Distribution, Unsorted Sample**

Size Fraction	Percentage of ASR (wt%)	
	Morselli <sup>1</sup>	Edo <sup>2,3</sup>
0-20 mm	45%	45%
20-50 mm	39%	46%
50-100 mm	14%	9%
>100 mm	2%	0%

<sup>1</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>2</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

<sup>3</sup> Only light fluff portion of ASR.

The coarse fraction (i.e. generally  $\geq 20$ mm) of ASR mainly consists of PUR (foam), plastics, rubbers and textiles. It has the lowest ash content and the highest calorific value (15–30 MJ/kg) and can thus easily be used as a fuel. The coarser particle size allows mechanical separation into recyclable fractions. Meanwhile the fine fraction (i.e. generally  $\leq 20$ mm) of ASR consists of pieces of glass, plastics and metals along with dust and dirt. It generally has a higher ash content and a lower calorific value (11–21 MJ/kg) than the coarse fraction and is thus less suited for combustion. Despite their significant share in the total ASR mass, fines are not currently considered for recycling due to their complex composition and the difficulty to allocate the different constituents to a single category of material. As a result, alternative techniques such as energy recovery (incineration), thermo-chemical recovery (pyrolysis/gasification) or direct incorporation of ASR in products (use as filler, binder, aggregate, etc.) are hence necessary in order to divert this fraction from being landfilled.<sup>62</sup>

<sup>60</sup> Ibid.

<sup>61</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

<sup>62</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

**Table 10: ASR Material Composition of Different Sized Fractions  
(% m/m)**

Material	Fraction 20<ASR<50 mm	Fraction 50<ASR<100 mm	Fraction >100 mm
Foam Rubber	32%	31%	38%
Cellulosic	1%	5%	-
Rubber	14%	12%	-
Metals	1%	4%	-
Soft Plastic	10%	5%	-
Rigid Plastic	27%	22%	62%
Textiles	14%	22%	-
Total	100%	100%	100%

Note: The fine fraction of ASR (i.e.  $\leq 20$ mm) was not analyzed due to difficulties in determining the actual constituents of this sized-fraction.

Source: Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

#### 4.4.3 Material Composition of ASR vs. Electric Appliance Shredder Residue

There are some major differences between ASR and electric appliance shredder residue. For instance, ASR contains fine materials at high percentages, mainly soil, glass and others, whereas this fraction is practically absent from electric appliance shredder residue. Meanwhile, electronic appliance shredder residues contains over 90% plastics, whereas ASR only contains in the vicinity of 15-40% plastic.<sup>63</sup> These differences in material composition between ASR and electronic appliance shredder residue indicates that there will be significant differences in the material composition of shredder residue (and chemical constituents in that shredder residue) among different shredders in Canada. These differences will relate to the different feedstocks that are used within their shredding operations, as well as other parameters (e.g. depollution and dismantling practices).

<sup>63</sup> Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

**Table 11: Comparison of the Differences in Material Composition Between ASR and Electronic Appliance Shredder Residue**

Type of Material	Mass Percentage (%)			
	Automobile Shredder Residue			Electric Appliance Shredder Residue
	Sample "K"	Sample "Y"	Sample "S"	Sample "W"
Hard Plastics	17.1%	7.5%	18.6%	36.6%
Soft Plastics	4.1%	8.9%	19.5%	54.0%
Rubber and Leather	11.6%	10.2%	6.6%	0.0%
Fine Materials (soil, glass, wood, paper)	61.6%	51.6%	45.0%	0.01%
Metals	5.6%	21.8%	10.3%	9.4%

Source: Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

## 4.5 Chemical Composition of Automotive Shredder Residue

ASR is a waste stream known to contain high concentrations of PCDDs/PCDFs, PCBs and also plasticizers such as di-2-ethylhexyl-phthalate (DEHP).<sup>64</sup> The shredder residue literature reviewed during this study identified seven different categories of chemical constituents that were analyzed in terms of their content within ASR, specifically: (i) metals, in particular heavy metals; (ii) chlorine/chlorinated substances; (iii) bromine/brominated substances; (iv) polycyclic aromatic hydrocarbons; (v) phthalates; (vi) organotin substances; and (vii) oils/petroleum substances. The extent to which these chemicals/substances are contained within ASR is discussed within separate sections below.

### 4.5.1 Content of Metals (and Selected Minerals) in ASR

The table below summarizes the metals content of ASR from different literature sources. The metals with the highest concentrations in ASR are aluminum, copper, iron, lead and zinc. The fine ASR fraction generally contains the highest heavy metal concentrations. For some heavy metals, such as copper, cadmium, lead, nickel and zinc, concentrations may exceed the limit values of applicable landfill regulations and pose a threat for the environment as these metals can leach from the ASR.<sup>65</sup>

<sup>64</sup> Van Careghem, J., et. al. (2012), *Destruction and Formation of PCDDs/Fs in a Fluidised Bed Combustor Co-incinerating Automotive Shredder Residue with Refuse Derived Fuel and Wastewater Treatment Sludge*, published in the Journal of Hazardous Materials.

<sup>65</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

**Table 12: Metal (and Mineral) Concentrations in Automotive Shredder Residue, as Outlined in the Literature**

	1	2	3	4	5	6	7	8	9	10 (mixed SR)	11	12	13	14	15	16	17	18	19	20	Average Used in the Study
<b>METALS</b>																					
Al (wt%)				1.15						0.7-3	8.6			4-10	5.3						6.5%
As (ppm)	4.1-15.9		4.2-6.3			11	10.6							3-6	3.5				1		0.01 kg/tonne
Cd (ppm)	12.9-22.2		12			160	31.9					80		0-30	6.2				9.91-21.1		0.03 kg/tonne
Cr (ppm)	37.2-257		120-140			280	489			1,000-11,000		260		100-200					73.1-102	800	0.3 kg/tonne
Cu (ppm)	2,856-8,831		14,000-30,000	8,200			5,320	16,000		4,000-30,000		12,350		10,000-60,000	34,000	2,000-2,930			5,980-21,200	12,000	30 kg/tonne
Fe (wt%)				4.67						1-18	17.6			3-10	2.8						25.7 11%
Hg (ppm)	0.113-0.213		0.56-0.91			1.6								0-0.5	0.08				0.17-0.42		0.00025 kg/tonne
Ni (ppm)	33-257		180-230				366			400-1,500		2,910		50-100		280-550			34.8-38.6	700	0.33 kg/tonne
Pb (ppm)	2,167-2,458		1,500-1,800	1,400		100	2,710	1,400		1,000-11,000		2,000		0-5,000	1,700	3,000-10,200	7,000-33,000	4,600-11,600	442-600	2,000	4.0 kg/tonne
Sb (wt%)															0.04						0.04%
Se (ppm)	0.54-2.4														0.2				<0.1		0.0003 kg/tonne
Sn (ppm)																			54.6-169		0.11 kg/tonne
Ti (wt%)																				0.9	0.9%
Zn (ppm)	6,646-19,439		8,500-9,300				8,510	12,000		5,000-30,000		17,370		0-15,000	8,750	3,900-13,200	10,000-35,000		1,810-6,140	19,000	12.0 kg/tonne
<b>MINERALS</b>																					
Ca (wt%)				1.49	3.9									6-13	12.4						6%
K (wt%)															0.53						0.53%
Na (wt%)															1.89						1.89%
P (wt%)																				0.7	0.7%
Si (wt%)														9-35 (SiO <sub>2</sub> )	12.9					2.1	13%

Note: Al=aluminum; As=arsenic; Cd=cadmium; Cr=chromium; Cu=copper; Fe=iron; Hg=mercury; Ni=nickel; Pb=lead; Sb=tin; Se=selenium; Sn=antimony; Ti=titanium; Zn=zinc.

Note: Ca=calcium; K=potassium; Na=sodium; P=phosphorous; Si=silicon.

Note: There can be a wide range in the reported concentrations due to several factors, for instance differences in the material feedstock that was shredded, measurement techniques that were employed, specific metals/minerals that were tested for, etc.

- <sup>1</sup> Mancini G., et. al. (2010), *Thermal Process of Fluff: Preliminary Tests on a Full Scale Treatment Plant*, published in *Waste Management*.
  - <sup>2</sup> Tai, H.-S., et. al. (2007), *Dechlorination of Auto Shredder Residues*, published in the *Journal of Hazardous Materials*.
  - <sup>3</sup> Hjelmar, O., et. al. (2009), *Treatment Methods for Waste to be Landfilled*, prepared for the Nordic Council of Ministers.
  - <sup>4</sup> Kameda, T., et. al. (2009), *Efficient Dehalogenation of Automobile Shredder Residue in NaOH/Ethylene Glycol Using a Ball Mill*, published in *Chemosphere*.
  - <sup>5</sup> Kobyashi, N., et. al. (2005), *The Behaviour of Flue Gas from RDF Combustion in a Fluidized Bed*, published in *Powder Technology*.
  - <sup>6</sup> Saxena, S.C. et. al. (1995), *Combustion and co-combustion of Auto Fluff*, published in *Energy*.
  - <sup>7</sup> Gendebien, A., et. al., (2003), *Refuse Derived Fuel, Current Practice and Perspectives*, prepared for the European Commission.
  - <sup>8</sup> Trouvé, G., et. al. (1998), *Comparative Thermodynamic and Experimental Study of Some Heavy Metal Behaviors During Automotive Shredder Residue Incineration*, published in *Waste Management*.
  - <sup>9</sup> Lopes, M.H., et. al. (2009), *Leachability of Automotive Shredder Residues Burned in a Fluidized Bed System*, published in *Waste Management*.
  - <sup>10</sup> Jalkanen, H. (2006), *On the Direct Recycling of Automotive Shredder Residue and Electronic Scrap in Metallurgical Industry*, published in *Acta Metallurgica Slovaca*.
  - <sup>11</sup> Day, M., et. al. (1999), *Pyrolysis of Auto Shredder Residue: Experiments with a Laboratory Screw Kiln Reactor*, published in the *Journal of Analytical and Applied Pyrolysis*.
  - <sup>12</sup> Zolezzi, M. et. al. (2004), *Conventional and Fast Pyrolysis of Automobile Shredder Residue (ASR)*, published in *Waste Management*.
  - <sup>13</sup> Joung, H.T., et. al. (2007), *Distribution of Dioxins, Furans and Dioxin-Like PCBs in Solid Products and Generated by Pyrolysis and Melting of Automobile Shredder Residues*, published in *Chemosphere*.
  - <sup>14</sup> Vigano F., et. al., *Material and Energy Recovery from Automotive Shredder Residue (ASR) via Sequential Gasification and Combustion*, published in *Waste Management*.
  - <sup>15</sup> Osada, M., et. al., (2008), *Brominated Flame Retardants and Heavy Metals in Automobile Shredder Residue (ASR) and their Behaviour in the Melting Process*, published in the *Journal of Material Cycles and Waste Management*.
  - <sup>16</sup> Gonzalez-Fernandez, O., et. al., *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in *Environmental Pollution*.
  - <sup>17</sup> Pera (2004), *Valorization of Automotive Shredder Residue in Building Materials*.
  - <sup>18</sup> Gonzalez-Fernandez, O. (2009), et. al., *Analysis of Lead Content in Automotive Shredder Residue*, published in *Waste Management*.
  - <sup>19</sup> Santini, A., et. al. (2011), *End-of-Life Vehicles Management: Italian Material and Energy Recovery Efficiency*, published in *Waste Management*.
  - <sup>20</sup> Nourreddine, Menad (2007), *Recycling of Auto Shredder Residue*, published in the *Journal of Hazardous Materials*.
- Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the *Journal of Hazardous Materials*.

#### 4.5.1.1 Comparison of Metal Content of Shredder Residue to Automotive Shredder Residue

Outlined in the table below is a comparison of the metals content of ASR, shredder residue (SR) as well as certain segmentations of ASR and light fluff (LF). It appears that ASR has a significantly higher lead, copper and barium content than shredder residue, attributed to the presence of lead (e.g. wheel weights), copper (e.g. electrical wiring) and barium (e.g. alloying component in spark plugs) components in vehicles and less of a presence of these metals in other metallic shredded goods (e.g. white goods). Zinc was the only metal where it appears that shredder residue had a significantly higher concentration than ASR.

**Table 13: Metals Contents of SR/ASR Materials**

Sample	Al (%)	As (ppm)	Ba (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (%)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (%)
SR	0.38	11.3	7.90	19.0	3.93	93.0	0.37	1.78	209	72.8	45.8	0.53
ASR1	0.24	12.7	18.1	17.6	5.88	82.2	4.68	1.33	172	100	272	0.19
ASR2	0.99	8.1	33.4	10.3	9.08	172	4.56	1.65	173	75.0	309	0.24
LF	0.76	3.44	36.6	15.2	13.6	226	3.35	3.26	311	111	410	0.31
ASR<10 mm	1.73	14.2	28.0	19.7	13.3	111	2.34	2.66	301	89.4	1,100	0.33
LF<4mm	2.48	14.6	34.5	25.4	21.9	169	1.42	4.27	547	197	504	0.66
LF>4mm	0.36	2.45	24.6	10.8	8.3	114	0.34	1.67	167	76	139	0.26

Source: Fiore, S., et. al. (2012), *Automobile Shredder Residues in Italy: Characterization and Valorization Opportunities*, published in Waste Management.

Smaller pieces of ASR (i.e. <10 mm) appear to have much higher concentrations of some metals than ASR in general, for instance aluminum, iron, manganese and most dramatically, lead.

#### 4.5.2 Content of Chlorine/Chlorinated Substances (and Sulphur) in ASR

ASR may contain significant concentrations of chlorine. The chlorine content of ASR ranges from 0.5 to 4% (by weight) and is mainly due to the presence of chlorinated plastic components such as PVC or halobutyl rubber. Incineration of ASR may therefore lead to the formation of toxic compounds such as PCDDs (dioxins), PCDFs (furans) and hydrochloric acid, requiring proper flue gas treatment to avoid emissions to the environment.<sup>66</sup> Meanwhile the sulphur content of ASR is always below 1%, typically in the range of 0.2-0.6% (by weight).

<sup>66</sup> Ibid.

**Table 14: Chlorine and Sulphur Content of ASR, as Outlined in the Literature**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average
Energetic Value (MJ/kg)	19.7 (HHV) 18.7 (LHV)	29.3		25.1	18.2	18.3			10.2	21.0	21.0	13.4-25 (LHV)	21.5			20.3
Ash (wt%)	44.7	18.4		24.5	42.77			68.2	58.1	27.3	24.2		30.7	≈35		37.4
Cl (wt%)	0.943-4.660	1.8	2.49	3.4		0.56	3.7		0.5		2.2	0-2.5	2.9	≈0.95	ASR = 2.0-2.8% SR = 1.4%	2.0
S (wt%)	0.28-0.63	0.52	0.19	0.33	0.25	0.32	0.3	0.56	0.3	0.3	0.02	0-0.6	0.36	≈0.23		0.3

<sup>1</sup> Mancini G., et. al. (2010), *Thermal Process of Fluff: Preliminary Tests on a Full Scale Treatment Plant*, published in *Waste Management*.

<sup>2</sup> Tai, H.-S., et. al. (2007), *Dechlorination of Auto Shredder Residues*, published in the *Journal of Hazardous Materials*.

<sup>3</sup> Kameda, T., et. al. (2009), *Efficient Dehalogenation of Automobile Shredder Residue in NaOH/Ethylene Glycol Using a Ball Mill*, published in *Chemosphere*.

<sup>4</sup> Kobyashi, N., et. al. (2005), *The Behaviour of Flue Gas from RDF Combustion in a Fluidized Bed*, published in *Powder Technology*.

<sup>5</sup> Saxena, S.C. et. al. (1995), *Combustion and co-combustion of Auto Fluff*, published in *Energy*.

<sup>6</sup> Gendebien, A., et. al., (2003), *Refuse Derived Fuel, Current Practice and Perspectives*, prepared for the European Commission.

<sup>7</sup> Trouvé, G., et. al. (1998), *Comparative Thermodynamic and Experimental Study of Some Heavy Metal Behaviors During Automotive Shredder Residue Incineration*, published in *Waste Management*.

<sup>8</sup> Lopes, M.H., et. al. (2009), *Leachability of Automotive Shredder Residues Burned in a Fluidized Bed System*, published in *Waste Management*.

<sup>9</sup> Day, M., et. al. (1999), *Pyrolysis of Auto Shredder Residue: Experiments with a Laboratory Screw Kiln Reactor*, published in the *Journal of Analytical and Applied Pyrolysis*.

<sup>10</sup> Zolezzi, M. et. al. (2004), *Conventional and Fast Pyrolysis of Automobile Shredder Residue (ASR)*, published in *Waste Management*.

<sup>11</sup> Joung, H.T., et. al. (2007), *Distribution of Dioxins, Furans and Dioxin-Like PCBs in Solid Products and Generated by Pyrolysis and Melting of Automobile Shredder Residues*, published in *Chemosphere*.

<sup>12</sup> Vigano F., et. al., *Material and Energy Recovery from Automotive Shredder Residue (ASR) via Sequential Gasification and Combustion*, published in *Waste Management*.

<sup>13</sup> Osada, M., et. al., (2008), *Brominated Flame Retardants and Heavy Metals in Automobile Shredder Residue (ASR) and their Behaviour in the Melting Process*, published in the *Journal of Material Cycles and Waste Management*.

<sup>14</sup> Santini, A., et. al. (2011), *End-of-Life Vehicles Management: Italian Material and Energy Recovery Efficiency*, published in *Waste Management*.

<sup>15</sup> Redin, L., et. al. (2001), *Co-combustion of Shredder Residues and Municipal Solid Waste in a Swedish Municipal Solid Waste Incinerator*, published in *Waste Management & Research*.

Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the *Journal of Hazardous Materials*.

#### 4.5.2.1 Content of Specific Chlorinated Substances in ASR

With respect to the content of specific chlorinated substances in ASR, the literature has focused on polychlorinated dibenzo-p-dioxins and furans (PCDDs/PCDFs) and polychlorinated biphenyls (PCBs) and to a much lesser extent, polychlorinated naphthalenes, polychlorinated benzenes and polychlorinated phenols.

In one study, the concentration of persistent organic pollutants (POPs) in ASR was compared to the typically utilized waste feed at a fluidized bed combustor, which consisted of 30% refuse-derived fuel (RDF) and 70% wastewater treatment sludge. Due to the high concentrations of POPs in the ASR, the mix of 25% ASR, 25% RDF and 50% wastewater treatment sludge had significantly higher concentrations of POPs than the typical feed. Quantitatively, the PCDD/PCDF mass in the typical waste feed was approximately 20-100 times lower than in the mix of 25% ASR, 25% RDF and 50% wastewater treatment sludge. Furthermore, the typical waste feed contained approximately 25-100 times less dioxin-like PCBs and 7-30 times less PCBs. These differences were attributed to the high concentration of POPs in ASR. Comparing just ASR and RDF, the PCDD/PCDF and PCB concentrations in the RDF were roughly a factor of 100 lower than in the ASR. However, the PCDD/PCDF, dioxin-like PCB and PCB fingerprints (i.e. relative presence of different homologues) were very similar between RDF and ASR.<sup>67</sup> In another study by the same author, ASR contained six times more PCDDs/PCDFs than RDF and 10 times more than wastewater treatment sludge.<sup>68</sup>

The reason why shredder residue contains PCDD/PCDFs is not clear, however the identified possibilities are as follows: (i) shredder residues may have PCDD/PCDFs originally in synthetic leather; and (ii) formation by the heat of friction in the shredding process.<sup>69</sup> Existing literature has reported a PCDD/PCDF fingerprint of the textile and leather fraction of RDF from MSW; the relative contribution of the different congeners to the total PCDD/PCDF content agrees with the PCDD/PCDF fingerprints of the ASR reported. ASR can contain up to 40% of textiles and leather, suggesting that this fraction might be a contamination source of PCDD/PCDFs in ASR. As the reported fingerprint of ASR also resembled the PCDD/PCDF fingerprint of diesel exhaust, these exhausts may be another possible contamination source of PCDD/PCDFs in ASR.<sup>70</sup>

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<sup>67</sup> Van Caneghem, J., et. al. (2010), *Mass Balance for POPs in a Real Scale Fluidized Bed Combustor Co-Incinerating Automotive Shredder Residue*, published in the Journal of Hazardous Materials.

<sup>68</sup> Van Careghem, J., et. al. (2012), *Destruction and Formation of PCDDs/Fs in a Fluidised Bed Combustor Co-incinerating Automotive Shredder Residue with Refuse Derived Fuel and Wastewater Treatment Sludge*, published in the Journal of Hazardous Materials.

<sup>69</sup> Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

<sup>70</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

**Table 15: Content of Chlorinated Substances in Automotive Shredder Residue**

Chlorinated Substance	1	2	3	4	5	6	7 (ASR)	7 (SR)	8	9	Average
PCDDs/PCDFs	0.970 ng/g of waste	0.242–0.329 ng TEQ/g (dry weight)	9 ng/g (dry weight)	0.250 ng TEQ/g	0.0043-0.38 ng TEQ/g; or 0.97 ng/g	0.043-0.38 ng TEQ/g	<0.6 ng/g	<0.6 ng/g	0.003-0.004 ng TEQ/g	0.00302-0.007 ngTEQ/g	0.22 ng TEQ/g
Co-PCBs (Dioxin-like PCBs)	30 ng/g of waste	0.481-0.631 ng TEQ/g (dry weight) <sup>2a</sup>			0.014-0.027 ng TEQ/g; or 30 ng/g	0.014-0.015 ng TEQ/g					0.20 ng TEQ/g
MoBrPCDDs/PCDFs	Not Detected					<0.07-15 ng/g					7.5 ng/g
Polychlorinated Biphenyls		13,000–15,000 ng/g (dry weight) <sup>2b</sup>		1,200–24,000 ng/g	44–270 ng/g	44-230 ng/g	1,100–6,700 ng/g	12,000 ng/g	80.7-109.4 ng/g	7,930-24,300 ng/g	7,067 ng/g
Polychlorinated Naphthalenes					13-47 ng/g	13-47 ng/g					37 ng/g
Polychlorinated Benzenes							0.4–2.2 µg/g	0.8 µg/g			1.1 µg/g
Polychlorinated Phenols							0.3–1.4 µg/g	1.1 µg/g			1.0 µg/g

<sup>1</sup> Osada, M., et. al. (2008), *Brominated Flame Retardants and Heavy Metals in Automobile Shredder Residue (ASR) and their Behavior in the Melting Process*, published in the Journal of Material Cycles and Waste Management.

<sup>2</sup> Van Caneghem, J., et. al. (2010), *Mass Balance for POPs in a Real Scale Fluidized Bed Combustor Co-Incinerating Automotive Shredder Residue*, published in the Journal of Hazardous Materials.

<sup>2a</sup> sum of PCB 77, PCB 81, PCB 105, PCB 114, PCB 118, PCB 123, PCB 126, PCB 156, PCB 157, PCB 167, PCB 169 and PCB 189.

<sup>2b</sup> sum of PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153 and PCB 180.

<sup>3</sup> Van Caneghem, J., et. al. (2012), *Destruction and Formation of PCDDs/Fs in a Fluidised Bed Combustor Co-incinerating Automotive Shredder Residue with Refuse Derived Fuel and Wastewater Treatment Sludge*, published in the Journal of Hazardous Materials.

<sup>4</sup> Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

<sup>5</sup> Sakai, S., et. al. (1997), *End-of-life Vehicle Recycling and Automobile Shredder Residue Management in Japan*, published in the Journal of Material Cycles and Waste Management.

<sup>6</sup> Yamamoto, T., et. al. (2007), *Thermal Behavior of Brominated Flame Retardants and Brominated Dioxins During Combustion of Automobile Shredder Residue*.

<sup>7</sup> Redin, L., et. al. (2001), *Co-combustion of Shredder Residues and Municipal Solid Waste in a Swedish Municipal Solid Waste Incinerator*, published in Waste Management & Research. Note that the shredder residue in this study 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.

<sup>8</sup> Santini, A., et. al., (2011), *End-of-Life Vehicles Management: Italian Material and Energy Recovery Efficiency*, published in Waste Management.

<sup>9</sup> Mancini, G., et. al., (2010), *Thermal Process of Fluff: Preliminary Tests on a Full-Scale Treatment Plant*, published in Waste Management.

## Contribution of Different PCDD/PCDF Homologues in ASR

In one study, PCDD/PCDFs in most of the shredder residues were determined to be less than 0.1 ng/g. Total concentrations of PCDD and PCDF homologues were 70 and 10 ng/g respectively. Toxicity equivalent concentrations were 0.12 and 0.13 ng TEQ/g respectively.<sup>71</sup>

**Table 16: Result of PCDD/PCDFs Contents Analysis for Shredder Residue S**

Congener	Concentration (ng/g)	Toxicity Equivalency Concentration (ng TEQ/g)
2,3,7,8-T <sub>4</sub> CDD	ND<0.02	0
1,2,3,7,8-P <sub>5</sub> CDD	ND<0.02	0
1,2,3,4,7,8-H <sub>6</sub> CDD	0.04	0.004
1,2,3,6,7,8-H <sub>6</sub> CDD	0.15	0.015
1,2,3,7,8,9-H <sub>6</sub> CDD	0.08	0.008
1,2,3,4,6,7,8-H <sub>7</sub> CDD	3.5	0.035
O <sub>8</sub> CDD	59	0.059
Total PCDDs	70	0.12
2,3,7,8-T <sub>4</sub> CDF	0.08	0.008
1,2,3,7,8-P <sub>5</sub> CDF	0.17	0.0086
2,3,4,7,8-P <sub>5</sub> CDF	0.12	0.058
1,2,3,4,7,8-H <sub>6</sub> CDF	0.17	0.017
1,2,3,6,7,8-H <sub>6</sub> CDF	0.16	0.016
1,2,3,7,8,9-H <sub>6</sub> CDF	ND<0.02	0
2,3,4,6,7,8-H <sub>6</sub> CDF	0.14	0.014
1,2,3,4,6,7,8-H <sub>7</sub> CDF	0.61	0.0061
1,2,3,4,7,8,9-H <sub>7</sub> CDF	0.09	0.0009
O <sub>8</sub> CDF	0.96	0.00096
Total CDFs	10	0.13
Total PCDDs/DFs	80	0.25

Source: Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

A separate article has indicated that the PCDD/PCDF fingerprint of ASR is dominated by the higher chlorinated PCDD congeners. In their study, approximately 90% of the total PCDD/PCDF content of ASR was accounted for by hepta- and octa-CDD. Meanwhile,

<sup>71</sup> Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

the PCDFs represented only approximately 3-7% of total PCDD/PCDF content, with hepta-CDFs and octa-CDF being most abundant.<sup>72/73</sup>

### Contribution of Different PCB Homologues in ASR

The table below outlines the content of PCB homologues in shredder residues. The PCB concentration in shredder residue K and Y ranged from 1,800 to 11,000 ng/g and 15,000 to 24,000 ng/g, respectively. Therefore even the same shredder residue showed rather varied PCB content. PCBs concentration in the electronics shredder residue was 1,200 ng/g which was generally much lower than the PCB content observed in ASR.<sup>74</sup> With respect to PCB homologues, the tri-, tetra-, and penta-CB homologues contributed the most to the total PCB content in both ASR and electric appliance shredder residue.

**Table 17: Results of PCBs Contents Analysis for ASR and Electric Appliance Shredder Residue (ng/g)**

Homologue	Automobile Shredder Residue				Electric Appliance Shredder Residue	
	Sample "K"		Sample "Y"		Sample "S"	Sample "W"
	First	Second	First	Second		
M <sub>1</sub> CBs	2.1	9.6	19	27	2.5	1.3
D <sub>2</sub> CBs	200	800	1,300	1,600	73	80
T <sub>3</sub> CBs	720	4,200	4,600	6,800	390	320
T <sub>4</sub> CBs	450	3,100	3,700	5,300	380	310
P <sub>5</sub> CBs	280	1,600	3,400	6,400	180	340
H <sub>6</sub> CBs	140	770	1,600	3,200	130	170
H <sub>7</sub> CBs	21	120	280	600	30	25
O <sub>8</sub> CBs	2.1	11	28	70	6.8	1.8
N <sub>9</sub> CBs	0.2	1.1	3.1	6.0	0.49	0.2
D <sub>10</sub> CBs	0.3	ND<0.1	N.D.<0.1	N.D.<0.1	0.48	N.D.<0.1
Total CBs	1,800	11,000	15,000	24,000	1,200	1,200

Source: Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

<sup>72</sup> Van Careghem, J., et. al. (2012), *Destruction and Formation of PCDDs/Fs in a Fluidised Bed Combustor Co-incinerating Automotive Shredder Residue with Refuse Derived Fuel and Wastewater Treatment Sludge*, published in the Journal of Hazardous Materials.

<sup>73</sup> Van Caneghem, J., et. al. (2010), *Mass Balance for POPs in a Real Scale Fluidized Bed Combustor Co-Incinerating Automotive Shredder Residue*, published in the Journal of Hazardous Materials.

<sup>74</sup> Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

A separate article also indicated that ASR has a relatively high concentration of PCBs and that the congener profile (i.e. higher proportions of tetra- and pentachlorobiphenyls) of ASR suggested that its potential sources are technical PCB mixtures used in electrical equipment such as capacitors.<sup>75</sup>

Another study indicated that the dominant PCB homologues were PCB 28 (a tri-PCB) (approximately 55%), PCB 52 (a tetra-PCB) (approximately 15%) and PCB 101 (a penta-PCB) (approximately 10%).<sup>76</sup> In a separate article, the dioxin-like PCB fingerprint was dominated by low chlorinated PCBs, PCB 105 (a penta-PCB) (approximately 40%), PCB 77 (a tetra-PCB) (approximately 30%) and PCB 118 (a penta-PCB) (approximately 20%) being most important.<sup>77</sup>

#### 4.5.3 Content of Bromine/Brominated Substances in ASR

The levels of bromine in ASR have been determined to be between 100 and 1,000 times lower than the corresponding levels of chlorine.<sup>78</sup> Two separate articles have indicated that the bromine content of ASR is in the vicinity of 0.03-0.04%.<sup>79/80</sup>

Only two articles<sup>81/82</sup> were identified that determined the content of brominated substances in ASR (and a further third article<sup>83</sup> that summarized the two other articles). ASR contains polybrominated diphenyl ethers (PBDEs) at levels of a few hundred ppm. ASR also contains hexabromocyclododecane (HBCD), tetrabromobisphenol A (TBBPA), and tribromophenols (TBPs) in the range of sub-ppm levels to several ppm.<sup>84</sup> PBDEs, HBCD and TBBPA have historically been the three largest volume brominated flame retardants produced globally.

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<sup>75</sup> Osada, M., et. al. (2008), *Brominated Flame Retardants and Heavy Metals in Automobile Shredder Residue (ASR) and their Behavior in the Melting Process*, published in the Journal of Material Cycles and Waste Management.

<sup>76</sup> Van Caneghem, J., et. al. (2010), *Mass Balance for POPs in a Real Scale Fluidized Bed Combustor Co-Incinerating Automotive Shredder Residue*, published in the Journal of Hazardous Materials.

<sup>77</sup> Ibid.

<sup>78</sup> Redin, L., et. al. (2001), *Co-combustion of Shredder Residues and Municipal Solid Waste in a Swedish Municipal Solid Waste Incinerator*, published in Waste Management & Research.

<sup>79</sup> Yamamoto, T., et. al. (2007), *Thermal Behavior of Brominated Flame Retardants and Brominated Dioxins During Combustion of Automobile Shredder Residue*.

<sup>80</sup> Osada, M., et. al. (2008), *Brominated Flame Retardants and Heavy Metals in Automobile Shredder Residue (ASR) and their Behavior in the Melting Process*, published in the Journal of Material Cycles and Waste Management.

<sup>81</sup> Ibid.

<sup>82</sup> Yamamoto, T., et. al. (2007), *Thermal Behavior of Brominated Flame Retardants and Brominated Dioxins During Combustion of Automobile Shredder Residue*.

<sup>83</sup> Sakai, S., et. al., *End-of-life Vehicle Recycling and Automobile Shredder Residue Management in Japan*, published in the Journal of Material Cycles and Waste Management.

<sup>84</sup> Ibid.

Among the congeners of PBDEs and PBDD/PBDFs detected in ASR, higher brominated congeners such as decabromodiphenylethers (DeBDEs) and octabrominated dibenzofurans (OBDFs) showed the highest proportions - 94% and 60%, respectively. Such congener patterns of brominated flame retardants and PBDD/PBDFs in ASR were similar to those reported in brominated flame retardant-treated plastics such as those in waste television sets in Japan. Compared with municipal solid waste and waste television sets that the authors previously investigated, the amount of brominated substances such as PBDD/PBDFs, PBDEs, and TBBPA in ASR was found to be higher than that in municipal solid waste and lower than that in waste television sets.

The brominated dioxins in ASR were thought to have originated from impurities contained in brominated flame retardants and/or as thermal by-products of the processing of brominated flame retardant-containing materials.<sup>85</sup>

It is interesting to note that one of the articles indicated that the levels of brominated flame retardants in ASR collected before enforcement of the law for recycling of ELVs (in Japan) was higher than in ASR collected after enforcement the law.<sup>86</sup>

It should be noted that there are concerns with the estimates provided by the Osada article outlined in the table below, in terms of whether there was a mistake in the units presented in the article (specifically for PBDDs/PBDFs and tetrabromobisphenol A). The Osada estimates are provided in the table below, but caution is urged with respect to reliance on them.

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<sup>85</sup> Ibid.

<sup>86</sup> Yamamoto, T., et. al. (2007), *Thermal Behavior of Brominated Flame Retardants and Brominated Dioxins During Combustion of Automobile Shredder Residue*.

**Table 18: Content of Brominated Substances in Automotive Shredder Residue**

<b>Brominated Substance</b>	<b>Osada (2008)<sup>1</sup></b>	<b>Yamamoto (2007)<sup>2</sup></b>
PBDDs/PBDFs	30,000 ng/g	10-120 ng/g
Brominated diphenyl ethers	310,000 ng/g	110,000-240,000 ng/g
Tetrabromobisphenol A	15,000 ng/g	220-950 ng/g
Hexabromocyclododecane	-	990-5,700 ng/g
Tribromophenol	-	68-180 ng/g

<sup>1</sup> Osada, M., et. al. (2008), *Brominated Flame Retardants and Heavy Metals in Automobile Shredder Residue (ASR) and their Behavior in the Melting Process*, published in the Journal of Material Cycles and Waste Management.

<sup>2</sup> Yamamoto, T., et. al. (2007), *Thermal Behavior of Brominated Flame Retardants and Brominated Dioxins During Combustion of Automobile Shredder Residue*.

#### 4.5.4 Content of Polycyclic Aromatic Hydrocarbons in ASR

Outlined in the table below is a summary of the measured polycyclic aromatic hydrocarbon (PAH) concentrations in ASR that was identified in the literature. The most abundant PAHs in ASR were found to be fluoranthene (20%), fenanthrene and pyrene (both approximately 15%), but also chrysene, benzo(a)anthracene and benzo(b)fluoranthene (each approximately 10%) are present in considerable amounts.<sup>87</sup>

**Table 19: Content of PAHs in Automotive Shredder Residue**

Article	Concentration in ASR
Redin <sup>1</sup>	ASR – 7,400-11,000 ng/g SR – 15,000 ng/g
Van Caneghem <sup>2</sup>	37,000–140,000 ng/g
Santini <sup>3</sup>	4,000-6,400 ng/g
Yamamoto <sup>4</sup>	34,000-36,000 ng/g
Mancini <sup>5</sup>	5,580-12,200 ng/g
Average	29,950 ng/g

<sup>1</sup> Redin, L., et. al. (2001), *Co-combustion of Shredder Residues and Municipal Solid Waste in a Swedish Municipal Solid Waste Incinerator*, published in Waste Management & Research.

<sup>2</sup> Van Caneghem, J., et. al. (2010), *Mass Balance for POPs in a Real Scale Fluidized Bed Combustor Co-Incinerating Automotive Shredder Residue*, published in the Journal of Hazardous Materials.

<sup>3</sup> Santini, A., et. al., (2011), *End-of-Life Vehicles Management: Italian Material and Energy Recovery Efficiency*, published in Waste Management.

<sup>4</sup> Yamamoto, T., et. al. (2007), *Thermal Behavior of Brominated Flame Retardants and Brominated Dioxins During Combustion of Automobile Shredder Residue*.

<sup>5</sup> Mancini, G., et. al., (2010), *Thermal Process of Fluff: Preliminary Tests on a Full-Scale Treatment Plant*, published in Waste Management.

The mass of PAHs in a waste feed of 30% refuse-derived fuel (RDF) and 70% wastewater treatment sludge was determined to be 2-10 times lower than in a mixture of 25% ASR, 25% RDF and 50% wastewater treatment sludge. Comparing just ASR and RDF the PAH concentrations were a factor of 10 lower in the RDF. These differences were attributed to the high concentration of PAHs in ASR.<sup>88</sup>

#### 4.5.5 Content of Phthalates in ASR

Plasticizers such as di (2-ethylhexyl) phthalate (DEHP) are contained in shredder residues because these residues contain large quantity of plastics such as PVC (where

<sup>87</sup> Van Caneghem, J., et. al. (2010), *Mass Balance for POPs in a Real Scale Fluidized Bed Combustor Co-Incinerating Automotive Shredder Residue*, published in the Journal of Hazardous Materials.

<sup>88</sup> Ibid.

phthalates are used).<sup>89</sup> In one article, the DEHP concentration in ASR was determined to be 2,900-8,300 µg/g.<sup>90</sup> The only other article to report DEHP concentrations in ASR indicated a level of 11,000 µg/g.<sup>91</sup> DEHP was selected for analysis in these articles since it has been traditionally the largest globally produced phthalate plasticizer. However there will be other phthalate plasticizers that will be contained in ASR, however existing literature was not identified that determined the concentration of these other phthalates in ASR.

#### 4.5.6 Content of Organotin Substances in ASR

The authors of a report<sup>92</sup> detailing the content of organotin species in ASR indicated that it was the only known study that had determined these concentrations. Three types of butyltin compounds (monobutyltin, dibutyltin and tributyltin) and three types of octyltin compounds (mono-octyltin, dioctyltin and trioctyltin) were detected in the ASR (sourced from Japan). The concentrations of mono-octyltin, monobutyltin and dibutyltins, were the highest in the ASR, and the concentration levels and patterns in ASR were similar to results reported for household plastic materials made from polyvinyl chloride, silicone resins, and polyurethane foam. Mono- and disubstituted alkyltins have been widely used as PVC stabilizers and synthetic catalysts for silicone resins and polyurethane foams. Tributyltins and trioctyltins may be included in alkyltin-based stabilizers and/or catalysts as by-products, thus explaining their presence in ASR.<sup>93</sup>

It should be noted that there are concerns with the estimates provided by the Osada article outlined in the table below, in terms of whether there was a mistake in the units presented in the article (for all organotin species). The Osada estimates are provided in the table below, but caution is urged with respect to reliance on them.

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<sup>89</sup> Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

<sup>90</sup> Van Caneghem, J., et. al. (2010), *Mass Balance for POPs in a Real Scale Fluidized Bed Combustor Co-Incinerating Automotive Shredder Residue*, published in the Journal of Hazardous Materials.

<sup>91</sup> Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

<sup>92</sup> Osada, M., et. al. (2008), *Brominated Flame Retardants and Heavy Metals in Automobile Shredder Residue (ASR) and their Behavior in the Melting Process*, published in the Journal of Material Cycles and Waste Management.

<sup>93</sup> Ibid.

**Table 20: Content of Organotin Species in Automotive Shredder Residue (mg/ton of waste)**

<b>Organotin Species</b>	<b>Content in ASR</b>
Monobutyltin	51,000,000
Dibutyltins	25,000,000
Tributyltins	420,000
Monooctyltin	54,000,000
Diocetylins	8,000,000
Triocetylins	890,000
<b>Total Organotins</b>	<b>140,000,000</b>

Source: Osada, M., et. al. (2008), *Brominated Flame Retardants and Heavy Metals in Automobile Shredder Residue (ASR) and their Behavior in the Melting Process*, published in the Journal of Material Cycles and Waste Management.

#### 4.5.7 Content of Oils/Petroleum Substances in ASR

There were a few other substances that have been quantified with respect to their presence in ASR, which have been grouped under the category “oils/petroleum substances”. However, these substances have been the subject of much less study than those that have already been outlined in the previous sections. Those additional substances that were identified during the study were mineral oils, benzene and hydrocarbons.

**Table 21: Content of Oils/Petroleum Substances in ASR, as Identified in the Literature**

<b>Article</b>	<b>Substance</b>	<b>Concentration in ASR</b>
Mancini <sup>1</sup>	Mineral Oils	20,300-22,300 mg/kg
Santini <sup>2</sup>	Mineral Oils	24,300-25,800 mg/kg
	Benzene	<0.005 mg/kg
	Hydrocarbons	6,230-7,670 mg/kg

<sup>1</sup> Mancini, G., et. al., (2010), *Thermal Process of Fluff: Preliminary Tests on a Full-Scale Treatment Plant*, published in Waste Management.

<sup>2</sup> Santini, A., et. al., (2011), *End-of-Life Vehicles Management: Italian Material and Energy Recovery Efficiency*, published in Waste Management.

#### 4.5.8 Chemical Constituents in Different Size Fractions of ASR

Outlined in this section is a summary of available information on the chemical constituents of different sized fractions of ASR.

#### 4.5.8.1 Metal and Chlorine Content of Different Sized Fractions of ASR

The metal content of four ASR material fractions are shown in the table below. The fines material contained the highest metal concentration compared to the raw material, 20–50 mm and 50–100 mm sized fractions respectively. As the data show, aluminum, chromium, manganese, iron, nickel and zinc exhibited the same trend. Copper and iron were the most abundant metals in all samples. The 50–100 mm sized fraction had the lowest iron and copper content compared to the other three material fractions. Copper values reached 55,600 mg/kg dry sample in the 20–50 mm material fraction. A high content of copper can be attributed to the wiring and electrical components of a vehicle and light fluff can contain around 3% (by weight) of these components.<sup>94</sup>

**Table 22: Metal and Chlorine Content of ASR Fractions (mg/kg dry sample)**

Parameter	Raw Material	0-20 mm	20-50 mm	50-100 mm
Al	4,690	7,870	2,310	1,130
Cr	150	280	60	20
Mn	340	530	200	90
Fe	63,100	117,000	22,390	5,690
Ni	130	200	80	25
Cu	35,630	21,030	55,600	7,490
Zn	7,280	11,210	4,590	1,700
Pb	630	705	660	130
As	5.2	4.9	5.4	5.9
Cd	4.2	5.2	4.1	0.8
Hg	0.3	0.3	0.3	0.3
Chlorine	8,013	8,440	8,800	2,120

Source: Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

The content of iron reached 117,000 mg/kg dry sample in the fines fraction, and is attributed to wheel rims and chassis being made of this metal. Zinc, which is used as an anti-corrosion agent for the chassis, was among the three top metals found in the ASR samples analyzed. Zinc concentrations varied from 1,700 to 11,210 mg/kg dry sample in 50–100 mm and fines, respectively. Aluminum is also an abundant metal in car fluff since it is used in the manufacturing of many car components, for instance the frame, engine and rims. The mercury content of all samples analyzed was around 0.30 mg/kg dry sample, which is considered low. Cadmium and arsenic concentrations were higher than that of mercury. All samples had similar lead concentrations (630–705 mg/kg dry

<sup>94</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

sample) except for the 50–100 mm sample, whose concentration was lower, 130 mg/kg dry sample.<sup>95</sup>

Total chlorine was determined in all particle size fraction samples. The 50–100 mm fraction had the lowest chlorine concentration at 2,120 mg/kg.<sup>96</sup>

In another study, four of the metals with the highest concentrations in ASR were evaluated across different sized fractions. In that study, there were very noticeable higher lead and zinc concentrations in the smaller sized ASR fractions. For lead, concentrations increase in a continuous manner as the ASR fractions decreased in size. A very similar pattern for zinc is also observed. Although not as dramatic, the highest concentrations of copper and nickel were also observed in the two smallest sized fractions. The results of this study clearly indicate that the smaller sized ASR fractions will contain the higher concentrations of these four metals.<sup>97</sup>

**Table 23: Total Metal Content in Different Sized Fractions of ASR (mg/kg)**

Fraction Size (µm)	Copper	Nickel	Lead	Zinc
2,000-6,000	2,000	280	3,000	3,900
1,000-2,000	2,550	360	4,100	7,900
500-1,000	2,300	290	6,400	10,000
250-500	2,650	370	7,600	12,450
125-250	2,930	550	7,700	13,200
<125	2,700	390	10,200	11,700

Source: Gonzalez-Fernandez, O., et. al., *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution.

A separate study was focused exclusively on lead and found identical results in terms of the continuous increase in lead content to the finest fraction of ASR. The content of lead was determined to be three times higher in the ASR fine fraction than the values found in the coarser fraction. Therefore it is the smaller fractions of ASR that have a more elevated value of lead indicating that these are the fractions having a more important environmental risk.<sup>98</sup>

<sup>95</sup> Ibid.

<sup>96</sup> Ibid.

<sup>97</sup> Gonzalez-Fernandez, O., et. al., *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution.

<sup>98</sup> Gonzalez-Fernandez, O. (2009), et. al., *Analysis of Lead Content in Automotive Shredder Residue*, published in Waste Management.

**Table 24: Lead Concentrations in Different-Sized ASR Fractions**

<b>Fraction Size (<math>\mu\text{m}</math>)</b>	<b>Lead Content (mg/kg)</b>
<125	11,600 $\pm$ 650
125-250	8,800 $\pm$ 370
250-500	8,100 $\pm$ 400
500-1,000	6,500 $\pm$ 320
1,000-2,000	5,450 $\pm$ 310
2,000-6,000	4,600 $\pm$ 360

Source: Gonzalez-Fernandez, O. (2009), et. al., *Analysis of Lead Content in Automotive Shredder Residue*, published in Waste Management.

**Table 25: Elemental Composition and Characteristics of ASR as a Function of Fraction Size**

	1 (<20mm)	1 (20-50mm)	1 (>50mm)	2 (<2mm)	2 (<12.7mm)	2 SR (12.7-38.1mm)	3 SR (>38.1 mm)	3 (<2mm)	3 (>2mm)	4 (<2mm)
Cl (wt%)					0.8	2.1	3.2			0.5
S (wt%)	0.15	0.1	0.09		0.27	0.31	0.49			0.2
Ca (wt%)					3.11	2.45	1.74			
Si (wt%)					0.44	0.28	0.11			2.1
Fe (wt%)				12.1	2.0	1.3	1.4	12-14	6.0	25.7
Al (wt%)				1.3	1.2	0.9	0.4	1.2-2	0.7	
As (ppm)	16	20	9		9	4	4			
Cd (ppm)	6.7	7.0	5.5	99				30-120	20	
Cr (ppm)	270	390	194	272	130	67	101	180-300	88	800
Cu (ppm)	34	16	32	11,692	15,839	26,958	15,735	2,300- 22,000	2,000- 5,000	12,000
Hg (ppm)	0.65	0.9	1.0							
Ni (ppm)	230	210	144	271	224	162	148	140-550	80-280	700
Pb (ppm)	3,800	5,000	2,000	4,310	738	354	64	1,030- 10,200	1,200- 3,000	2,000
Zn (ppm)				14,385	6,787	7,441	3,415	7,900- 16,000	3,900- 5,000	19,000

Note: Cl=chlorine; S=sulphur; Ca=calcium; Si=silicon; Fe=iron; Al=aluminum; As=arsenic; Cd=cadmium; Cr=chromium; Cu=copper; Hg=mercury; Ni=nickel; Pb=lead; Zn=zinc.

<sup>1</sup> Morselli, L., et. al. (2010), *Automotive Shredder Residue (ASR) Characterization from Valuable Management*, published in Waste Management.

<sup>2</sup> Boughton, B. (2007), *Evaluation of Shredder Residue as Cement Manufacturing Feedstock*, published in Resource Conservation & Recycling.

<sup>3</sup> Gonzalez-Fernandez, O., et. al. (2008), *Heavy Metals Content of Automobile Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution.

<sup>4</sup> Mirabile, D., et. al. (2002), *Thermal Valorisation of Automobile Shredder Residue: Injection in Blast Furnace*, published in Waste Management.

Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

#### 4.5.9 Characterization of ASR Fraction Size/Chemical Constituents for Use as a Fuel

The table below outlines the results of four particle size ASR fractions in terms of parameters that are useful for characterization of viability as a fuel. Lower heating values varied from 15 MJ/kg dry sample to 24.6 MJ/kg dry sample. The 20–50 mm and 50–100 mm fractions are the richest in polymers, and this is in agreement with the observation that these two fractions have the highest heating values. The fines fraction presented the highest ash content (50% by weight) and, as a consequence, the lowest calorific value. The 20–50 mm and 50–100 mm fractions exhibited very similar properties. None of the fractions presented a high sulphur content (0.4–0.8 wt.%).<sup>99</sup>

**Table 26: Chemical Analysis Results on ASR Fractions**

Parameter	Units	Raw Material	0-20 mm	20-50 mm	50-100 mm
Humidity	Wt%	1.2	1.3	1.2	1.1
Ash content	Wt%	38.5	50.6	25.5	29.0
C	Wt% <sup>a</sup>	41.2	35.0	59.9	49.1
H	Wt% <sup>a</sup>	5.0	4.8	8.6	67
N	Wt% <sup>a</sup>	1.3	0.6	1.8	1.3
S	Wt% <sup>a</sup>	0.5	0.4	0.5	0.8
Upper Heating Value	MJ/kg <sup>a</sup>	19.9	16.1	25.7	26.2
Lower Heating Value	MJ/kg <sup>a</sup>	18.7	15.0	23.7	24.6

Note: C=carbon; H=hydrogen; N=nitrogen; S=sulphur.

<sup>a</sup> – calculated on a dry basis.

Source: Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

A separate study corroborated that fines (0-20 mm) are the fraction with the highest contents of ash and mineral oil. LHV increases with particle size while ash shows an inverse trend. This may be ascribed to dirt, soil, metals, glass and other incombustibles, making the finer fraction unsuitable for energy recovery processes. Furthermore, some heavy metals (As, Mn, Pb and Cd) are more concentrated in the finer fractions but, on the other hand, PCBs tend to distribute into the coarser fractions. It has been indicated that many parameters (e.g. ash content, LHV, As, Cr, Mn, Ni, and Pb) do not meet the reference values for the use of ASR as RDF. Screening of the finer fraction may lead to an overall improvement, since the higher values of ash and the lower value of LHV are found in the finest fraction. Fractions 20–50 mm and 50–100 mm are rich in polymers. Plastics, rubber and foam accounts for more than 70% of the total. Textiles and cellulosic

<sup>99</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

lies mainly in the 50–100 mm fractions. Fraction >100 mm is made of large pieces of plastics and foam rubber which have not been broken during the shredding process.<sup>100</sup>

**Table 27: Physico-Chemical Properties of ASR, as a Whole and in Different Fractions**

Parameter	Unit	Original Sample	0-20 mm	20-50 mm	50-100 mm	>100 mm
Humidity	%	10	13.8	4.4	13.9	1.3
Ash	% d.w.	28.2	40.4	16.4	24	2.5
LHV	kJ/kg	13,800	10,700	15,200	18,700	23,800
UHV	kJ/kg	15,000	11,700	16,400	20,000	25,900
Mineral oils	mg/kg	26,800	32,800	23,000	18,000	22,100
Chlorine	%	<0.05	<0.05	<0.05	<0.05	<0.05
Organic Chlorine	mg/kg	16.4	6.7	28.7	13.1	22.4
S	%	0.12	0.15	0.10	0.09	0.08
As	mg/kg d.w.	16	16	20	9	11
Cr	mg/kg d.w.	300	270	390	170	360
Mn	mg/kg d.w.	880	1,220	660	460	500
Ni	mg/kg d.w.	210	230	210	140	170
Pb	mg/kg d.w.	4,000	3,800	5,000	2,000	2,000
Pb-volatile	mg/kg d.w.	3,700	3,500	5,000	1,100	1,900
Cu	mg/kg d.w.	27	34	16	30	42
Cd	mg/kg d.w.	6.0	6.7	7.0	5.6	4.6
Hg	mg/kg d.w.	0.80	0.65	0.90	1.02	0.87
Cd+Hg	mg/kg d.w.	6.6	7.4	7.9	5.7	5.5
Se	mg/kg d.w.	<1	<1	<1	<1	<1
PCBs	mg/kg d.w.	5.3	2.5	7.7	7.3	8.4
PAHs	mg/kg d.w.	4.4	3.6	4.8	5.6	4.4

Note: S=sulphur; AS=arsenic; Cr=chromium; Mn=manganese; Ni=nickel; Pb=lead; Cu=copper; Cd=cadmium; Hg=mercury; Se=selenium; PCBs= polychlorinated biphenyls; PAHs=polycyclic aromatic hydrocarbons.

Source: Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

#### 4.6 Likelihood of Challenge Substances Declared Toxic Being Present in ASR

Several Challenge substances from CMP I have been declared toxic. The federal government is now in the process of determining the toxicity status of CMP II substances. CMP II substances have largely been allocated into one of nine groupings, specifically: (i) aromatic azo- and benzidine-based substances; (ii) boron-containing

<sup>100</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

substances; (iii) internationally classified substances; (iv) certain organic flame retardants; (v) cobalt-containing substances; (vi) methylenediphenyl diisocyanates and diamines (MDI/MDA); (vii) phthalates; (viii) selenium-containing substances; and (ix) substituted diphenylamines. Some of these CMP I and II substances are found in vehicles, and therefore some of these substances may be present in ASR.

Insufficient data exists with which to characterize the levels of many of these substances in ASR, however, some anecdotal data can be presented. The following table describes whether or not specific Challenge substances are expected to be found in vehicles (as well as where the substances are found), and provides a general description of the expected concentration of these substances in ASR. Also provided is the level of uncertainty regarding this concentration figure and whether or not any particular vehicle may actually contain the substance at any concentration.

For example, 2-propenamide (CAS 76-06-1) is a chemical used as an intermediate in the manufacture of polyacrylamide, which is then used in the manufacture of plastics, coatings and adhesive tape formulations. 2-Propenamide could potentially be present in low concentrations in vehicles, because it is used in the manufacture of a chemical that can then potentially be used in the manufacture of some vehicle components. However, the presence of 2-propenamide in ELVs is very uncertain because:

- not all coatings and/or plastics are manufactured using 2-propenamide, and no figures were identified regarding how commonly 2-propenamide is found in these materials; and
- 2-propenamide is used in paints or coatings that would be painted onto steel components, and therefore coatings containing 2-propenamide would likely not be in ASR in high concentrations because they would remain bonded to metals that are largely separated from ASR.

Therefore, when describing the potential presence of 2-propenamide in ASR, the table below states that the concentration of 2-propenamide would be low, and that the uncertainty regarding the presence of 2-propenamide in ASR is high.

There are several instances where there was insufficient data to make even these assumptions, and concentrations were listed as “unknown.” Additionally, several of the toxic Challenge substances were not known to be used in vehicles, and assumptions for concentrations and data uncertainty were not developed for these substances.

There were 3 common reasons that explained potential chemical concentration levels in ASR. To simplify the table, the number 1, 2, or 3 was commonly assigned to a concentration value. These numbers represent the following:

1. The substance is present in small volumes within another chemical that is used in small volumes as an ingredient in an end product (e.g. plastic/fluid/foam) that may be in ASR (low concentration in vehicle component is assumed).
2. The substance is utilized in low concentrations in an end product (e.g. plastic/fluid/foam) that may be in ASR.
3. The substance is used during manufacture, but volatilizes/reacts during manufacture in such a way that very limited quantities remain in finished products.

There were five common reasons that explained the uncertainty of whether or not the substance might be contained in ASR or any particular vehicle. To simplify the table, these reasons were given identifying letters and were assigned to the uncertainty descriptors. These letters represent the following:

- A. Few (only 1 or 2) sources that stated the substance may be utilized in ELVs, and confidence in the information is low.
- B. The substance is utilized primarily in vehicle components that are largely separated from ASR (painted onto steel bodywork, found in rubber utilized for tires, found in brake fluid/fuel drained from vehicle, etc.)
- C. No data was identified that describes how many vehicle/component manufacturers use this chemical as opposed to another chemical that can fulfill the same role.
- D. The chemical is primarily used for other purposes, and may not be widely used in vehicles.
- E. Could potentially be present in multiple products found in vehicles that could be found in ASR.

**Table 28: Description of the Potential Presence of Toxic Challenge Substances in ASR**  
(note GADSL = Global Automotive Declarable Substance List)

Substance	CAS RN	Description of Presence in ELVs	Potential Concentration in ASR
Oxirane, methyl-	75-56-9	This chemical was not identified in GADSL as being used in vehicles. However, it is generally converted into polyether polyols, which are then used for the production of polyurethane plastics, which could be present in vehicles.	<b>Unknown Concentration:</b> 1, 3 <b>High Uncertainty:</b> C, D, No information found that indicates this chemical is used in vehicles.
Peroxide, (1,1,4,4-tetramethyl-1,4-butanediyl)bis(1,1-dimethylethyl)	78-63-7	This chemical was not identified in GADSL as being used in vehicles. No other data was identified that describes this chemical as being utilized in vehicles.	Not identified as present in vehicles.
Benzene, 1,3-diisocyanato-2-methyl-	91-08-7	Benzene, 1,3-diisocyanato-2-methyl- (2,6 - TDI) is one of two TDI's that are often used together in mixtures and reacted with polyols to make polyurethanes. Polyurethanes are used in plastics and foams, which are used in a variety of vehicle components.	<b>Unknown Concentration:</b> No data was found on the amount of TDI remaining in polyurethane components at a vehicles end of life. <b>High Uncertainty:</b> C, E
Naphthalene	91-20-3	The principal use of naphthalene in the United States is as an intermediate in the production of phthalic anhydride, which in turn is an intermediate in the production of phthalate plasticizers, pharmaceuticals, insect repellents, and other materials. Also present in gasoline.	<b>Low Concentration:</b> 1 <b>Low Uncertainty:</b> E
Oxirane, ethyl-	106-88-7	This chemical was not identified in GADSL as being used in vehicles. Can be used as an intermediate in the production of fuel additives, non-ionic surfactants, defoamers and various other products.	<b>Unknown Concentration:</b> 2 <b>High Uncertainty:</b> No information was identified that indicates this chemical is used in vehicles.
1,2-Benzenediol	120-80-9	This chemical was not identified in GADSL as being used in vehicles. No other data was identified that describes this chemical as being utilized in vehicles.	Not identified as present in vehicles.
1,4-Benzenediol	123-31-9	This chemical was not identified in GADSL as being used in vehicles. No other data was identified that describes this chemical as being utilized in vehicles.	Not identified as present in vehicles.
Benzene, 2,4-diisocyanato-1-methyl-	584-84-9	Benzene, 2,4-diisocyanato-1-methyl- (2,4 - TDI) is one of two TDI's that are often used together in mixtures and reacted with polyols to make polyurethanes. Polyurethanes are used in plastics and foams, which are used in a variety of vehicle components.	<b>Unknown Concentration:</b> No data was found on the amount of TDI remaining in polyurethane components at a vehicles end of life. <b>High Uncertainty:</b> C, E
Peroxide, (1,1,4,4-tetramethyl-2-butyne-1,4-diyl)bis(1,1-dimethylethyl)	1068-27-5	This chemical was not identified in GADSL as being used in vehicles. No other data was identified that describes this chemical as being utilized in vehicles.	Not identified as present in vehicles.
Peroxide, (3,3,5-trimethylcyclohexylidene)bis(1,1-dimethylethyl)	6731-36-8	This chemical was not identified in GADSL as being used in vehicles. No other data was identified that describes this chemical as being utilized in vehicles.	Not identified as present in vehicles.
Benzene, 1,3-diisocyanatomethyl-	26471-62-5	Benzene, 1,3-diisocyanatomethyl (TDI mixed isomers) is a mixture of two TDI's that are often reacted with polyols to make polyurethanes. Polyurethanes are used in plastics and foams, which are used in a variety of vehicle components.	<b>Unknown Concentration:</b> No data was found on the amount of TDI remaining in polyurethane components at a vehicles end of life. <b>High Uncertainty:</b> C, E
Propanedinitrile, [[4-[[2-(4-cyclohexylphenoxy)ethyl]ethylamino]-2-methylphenyl]methylene]-	54079-53-7	This chemical was not identified in GADSL as being used in vehicles. No other data was identified that describes this chemical as being utilized in vehicles.	Not identified as present in vehicles.
1,3-Butadiene, 2-methyl-	78-79-5	Isoprene is used mainly as a monomer in the production of polyisoprene (isoprene rubber), butyl rubber (isobutene-isoprene copolymer), thermoplastic and elastomeric co-block polymers (e.g., styrene-isoprene-styrene rubber). Largely utilized in the manufacture of tires.	<b>Low Concentration:</b> 1 <b>Low Uncertainty:</b> B, E Multiple sources described polyisoprene being used to replace natural rubber in tires.

Phenol, 4,4'-(1-methylethylidene)bis-	80-05-7	The vast majority of bisphenol A (BPA) is used as a reactive raw material in the production of two major resins, which are in turn used to manufacture a great variety of finished products. Generally the BPA content in these finished products are in the parts per million range and provides no functionality in these products. <sup>101</sup>	<b>Low Concentrations:</b> 2, 3 <b>High Uncertainty:</b> C, D, E
Cyclotetrasiloxane, octamethyl-	556-67-2	Cyclotetrasiloxane, octamethyl (D5) is an intermediate in the production of polydimethylsiloxanes (PDMS) silicone polymers, and all PDMS polymers contain residual amounts of volatile cyclosiloxanes, including and D5. Silicone rubbers can be used for gaskets or seals in engines, radiators, sunroofs, transmissions and other weather seals (around windows) in vehicles.	<b>Low Concentration:</b> 1 <b>Low Uncertainty:</b> C, E, Multiple sources described silicone rubbers being used in vehicles.
Thiourea	62-56-6	Thiourea is used in a very wide range of applications, but the main applications of potential interest for vehicles is as an accelerant in rubber production, a rust inhibitor, in the production of resins used in nylon and as an auxiliary agent in the textile industry.	<b>Unknown Concentration:</b> Used in an unknown number of different components of an automobile, and possibly in varying concentrations. <b>High Uncertainty:</b> C, D, E
Oxirane, (chloromethyl)-	106-89-8	GADSL identifies Oxirane, (chloromethyl) (epichlorohydrin) as being present as a residual monomer in epoxy resins. Epichlorohydrin is a chemical intermediate used to make a variety of chemical products, primarily epoxy resins.	<b>Unknown Concentration:</b> 2, 3 <b>Medium Uncertainty:</b> C, E
Phenol, 2,4,6-tris(1,1-dimethylethyl)-	732-26-3	GADSL identifies this chemical as being present in vehicles, and Environment Canada data describes this chemical as being used as a fuel/lubricant additive. <sup>102</sup>	<b>Unknown Concentration:</b> 2, 3 <b>High Uncertainty:</b> B, C
C.I. Pigment Yellow 34	1344-37-2	Pigment yellow 34 is used a colourant in paints, printing inks, cellulose acetate plastics, textile printing, leather finishes, linoleum, paper, car refinishing, most vinyl applications such as construction products, medical devices and packaging and artist's colours.	<b>Low Concentration:</b> 2 <b>High Uncertainty:</b> B, C, D
C.I. Pigment Red 104	12656-85-8	Pigment red 104 is used a colourant in a variety of substances, including paints, printing inks, plastics, paper, rubber and textile printing.	<b>Low Concentration:</b> 2 <b>High Uncertainty:</b> B, C, D
1-Propanol, 2-methoxy-	1589-47-5	Could be present in minor quantities in paints/coatings that may or may not be used on vehicles, and may be present in minor quantities in greases and antifreeze.	<b>Low Concentration:</b> 1 <b>High Uncertainty:</b> A, B, C
Ethanol, 2-methoxy-, acetate	110-49-6	This chemical was not identified by GADSL as being used in vehicles. Ethanol, 2-methoxy-, acetate (2-MEA) is no longer used in the U.S. or the European Union, and is unlikely to be present in vehicles. <sup>103</sup>	Not identified as present in vehicles.
Ethanol, 2-(2-methoxyethoxy)-	111-77-3	Has been found to be an ingredient in water and solvent based paints, windshield washer fluid, plasticizers and hydraulic fluids/brake fluid.	<b>Low Concentration:</b> 2 <b>Medium Uncertainty:</b> B, C, E
2-Naphthalenol, 1-[(4-methyl-2-nitrophenyl)azo]-	2425-85-6	Used as a pigment in the manufacturing of paints, inks, plastics, rubber and textile printing.	<b>Unknown Concentration</b> <b>Medium Uncertainty:</b> C, D, E
Sulfuric acid, diethyl ester	64-67-5	Sulfuric acid, diethyl ester (diethyl sulphate) was not identified by GADSL as being used in vehicles. Diethyl Sulphate is used principally as an intermediate (ethylating agent) in the manufacture of dyes, pigments and textile chemicals, and as a finishing agent in textile production.	Not identified as present in vehicles.
Sulfuric acid, dimethyl ester	77-78-1	Dimethyl sulfate is used primarily as a methylating agent to convert compounds such as phenols, amines, and thiols to the corresponding methyl derivatives. The chemical was not identified by GADSL as being used in vehicles.	Not identified as present in vehicles.

<sup>101</sup> ICIS Chemical Business, *Chemical Profile – Bisphenol A*, January 14-20, 2008.

<sup>102</sup> Environment Canada, *Proposed Risk Management Approach - Phenol, 2,4,6-tris(1,1-dimethylethyl) (2,4,6-tri-tert-butylphenol)*

<sup>103</sup> Environment Canada, *Proposed Risk Management Approach - Ethanol, 2-methoxy-, acetate (2-Methoxyethanol acetate, 2-MEA)*, *Chemical Abstracts Registry Number 110-49-6*.

Benzenamine, N-phenyl-, reaction products with styrene and 2,4,4-trimethylpentene	68921-45-9	Used as an antioxidant in some vehicle engine oils (at 0.2-0.25% concentrations) and in commercial/industrial lubricants.	<b>Medium Concentration:</b> Environment Canada study <sup>104</sup> found 0.2-0.25% concentration. <b>Low Uncertainty:</b> Multiple studies confirm presence in some engine oils.
2-Propenamide	79-06-1	Used as an intermediate to make polyacrylamide, which can be used in the manufacture of plastics, coatings (used on steel elements of vehicles), and adhesive tape formulations.	<b>Low Concentration:</b> 1 <b>High Uncertainty:</b> A, B, C, D
Ethanol, 2-chloro-, phosphate (3:1)	115-96-8	Ethanol, 2-chloro-, phosphate (3:1) (TCEP) is used as a flame retardant in polyurethane foams for automotive applications, a flame retardant in adhesives and in fire resistant coatings/paints, and a plasticizer in thermoplastic resins. TCEP has been classified as carcinogenic, and its use in polyurethane foams began to decline after 1989.	<b>Medium Concentration:</b> Seat foam (the main use of TCEP in vehicles) is estimated to make up about 10% of the weight of the polyurethanes in a vehicle. <sup>105</sup> <b>High Uncertainty:</b> <i>Use has been declining since 1989.</i>
2-Naphthalenol, 1-[[4-(phenylazo)phenyl]azo]-	85-86-9	2-Naphthalenol, 1-[[4-(phenylazo)phenyl]azo]- (solvent red 23) is used in cosmetics, perfumes, toiletries, and personal grooming products. Solvent red 23 was not identified by GADSL as being present in vehicles.	Not identified as present in vehicles.
Benzene, (chloromethyl)-	100-44-7	This chemical was not identified by GADSL as being present in vehicles, and was not otherwise found to be present in vehicles.	Not identified as present in vehicles.
Methanone, bis[4-(dimethylamino)phenyl]-	90-94-8	Found in low concentrations in dyes and pigments that can be used in textiles/leather.	<b>Low Concentration:</b> 1 <b>High Uncertainty:</b> C, D
2-Butanone, oxime	96-29-7	Could be used within alkyd paints, however these paints have not been used widely on vehicles since the 1970's.	<b>Low Concentration:</b> 2 <b>High Uncertainty:</b> B, C, D
Oxirane, (butoxymethyl)-	2426-08-6	Is used as a reactive diluent for in the formation of epoxy resins, which have potentially vehicular applications in coatings, adhesives and sealants.	<b>Low Concentration:</b> 1, 3 <b>Medium Uncertainty:</b> B, C, E
Propane, 2-nitro-	79-46-9	This substance can be utilized in products such as inks, paints, adhesives, and polymers. GADSL does not identify this substances as being present in vehicles, and no other information described this substance as being present in vehicles.	Not identified as present in vehicles.
Benzene, 1-methyl-2-nitro-	88-72-2	Benzene, 1-methyl-2-nitro- was not identified by GADSL as being present in vehicles, and is primarily utilized in the manufacture of explosives. No information was found that describes this substance being present in vehicles.	Not identified as present in vehicles.
Phenol, 2,6-bis(1,1-dimethylethyl)-4-(1-methylpropyl)-	17540-75-9	Is used as an antioxidant/corrosion inhibitor in brake fluid, and as an antioxidant/corrosion inhibitor/scavenger/antiscaling agent in the manufacture of plastic products. Additionally, is known to be used in flexible foams as a stabilizer/antioxidant.	<b>Low Concentration:</b> 2 <b>Medium Uncertainty:</b> C, D, E
Methylum, [4-(dimethylamino)phenyl]bis[4-(ethylamino)-3-methylphenyl]-, acetate	72102-55-7	The main use reported for this chemical is as a paper dye. No information was found that indicated this substance may be used in vehicles.	Not identified as present in vehicles.
Benzene, 1,2-dimethoxy-4-(2-propenyl)-	93-15-2	This substance was not identified by GADSL as being present in vehicles. Methyl eugenol is used as a flavouring ingredient in some foods and as a component of some pest control products. No information was identified that suggests this substance may be present in	Not identified as present in vehicles.

<sup>104</sup> Environment Canada and Health Canada (2009), *Screening Assessment for The Challenge, (Benzenamine, N-phenyl-, Reaction Products with Styrene and 2,4,4-Trimethylpentene)*, Chemical Abstracts Service Registry Number 68921-45-9.

<sup>105</sup> Ibid.

		vehicles.	
Vanadium oxide (V2O5)	1314-62-1	GADSL did not identify this substance as being present in vehicles. However, this substance is used in the formulation of ferrovanadium alloys for the manufacture of solid steel, and could therefore be present in small quantities in some automotive steel (although no information has been found that suggests this is the case). May also be present in aluminum in minute concentrations.	<b>Unknown Concentration: 1</b> <b>High Uncertainty: A, B, C, D</b>
Oxirane, 2,2',2'',2'''-[1,2-ethanediyliidenetetrakis(4,1-phenyleneoxymethylene)]tetrakis-	7328-97-4	GADSL did not identify this substance as being present in vehicles. The substance is used for mixing pigments, solvents and binders into paints and other coatings such as stains, varnishes, lacquers, enamels, shellacs etc. However, no information was identified that suggests this substance might be used in vehicles.	Not identified as present in vehicles.
Bromic acid, potassium salt	7758-01-2	GADSL did not identify this substance as being present in vehicles. This substance was primarily utilized as a food additive, but has not been permitted for this use in Canada since 1994. No information was identified suggesting that this substance could be used in vehicles.	Not identified as present in vehicles.
Hydrazine	302-01-2	GADSL identifies this substances as being present in residual monomers in plastics, pigments, adhesives, oils, and greases. All of these end-products could potentially be utilized in vehicles, and potentially be present in ASR.	<b>Low Concentration: 3</b> <b>Low Uncertainty: C, E</b>
Hexanedioic acid, bis(2-ethylhexyl) ester	103-23-1	Hexanedioic acid, bis(2-ethylhexyl) ester (DEHA) is primarily used as a plasticizer. The dominant end-use for DEHA is in PVC (estimated 80-90%) cling film (i.e. the film used to cover food items at home and in grocery stores). There is a wide range of other PVC products (besides cling film) where DEHA is also used as a plasticizer, for instance gloves, shoe soles, latex (e.g. luggage, tarpaulins, upholstery, wall coverings), medical products, children's products, garden hose, wire and cable, etc.	<b>Low Concentrations: 2</b> <b>High Uncertainty: C, D</b>
2-Propanone, reaction products with diphenylamine	68412-48-6	2-Propanone, reaction products with diphenylamine (PREPOD) is used as an antioxidant in rubber products, and as a paint and coating additive. According to an Environment Canada/Health Canada Screening Assessment, PREPOD is present in vehicle parts, including front mounting brackets for engines and in brake components. This Screening Assessment also states that PREPOD is present in already assembled vehicles at concentrations of 0.0003% by weight.	<b>Medium Concentrations:</b> Concentration described left. <b>Low Uncertainty:</b> Multiple reports confirm use of PREPOD in vehicles.
1,4-Benzenediamine, N,N'-mixed Ph and tolyl derivs.	68953-84-4	May be present in some rubber tires, elastomers in butyl rubber, anti-aging agents and sealants.	<b>Low Concentrations: 2</b> <b>Low Uncertainty: C, E</b>
Trisiloxane, octamethyl-	107-51-7	Trisiloxane, octamethyl (MDM), is primarily used as an ingredient in the preparation of polydimethylsiloxane (PDMS) polymers, oligomers and mixtures. PDMS formulations containing MDM can be found in lubricants, paints, coatings, adhesives, plastic products, and semiconductors.	<b>Low Concentration: 1</b> <b>High Uncertainty: C, D, E</b>

## 4.7 Estimate of the Amount of Certain Substances Present in ASR Generated Annually in Canada

Estimating the amount of any substance contained in ASR generated in Canada annually requires: (i) the number of ELVs retired and shredded in Canada annually; (ii) the quantity of ASR resulting from the dismantling/shredding of an average vehicle; and (iii) the approximate concentration of the substance in question within an average ASR mixture.

The number of ELVs retired annually in Canada is uncertain. Formal statistics do not track the number of ELVs recycled in Canada each year. This is because a formal process for tracking vehicle retirements, for example through VIN deregistration or industry reporting, does not exist in Canada. Previous estimates from the Automotive Recyclers of Canada suggest that approximately 1.2 million vehicles per year are recycled in Canada. During a recent study, Cheminfo updated this figure.<sup>106</sup> This study determined that the average age of a retired vehicle is approximately ten years, and therefore roughly 1.2 million vehicles would have been recycled annually between 2000 and 2006 based on the number of new motor vehicle sales ten years earlier. However, rapid growth in vehicle sales between 1996 and 2002 suggests that higher numbers of vehicles would have required processing and disposal between 2006 and 2012. Given new vehicle sales in Canada circa 2001, it is expected that approximately 1.6 million vehicles would have been retired and recycled in 2011. Similar numbers of ELVs should be expected over the next ten years given flat new vehicle sales between 2000 and 2010. This study assumes 1.6 million vehicles are retired and shredded in Canada annually.

Existing literature has indicated that dismantled ELVs produce approximately 200 kg of ASR per vehicle.<sup>107</sup> However, this figure is highly contentious. The following table outlines the materials present in discarded automotive hulks.

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<sup>106</sup> Cheminfo Services, (2012), *Study of the End-of-Life Vehicle Recycling and Management Sector in Canada*.

<sup>107</sup> Sakai, S., et. al., *End-of-life Vehicle Recycling and Automobile Shredder Residue Management in Japan*, published in the Journal of Material Cycles and Waste Management.

**Table 29: Materials in Discarded Automobiles Hulks**

Material	Share	Kg/Vehicle
Steel	66.0%	980.7
Plastic	7.5%	111.4
Aluminum	7.2%	107.3
Fluids & Lubricants	5.9%	88.2
Rubber	4.3%	64.5
Glass	2.9%	44.1
Copper & Brass	1.4%	20.7
Powder Metals	1.1%	15.9
Zinc	0.4%	5.5
Magnesium	0.2%	3.2
Other Materials	3.1%	46.8
<b>Total</b>	<b>100.0%</b>	<b>1,488.3</b>

Source: Natural Resources Canada (2006), *An Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Emission Implications*.

The materials largely present within ASR include plastic, rubber, glass, powder metals, and “other materials” (vehicle fluids are largely removed during depollution). Based upon the above table, these materials account for approximately 280 kg per vehicle. Therefore for the purposes of estimating the amount of certain substances in ASR generated annually in Canada, the figures of 200 and 280 kilograms per vehicle are applied.

Using the figures of 1.6 million ELVs shredded and between 200-280 kilograms of ASR generated per vehicle, a total of between 320,000-448,000 tonnes of ASR is generated annually in Canada. These values are in-line with existing estimates in the literature with respect to annual ASR generation in other regions/countries. For instance, the U.S. EPA has estimated that in the U.S., over 4 million tons of ASR is generated annually.<sup>108</sup> Therefore Canada would be expected to be approximately 10% of this amount, or in the vicinity of 400,000 tonnes of ASR per year. Another estimate for Canada that was identified was by Natural Resources Canada, which estimated that approximately 357,000 tonnes of ASR is generated annually in Canada.<sup>109</sup>

In terms of the last parameter required, the earlier sections of this chapter summarized the concentrations of several chemicals in ASR, and averages of these figures were utilized to calculate the estimated quantity of specified substances contained in ASR generated annually in Canada.

<sup>108</sup> U.S. Environmental Protection Agency (2004), *Using Auto Shredder Residue as Cement Manufacturing Feedstock*.

<sup>109</sup> Natural Resources Canada (March, 2006), *An Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Implications*.

The table below provides a list of the substances for which ASR concentrations were identified, and estimates of the quantity of these substances contained in ASR generated annually in Canada (one group of estimates is based on 200 kilograms of ASR per vehicle, while the other group of estimates is based on 280 kilograms of ASR per vehicle). Please note that these figures are gross estimates, and that the three parameters upon which the calculations are based are all approximations. In addition, please note that we have not provided estimates in the table below of the quantity of organotin species present in ASR, even though concentration data for these species was identified in the literature. This is attributed to the fact that the organotin concentration data for ASR is only available from one study and it is believed that there is an error with respect to the specification of units in that article.

**Table 30: Estimated Quantity of Specified Substances Contained in ASR Generated Annually in Canada**

Substance	Assumed Concentration in ASR (kg/tonne) or (wt%)	Estimated Quantity Contained in ASR Generated Annually in Canada Assuming 200 kg of ASR per Vehicle (tonnes)	Estimated Quantity Contained in ASR Generated Annually in Canada Assuming 280 kg of ASR per Vehicle (tonnes)
<b>Metals</b>			
Aluminum	6.5%	20,800	29,120
Arsenic	0.01	1.9	2.69
Cadmium	0.03	8.0	11.2
Chromium	0.3	96.0	134.4
Copper	30	9,600	13,440
Iron	11%	35,200	49,280
Mercury	0.00025	0.08	0.11
Nickel	0.33	104	145.6
Lead	4.0	1,280	1,792
Tin	0.04%	128	179.2
Selenium	0.0003	0.1	0.13
Antimony	0.11	33.6	47.04
Titanium	0.9%	2,880	4,032
Zinc	12.0	3,840	5,376
Calcium	6%	19,200	26,880
Potassium	0.53%	1,696	2,374.4
Sodium	1.89%	6,048	8,467.2
Phosphorous	0.7%	2,240	3,136
Silicon	13%	41,600	58,240
Cobalt	0.01	3.8	5.38



Substance	Assumed Concentration in ASR (kg/tonne) or (wt%)	Estimated Quantity Contained in ASR Generated Annually in Canada Assuming 200 kg of ASR per Vehicle (tonnes)	Estimated Quantity Contained in ASR Generated Annually in Canada Assuming 280 kg of ASR per Vehicle (tonnes)
<b><u>Chlorinated Substances</u></b>			
PCDDs/PCDFs*	1.50E-07	4.80E-05	6.72E-05
CoPCBs*	3.00E-08	9.60E-06	1.34E-05
MoBrPCDDs/PCDFs	7.00E-06	2.24E-03	3.14E-03
Polychlorinated Biphenyls	5.00E-03	1.6	2.24
Polychlorinated Naphthalenes	3.00E-05	0.01	0.01
Polychlorinated Benzenes	1.00E-03	0.32	0.45
Polychlorinated Phenols	8.00E-04	0.26	0.36
<b><u>Brominated Substances</u></b>			
PBDDs/PBDFs	0.00004	0.01280	0.01792
Brominated diphenyl ethers	0.16	51.20	71.68
Tetrabromobisphenol A	0.00055	0.18	0.25
Hexabromocyclododecane	0.003	0.96	1.34
Tribromophenol	0.000120	0.03840	0.05376
<b><u>Polycyclic Aromatic Hydrocarbons</u></b>	0.01	4.16	5.82
<b><u>Phthalates (DEHP)</u></b>	5.5	1,760	2,464
<b><u>Minerals/Oils</u></b>			
Mineral Oils	22.5	7,200	10,080
Benzene	0.000003	0.00096	0.001344
Hydrocarbons	6.6	2,112	2,956.8

#### 4.8 Information Gaps Related to the Material Composition/Chemical Constituents of Shredder Residue

There is a significant amount of information available on the material composition and chemical constituents of ASR. However, it is difficult to determine whether the information provided on ASR actually refers to shredder residue as the literature generally just uses the term ASR. However most shredders do not shred only vehicles and therefore the residue from their operations should encompass more than just ASR. Therefore a potential information gap for the study would be more comprehensive information on material composition and chemical constituents of shredder residue (which reflects shredded material from ELVs and other metal goods). However it is

expected that most of the information provided in this chapter actually does refer to shredder residue and not specifically ASR.

The major information gap identified during the study was available data on the chemical constituents of ASR or shredder residue of specific CMP substances that have been declared toxic. This chapter contains all information identified during the study on specific chemical constituents of shredder residue. A somewhat significant list of these substances was identified and consequently we were able to use that data to estimate the amount of these substances that are present in ASR that is generated annually in Canada. However very few of these substances are Challenge substances that have been declared toxic in Canada. In addition, ASR recycling is complicated because this material is very heterogeneous, density and moisture content change from site to site and from day to day as different types of source materials, automobiles and white goods, are shredded.<sup>110</sup> Therefore even the information on chemical constituents of ASR provided in this chapter may not be entirely representative of Canadian conditions.

As such, Environment Canada may want to consider the potential of conducting their own testing of ASR or shredder residue, likely focused on specific substances that are of particular interest to them and which do not have existing information in the literature with regards to their concentration in ASR.

## 4.9 Conclusions

Shredder residue is a highly heterogeneous mixture of residual ferrous and non-ferrous metals, plastics, rubber, textile and fibre material, wood, and glass. The exact composition and physical properties of shredder residue depends mainly on the depollution operations conducted on vehicles, the specific shredder input (e.g. vehicles, white goods and ferrous waste combination), shredder equipment utilized, and post-shredder separation processes. Summarizing the material composition of shredder residue from the literature indicates that plastics generally represent 20-45% of this material, metals 5-20%, rubber 5-25%, foam 0-15%, wood/cardboard 0-5%, textiles/fibres 5-30%, glass 0-20% and miscellaneous/undetermined materials 5-35%.

The existing literature has attempted to quantify the amount of metals, chlorinated substances, brominated substances, PAHs, phthalates and minerals/oils present in shredder residue. Amongst the metals, aluminum, iron, copper, calcium and silicon are most abundant in shredder residue. Amongst the chlorinated substances, polychlorinated biphenyls, polychlorinated phenols and polychlorinated benzenes were present in the highest concentrations. Amongst the brominated substances, brominated diphenyl ethers are present in shredder residue in the highest concentrations – higher than any other

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<sup>110</sup> Nourreddine, M. (2007), *Recycling of Auto Shredder Residue*, published in the Journal of Hazardous Materials.

brominated or chlorinated substance. Amongst the other miscellaneous substances detected in shredder residue, certain phthalates, mineral oils and hydrocarbons are present in the highest amounts. Finally it is important to note that although not tested for in shredder residue (with the identified literature), many CMP substances are present in vehicles and are therefore expected to be present, to some extent, in shredder residue.

## 5. Leaching of Chemical Substances from Shredder Residue Disposed of in Landfills

### 5.1 Introduction

Shredder residue is widely landfilled, and the landfilling of waste generates landfill leachate. Landfill leachate can be defined as a liquid that has passed through the landfilled material, thereby extracting solutes, suspended solids or other components (both environmentally harmless and harmful) of the material through which it has passed. Typically, leachate contains:<sup>111</sup>

- dissolved organic matter (for example, acids, aldehydes and sugars);
- inorganic cations/anions including sulphate, chloride, iron, aluminum, zinc and ammonia);
- heavy metals (for example lead, nickel, copper, mercury); and
- organic compounds such as polychlorinated biphenyls (PCBs), brominated flame retardants (BFRs) and dioxins.

The leachability characteristics of shredder residue can be critical. Studies highlight the potential risk linked to the presence of metals and dissolved organic carbon (DOC) content in landfill leachate.<sup>112</sup> Other studies indicate that persistent organic pollutants (POPs) such as PCDD/PCDFs and PCBs are found in shredder residue, and when the shredder residue is exposed to landfill leachate the amount of these POPs that leach out of the residue increases.<sup>113</sup>

This section of the report reviews identified literature on the behaviour (e.g. leachability) of shredder residue in landfills. However, there has been relatively little work undertaken on trying to identify all of the chemicals or products that leach out of shredder residues into landfills. Therefore the four studies reviewed during the research phases of this project were predominantly focused on certain chemicals (metals or POPs), and no studies were found that provide a detailed breakdown of all substances that leach from shredder residue in landfills.

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<sup>111</sup> DHI, *Landfilling of Shredder Residue – Reduced Environmental Impact and Costs by Shorter Landfill After-Care Period*.

<sup>112</sup> Cossu, R. & Lai, T. (2013), *Washing Treatment of Automotive Shredder Residue*, published in Waste Management.

<sup>113</sup> Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

The four primary studies on landfill leachate characteristics of shredder residue are as follows:

- Khudre et al., (1991), *Trace Elements in the Leachate of Automobile-Scrap Shredder Waste*, published in Waste Management;
- Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere;
- Gonzalez-Fernandez et al., (2008), *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution; and
- Kim, Y and Osako, M and Sakai S, (2006), *Leaching Characteristics of Polybrominated Diphenyl Ethers (PBDEs) From Flame-Retardant Plastics*, published in Chemosphere.

The subsections below will discuss the above studies and provide some information on:

- the leaching characteristics of shredder residue in general (using the Khudre and Sakai studies above);
- the leaching of POPs from shredder residue in landfills (using data from the Sakai study above)
- the leaching of metals from shredder residue in landfills (using the Gonzalez-Fernandez study above); and
- landfill leaching behaviour of brominated flame retardants and polybrominated diphenyl ethers from plastics (using the Kim study above).

## 5.2 General information on the Leaching Characteristics of Shredder Residue

All of the studies reviewed during research for this project indicated that shredder residues are varied, and the pollutants or substances present in one sample of shredder residue can be different from another sample (even when the sampling is conducted at a single landfill or shredder).<sup>114/115/116</sup> Therefore studies that provide figures on shredder residue leaching characteristics often rely on multiple samples or composite sampling strategies to assemble viable data.

For example, the Khudre study was conducted to evaluate the viability of different sampling methodologies that are used to determine the trace element toxicity

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<sup>114</sup> Ibid.

<sup>115</sup> Khudre et al., (1991), *Trace Elements in the Leachate of Automobile-Scrap Shredder Waste*, published in Waste Management.

<sup>116</sup> Gonzalez-Fernandez et al., (2008), *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution

characteristics of automobile-scrap shredder waste. Samples collected using a composite sampling strategy and a random sampling strategy were tested using the toxicity characteristic leaching procedure (TCLP) recommended by the U.S. EPA for determination of mobility of contaminants. For the purposes of this report, the main relevant conclusions derived from the Khudre study are that shredder residue can leach metals such as barium, copper and lead, and that composite sampling procedures can be utilized to replace random sampling procedures that use a high number of samples and are therefore more expensive.<sup>117</sup>

The Khudre study also concluded (along with both of the other studies) that shredder residue leaching characteristics depend on more than just the shredder residue itself. Landfill leachate has been found to contain detergents, acids, and several other substances that can affect the leachability of any materials they come into contact with.<sup>118</sup> The study on the leaching characteristics of POPs from shredder residue that was reviewed for this project (the Sakai study) used a few different substances to test the effect that different leachates might have on the leaching characteristics of shredder residue.

Dodecyl sodium sulfate (LAS), humic acid, leachate from an industrial waste landfill site and distilled water were used in the Sakai study leaching tests. LAS is a detergent, and has been detected widely in the water environment although the biodegradability is relatively high. At a landfill site, LAS may be contained in industrial waste and sewage sludge. Humic acid, which is a very stable substance formed in nature by degradation of high molecular organic substances, has been detected in landfill leachate in Japan ranging from tens to hundreds mg/l. Although humic acid doesn't have a designated structural formation generally, it has many benzene rings and various functional groups. Humic acid and LAS "leachants" were set up at two concentrations. The lower one is a detectable concentration in the environment, and the higher one is set up considering Critical Micelle Concentration (CMC). It is reported that if the micelle is formed, leaching concentration of hydrophobic substances increases being surrounded by surfactants.<sup>119</sup> The table below shows the different concentrations of humic acid and LAS that were utilized in the Sakai study to simulate leachate, as well as the concentrations of humic acid and LAS that were present in the actual leachate utilized in the study.

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<sup>117</sup> Khudre et al., (1991), *Trace Elements in the Leachate of Automobile-Scrap Shredder Waste*, published in Waste Management.

<sup>118</sup> Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

<sup>119</sup> Ibid.

**Table 31: Leachant Used in Sakai Study**

Leachant	Concentration (mg/l)	
Distilled Water	-	
LAS	10	
	1,000	
Humic Acid	10	
	200	
Leachate From Industrial Waste Landfill Site	Humic Acid	8.4
	LAS	0.33

Source: Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

While the conclusions of the Sakai study will be discussed in more detail below, in general it was found that the leaching concentrations of PCDD/PCDFs and PCBs from shredder residues were strongly increased by surfactants. In the case of PCBs, the leaching concentration, using LAS 1,000 mg/l leachant was 68 times higher than that of distilled water. PCBs concentration with humic acid 200 mg/l solution was about 4.6 times higher compared to the results of distilled water. PCDD/PCDFs was leached out at 1.1 ng/l with LAS 1,000 mg/l solution.<sup>120</sup> The Khudre study similarly concluded that a more acidic extraction fluid (or more acidic leachate) can leach more environmentally important elements (such as barium, cadmium, copper and lead) from shredder waste than neutral leachate.

Interviews conducted in support of this study stated that some substances (such as PCBs) are strongly hydrophobic (water repelling) and have negative solubility in water. Therefore some methodologies (such as the *USEPA Method 1311: Toxicity Characteristic Leaching Procedure*) will not typically produce significant quantities of PCBs or other POPs through testing. Instead (as shown in the Sakai study) detergents (which can be found in shredder residue) or other substances such as hexane should be utilized to determine the leachability characteristics of PCBs and some other POPs from shredder residue.

### **5.3 Landfill Leaching Behaviour of Persistent Organic Pollutants Present in Shredder Residue**

The Sakai study provides figures for the amount of PCBs and PCDDs/PCDFs in shredder residue leachate. The primary conclusions of the Sakai study were as follows:

1. PCBs contents in shredder residues used in this study ranged from 1.8 µg/g to 24 µg/g, and PCBs concentration were quite different among residues. Even a residue sampled

<sup>120</sup> Ibid.

in a shredding plant at the same time showed significant differences depending on the original waste materials. PCDD/PCDFs of 0.25 ng TEQ/g was detected in one shredder residue. In the others they were less than 0.1 ng/g.

2. Leaching concentrations of PCDD/PCDFs and PCBs from shredder residues were strongly increased by surfactants. As discussed in the above section, POPs were found to leach out of shredder residues up to 68 times more when soaked in surfactants than when soaked in distilled water. This finding should inform any potential landfill leachate testing procedures or requirements.

The following table shows the concentrations of the PCB homologues in shredder residue leachate tested during the Sakai study.

**Table 32: PCB Concentrations Found in Leachate Tested in the Sakai Study**

Homologue	PCBs Concentration [ng/l]					
	Distilled Water	Leachate from Industrial Disposal Site	Humic Acid		LAS	
			10 mg/l	200 mg/l	10 mg/l	1000 mg/l
M.CBs	0.12	0.14	N.D.<0.1	N.D.<0.1	0.15	5.1
D.CBs	8.8	16	5.7	18	12	360
T.CBs	26	52	31	110	74	1500
T <sub>4</sub> CBs	16	28	27	91	57	900
P <sub>3</sub> CBs	8.1	15	7.5	51	28	990
H <sub>2</sub> CBs	6.9	12	6.2	38	28	650
H <sub>1</sub> CBs	2.3	2.5	1.2	7.4	9.9	130
O <sub>1</sub> CBs	0.15	0.24	0.20	1.4	0.75	23
N <sub>1</sub> CBs	N.D.<0.1	N.D.<0.1	N.D.<0.1	0.22	0.10	2.0
D <sub>10</sub> CB	N.D.<0.1	N.D.<0.1	N.D.<0.1	N.D.<0.1	0.10	0.52
Total CBs	68	130 <b>(1.91)</b>	79 <b>(1.16)</b>	310 <b>(4.56)</b>	210 <b>(3.09)</b>	4600 <b>(67.6)</b>

Source: Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in *Chemosphere*.

The Sakai study also investigated the leaching of PCDDs and PCDFs from shredder residue, and the results are shown below.

**Table 33: PCDDs/PCDFs Concentrations Found in Leachates Tested in the Sakai Study**

Homologs	Leachant	
	LAS 10mg/l	LAS 1000mg/l
T <sub>4</sub> CDDs	N.D. < 0.05	0.13
P <sub>2</sub> CDDs	N.D. < 0.05	0.08
H <sub>6</sub> CDDs	N.D. < 0.05	0.35
H <sub>7</sub> CDDs	N.D. < 0.05	0.67
O <sub>8</sub> CDDs	N.D. < 0.05	2.5
Total CDDs	N.D. < 0.05	3.7
T <sub>4</sub> CDFs	N.D. < 0.05	0.32
P <sub>2</sub> CDFs	N.D. < 0.05	0.25
H <sub>6</sub> CDFs	N.D. < 0.05	0.19
H <sub>7</sub> CDFs	N.D. < 0.05	0.18
O <sub>8</sub> CDFs	N.D. < 0.05	0.14
Total CDFs	N.D. < 0.05	1.1

Source: Sakai, S., et. al. (1998), *Leaching Behavior of Persistent Organic Pollutants (POPs) in Shredder Residues*, published in Chemosphere.

## 5.4 Landfill Leaching Behaviour of Metals Present in Shredder Residue

Information on the presence of metals and their leaching behaviour from shredder residues were gathered primarily from one study conducted in 2008.<sup>121</sup> This study's main objective was the evaluation of environmental risk due to shredder residue in landfills. Three main tests were performed on shredder residue. The first test was the German leaching test (DIN 38414-S4) utilized to determine the leaching behaviour of metals from shredder residue. The second test was the US EPA Toxicity Characteristic Leaching Procedure (TCLP) test, which was created to evaluate the toxicity of 39 compounds, with three of them being Cd, Pb and Zn. For these 39 compounds the U.S. EPA established a limit value (called NIPDWS). These values are used to evaluate the toxicity or non-toxicity of wastes. Additionally, an extraction test with acetone was performed in order to recognize metals bounded to organic matter.

The results detailed in the table below show the metal content of leachates obtained from the German DIN 38414-S4 tests. Results do not overpass the official E.U. regulations (Cd, 0.2 mg L<sup>-1</sup>; Cu, 5 mg L<sup>-1</sup>; Ni, 1 mg<sup>-1</sup>; Pb, 1 mg<sup>-1</sup> and Zn, 5 mg<sup>-1</sup>) and therefore under

<sup>121</sup> Gonzalez-Fernandez et al., (2008), *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution

those regulations ASR need not be classified from the test as a hazardous waste or a waste that needs to be landfilled. Lead, copper and cadmium are below the detection limit, and nickel exhibits detectable concentrations in the fine fractions. Zinc increases their leachability both in fine and coarse fractions. Cadmium was also included in the table because of its toxicity, its presence in the Spanish regulations, and due to the fact that it is detected in the inductively coupled plasma (ICP) analysis of TCLP tests. Lead concentration is one of the common concerns in shredder residue and the Gonzalez-Fernandez study notes that the official limit value in the E.U. is commonly exceeded.<sup>122</sup> The low release of Pb from ASR in this study was due to the final pH of the leaching test (which was always basic), ranging from 8.5 to 9.7, which disabled metal transfer to aqueous media.

**Table 34: Metal Content of Leachates  
Obtained From DIN 38414-S4 Tests  
( $\mu\text{gL}^{-1}$ )**

Fraction	Cd	Cu	Ni	Pb	Zn	pH, 24 h
1	<0.5	<30	<30	<30	175 ± 13	8.75
2	<0.5	<30	<30	<30	87 ± 10	9.71
3	<0.5	<30	<30	<30	57 ± 10	9.50
4	<0.5	<30	50 ± 10	<30	80 ± 10	9.30
5	<0.5	<30	71 ± 15	<30	63 ± 15	9.10
6	<0.5	<30	126 ± 23	<30	122 ± 22	8.55

Source: Gonzalez-Fernandez et al., (2008), *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution

The TCLP test results are detailed in the table below. The table shows the results for the bulk ASR waste and the data for different fractions of the shredder residue. This was evaluated through the use of different extractants to recover leachates from residues or wastes. The results of the study also reveal that the variability of data (as discussed in “general information on leaching characteristics of shredder residue” above) is a common aspect for the TCLP tests and among the different grain-size classes, due to the differences between different shredder residue samples.

The NIPDWS value for Cd is  $0.50 \text{ mg L}^{-1}$ . Fractions 2, 4 and 6 exhibit TCLP data for Cd not excessively far from the threshold value, and no trend was observed on grain-size fractions. Regarding Zn, the values are three to seven times below the limiting value ( $500 \text{ mg L}^{-1}$ ). The results for Pb exhibit that the gross ASR waste clearly exceeds the threshold value in the two TCLP replicates. Also fractions 1 and 4 do not accomplish the regulated limits and the results for Pb on TCLP test runs allow the classification of ASR as a hazardous waste and correction measures should be applied for the management of such residues. Cu and Ni have no limit values in the evaluation of TCLP datasets. However

<sup>122</sup> Ibid.

from a different guideline dataset for drinking water<sup>123</sup> (source was cited within the Gonzalez-Fernandez study) the limit value for Ni, from the toxicological point of view, ranges close to the value of Pb and those reported for Cu are around half of the value reported for Zn. Therefore, we can approximately evaluate the toxic potential of these two elements. From the results reported in the table below we can consider a low potential risk for Cu, whilst Ni leachates exhibit concentration values near those reported for Pb, and might be considered for risk assessment of ASR. From the reported data for TCLP and DIN tests it is noteworthy that changes in the pH of the solution in contact with ASR can change the release of metals in several orders of magnitude. The values obtained for TCLP leachate metal content are similar to those reported in another study conducted in 2006,<sup>124</sup> using shredder CPU wastes.

**Table 35: Metal Content and Final pH of Leachates Obtained From TCLP Extraction (mg L<sup>-1</sup>)**

Fraction	Cd	Cu	Ni	Pb	Zn	pH
Gross ASR replicates	0.134 ± 0.002 0.162 ± 0.002	0.200 ± 0.005 0.172 ± 0.005	1.18 ± 0.02 <0.24	2.44 ± 0.04 2.09 ± 0.02	128 ± 1 109 ± 2	5.68 5.64
1	<0.072	0.48 ± 0.02	0.410 ± 0.006	2.59 ± 0.05	68 ± 1	4.62
2	0.350 ± 0.008	0.64 ± 0.01	1.87 ± 0.02	1.36 ± 0.01	68.4 ± 0.2	5.26
3	<0.072	<0.12	0.86 ± 0.02	<0.72	125 ± 1	5.90
4	0.453 ± 0.006	0.772 ± 0.008	1.037 ± 0.009	2.43 ± 0.02	155 ± 3	5.66
5	0.154 ± 0.003	1.05 ± 0.02	1.000 ± 0.009	1.085 ± 0.007	170 ± 1	5.73
6	0.380 ± 0.009	7.0 ± 0.1	1.39 ± 0.02	0.64 ± 0.02	150 ± 2	5.20

Source: Gonzalez-Fernandez et al., (2008), *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution

The results for acetone extraction tests have been included in the next table, together with those reported for the other tests, referred to the total content of ASR, and for the comparison of metals' leachability under different conditions. Acetone extraction reported low values for the metals considered. Ni and Cu leachate concentrations are below the detection limit. On the other hand, results for Pb and Zn exhibit higher values than obtained following the official DIN method, but usually lower than those obtained by TCLP.

The results in the table below show that there is a low transfer from ASR residues to leachates. This indicates that an important fraction of the metals' is retained in the waste and is not easy to mobilise. Regarding the elemental behaviour through the extraction procedures the overall mobility of metals in ASR residues can be assessed. From all the extractions in the different ASR fractions we can observe that about 25% of Zn can be released to the surrounding environment in all the grain-size fractions. Ni results

<sup>123</sup> Reimann, C., Caritat, P., (1998) *Chemical Elements in the Environment: Factsheets for the Geochemist and Environmental Scientist*. Springer-Verlag.

<sup>124</sup> Vann, K.N., Musson, S.E., Townsend, T.G., (2006) *Factors affecting TCLP lead leachability from computer CPUs*, published in Waste Management.

demonstrate that the leaching behaviour is different in each grain-size the study considered and the release range is from 3 to 10% of the total Ni content. Only a few portion of Pb content is released from the extraction tests (0.1-1.7%). However, due to the low threshold values in regulations, Pb exceeds the limit established to be considered as a hazardous waste. Cu exhibits low percentages of leaching and irregular trend among grain-size fractions.

**Table 36: Total Metal Content of ASR Fractions (XRF, X-ray Fluorescence Analysis), Metal Content of Leachates (ICP Analysis) and Metal Leachability (Percentage From While Dry Waste) (mg kg<sup>-1</sup>)**

		Cu		Ni		Zn		Pb	
		Abs	%	Abs	%	Abs	%	Abs	%
Fraction 1	XRF	2000.00	100.00	280.00	100.00	3000.00	100.00	3900.00	100.00
	TCLP	9.60	0.48	8.00	2.86	52.00	1.70	1360.00	34.90
	ACE	30.50	1.53	<12.50	<4.50	14.50	0.50	57.50	1.50
	DIN	<0.6	<0.03	<0.6	<0.2	<0.6	<0.02	3.50	0.09
Fraction 2	XRF	2550.00	100.00	360.00	100.00	4100.00	100.00	7900.00	100.00
	TCLP	12.80	0.50	37.00	10.30	27.00	0.65	1370.00	17.30
	ACE	<25.00	<0.98	<12.50	<3.50	21.50	0.50	37.00	0.50
	DIN	<0.6	<0.02	<0.6	<0.20	<0.6	<0.01	1.75	0.02
Fraction 3	XRF	2300.00	100.00	290.00	100.00	6400.00	100.00	10,000.00	100.00
	TCLP	2.40	0.10	17.00	5.90	<15.00	<0.23	2500.00	25.00
	ACE	<25.00	<1.09	<12.50	<4.30	24.50	0.40	45.00	0.45
	DIN	<0.6	<0.03	<0.6	<0.20	<0.6	<0.01	1.15	0.01
Fraction 4	XRF	2650.00	100.00	370.00	100.00	7600.00	100.00	12,450.00	100.00
	TCLP	15.44	0.58	20.74	5.62	48.60	0.64	3100.00	24.90
	ACE	<25.00	<0.94	<12.50	<3.39	15.00	0.20	34.13	0.27
	DIN	<0.6	<0.02	1.00	0.27	<0.60	<0.01	1.60	0.01
Fraction 5	XRF	2930.00	100.00	550.00	100.00	7700.00	100.00	13,200.00	100.00
	TCLP	21.00	0.72	20.00	3.64	21.70	0.28	3400.00	25.81
	ACE	<25.00	<0.85	<12.50	<2.27	32.50	0.42	34.13	0.26
	DIN	<0.6	<0.02	1.43	0.26	<0.60	<0.01	1.26	0.01
Fraction 6	XRF	2700.00	100.00	390.00	100.00	10,200.00	100.00	11,700.00	100.00
	TCLP	140.00	5.20	27.80	7.22	12.80	0.13	3000.00	25.58
	ACE	33.00	1.23	<12.50	<3.25	15.00	0.15	39.63	0.34
	DIN	<0.6	<0.02	2.53	0.66	<0.60	<0.01	2.45	0.02

Abs, absolute values; ACE, acetone extraction.

Source: Gonzalez-Fernandez et al., (2008), *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution

The main conclusions that can be considered from the Gonzalez-Fernandez study are as follows:<sup>125</sup>

1. Dealing with the total metal content, an increase of Pb and Zn towards the finest fraction is observed whilst the other metals considered do not exhibit such clear

<sup>125</sup> Gonzalez-Fernandez et al., (2008), *Heavy Metals' Content of Automotive Shredder Residues (ASR): Evaluation of Environmental Risk*, published in Environmental Pollution

- grain-size dependence. Notwithstanding their total metal content, ASR does not overpass the threshold values for landfill disposal utilized in the E.U.
2. Mobility of metals in ASR is pH dependent, implying a potential toxic risk from variation of local conditions in a disposal site. Likewise, there is a different behaviour regarding the release of metals from extraction tests. Despite Zn being the more mobile metal of ASR, Ni exhibits TCLP leachability levels near the Pb threshold values and their release percentage is higher than Pb. Owing to the harmful effects of Ni, the values obtained in this study are enough to consider it in further studies.
  3. Although the percentage of total contained metals leaching from shredder residues is not very high, there is a high volume of ASR wastes daily produced in shredder treatment plants. Landfills that accept high volumes of shredder residue should be well sealed off to prevent the release of metals.

## 5.5 Landfill Leaching Behaviour of Brominated Flame Retardants and Polybrominated Diphenyl Ethers From Plastics

As discussed earlier in this report, between 20% and 40% of shredder residue is typically made up of plastics (both soft and rigid). While there has not been a great deal of detailed research into the leaching behaviour of shredder residue, there is an opportunity to further inform the potential leaching behaviour of shredder residue in landfills through better understanding some of the chemicals released from plastics in landfills. Brominated flame retardants (BFRs) are primarily used in plastics, such as acrylonitrile-butadiene-styrene (ABS) and high impact polystyrene (HIPS). Some BFRs are persistent, bioaccumulative, and structurally similar to polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT), and other persistent organic pollutants (POPs).<sup>126</sup> The following section primarily discusses plastics found in television housings, however these plastics can also be found in automobiles and are present in shredder residues.

BFRs are categorized as either reactive or additive, in terms of how they are integrated into the plastic product that needs to be flame retarded. Reactive combination produces plastics with covalently bonded flame retardants that are less likely to leach from the product. In contrast, additive flame retardants are simply mixed with the polymer resin and therefore are much more likely to leach from the final product. Additive BFRs may leach from landfills in high concentrations, however there have been relatively few studies on the fate of BFRs in landfills.<sup>127</sup>

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<sup>126</sup> US EPA, *Brominated Flame Retardants: Health Effects*, accessed on: June 13 2012, accessed at: [http://yosemite.epa.gov/R10/ECOCOMM.NSF/columbia/workshops/\\$FILE/Health\\_effects\\_of\\_Brominated\\_Flame\\_Retardants.pdf](http://yosemite.epa.gov/R10/ECOCOMM.NSF/columbia/workshops/$FILE/Health_effects_of_Brominated_Flame_Retardants.pdf)

<sup>127</sup> Kim, Y and Osako, M and Sakai S, (2006), *Leaching Characteristics Of Polybrominated Diphenyl Ethers (PBDEs) From Flame-Retardant Plastics*, published in *Chemosphere* 65.

The leaching process for additives in plastic wastes present in landfills is not yet fully understood. In particular, PBDEs and some other BFRs are so hydrophobic that they are not readily dissolved. Therefore their leachability could be affected by other constituents present in the leachate. For instance, dissolved organic matter in the leachate could interact with hydrophobic BFRs such as PBDEs contained in plastics to enhance their leachability. Alternatively even rainwater that penetrates landfill layers and contacts plastic wastes containing BFRs will cause relatively hydrophilic BFRs such as TBBPA to be dissolved into the leachate.<sup>128</sup>

One study was identified that isolated plastics and investigated how BFRs leach specifically from plastic (as opposed to being present in landfill leachate generally). The study was conducted in 2006, and was entitled “*Leaching Characteristics of Polybrominated Diphenyl Ethers (PBDEs) From Flame-Retardant Plastics.*”<sup>129</sup> This study conducted laboratory tests where landfill conditions were roughly simulated and plastics were soaked in simulated leachate for five days.

Four different samples representing high-impact television housing plastics were tested in this study, specifically: (i) sample 1 - ND-HIPS, was a non-DecaBDE flame retarded HIPS made up of grey pellets of approximately 2.4 mm diameter by 3 mm height; (ii) sample 2 - DB-HIPS, was a flame-retarded high-impact television housing composed mainly of DecaBDE, made up of black pellets of around 2.4 mm in diameter by 3 mm in height; (iii) sample 3 - RC-TV, was a mixture of roughly-cut actual television housings; and (iv) sample 4 - WC-TV, was well crushed samples of the preceding sample. Samples 3 and 4 were composed of front and back covers of television housings manufactured by three companies in 1992 and 1996.

The four plastic samples were analyzed for PBDEs before being soaked in leachate. The table below identifies the amount of PBDEs and antimony (Sb) (another additive used in conjunction with PBDEs as part of a flame retardant system for plastics) detected in the samples, broken down by individual congener. While many of these congeners are present in minor amounts in the main commercial PBDE mixtures, it is not surprising that the main ingredients in DecaBDE (N9BDE and D10BDE) were the most commonly found PBDEs in these tests. This is attributed to the fact that DecaBDE was the most common flame retardant used in television housings until the mid-2000s.

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<sup>128</sup> Osako, O and Kim Y-J and Sakai S, (2004), *Leaching Of Brominated Flame Retardants In Leachate From Landfills In Japan*, published in Chemosphere.

<sup>129</sup> Kim, Y and Osako, M and Sakai S, (2006), *Leaching Characteristics of Polybrominated Diphenyl Ethers (PBDEs) From Flame-Retardant Plastics*, published in Chemosphere.

**Table 37: Concentration of Antimony and PBDE Homologues in Four Plastic Samples Subjected to Simulated Landfill Leachate**

	Unit	ND-HIPS	DB-HIPS	RC-TV	WC-TV
M1BDEs	µg/g	<0.05	<0.05	<0.05	<0.05
D2BDEs	µg/g	<0.05	<0.05	<0.05	<0.05
T3BDEs	µg/g	<0.05	<0.05	<0.05	<0.05
T4BDEs	µg/g	<0.05	<0.05	<0.05	<0.05
P5BDEs	µg/g	<0.1	<0.1	<0.1	<0.1
H6BDEs	µg/g	<0.1	2	2	2
H7BDEs	µg/g	<0.2	3	3	2
O8BDEs	µg/g	<0.2	12	51	33
N9BDEs	µg/g	<0.3	4200	5900	3600
D10BDE	µg/g	1.0	21000	18000	21000
PBDEs	µg/g	1.0	25000	24000	25000
Sb	µg/g	32000	32000	27000	29000

Source: Kim, Y and Osako, M and Sakai S, (2006), *Leaching Characteristics Of Polybrominated Diphenyl Ethers (PBDEs) From Flame-Retardant Plastics*, published in Chemosphere.

One of the objectives of this study was to confirm that PBDEs would leach out of plastic when exposed to certain chemicals (that are often present in landfill leachate) at a greater rate than if the plastics were simply exposed to water. The table below clearly demonstrates this to be the case, with both the 20% methanol and dissolved humic matter solution causing far higher leaching rates of BFRs than water.

This study therefore demonstrates that PBDEs and other BFRs are likely to leach out of plastics at relatively high rates in landfills due to the properties of landfill leachate.

**Table 38: Concentrations of PBDE Homologues in Leachate Recovered Using Three Different Leachant Solutions Tested With Four Different High-Impact Plastics (ng/l)**

Leachant Sample	Distilled water				20% Methanol				Dissolved humic solution of 1000 mg-OC/l			
	ND-HIPS	DB-HIPS	RC-TV	WC-TV	ND-HIPS	DB-HIPS	RC-TV	WC-TV	ND- HIPS	DB-HIPS	RC-TV	WC-TV
M1BDEs	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
D2BDEs	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.064	0.082	<0.005	0.14	0.035	<0.005
T3BDEs	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.70	0.67	<0.005	<0.005	0.21	0.10
T4BDEs	<0.005	<0.005	0.013	<0.005	<0.005	<0.005	1.8	0.31	0.040	0.12	0.75	0.38
P5BDEs	<0.01	<0.01	<0.01	<0.01	<0.01	0.036	0.82	2.6	0.033	0.057	0.29	0.17
H6BDEs	<0.01	<0.01	<0.01	<0.01	<0.01	0.53	1.5	22	<0.01	0.31	0.54	0.76
H7BDEs	<0.02	<0.02	<0.02	<0.02	<0.02	0.20	31	100	0.019	0.18	3.3	1.5
O8BDEs	<0.02	<0.02	0.12	0.33	1.3	3.6	340	2100	0.32	2.5	23	11
N9BDEs	1.0	4.4	27	140	25	1600	12000	13000	24	340	560	1000
D10BDE	0.21	2.8	17	77	8.9	4600	4000	7600	10	150	98	210
PBDEs	1.2	7.2	44	220	35	6200	16000	23000	34	490	690	1200

Source: Kim, Y and Osako, M and Sakai S, (2006), *Leaching Characteristics Of Polybrominated Diphenyl Ethers (PBDEs) From Flame-Retardant Plastics*, published in Chemosphere.

## 5.6 Conclusions

Shredder residue can contain potentially harmful substances such as metals, PBDEs, BFRs, PCDDs, PCDFs, PCBs and other POPs. Landfill leachate can have characteristics which cause these substances to leach out of shredder residue at increased rates, higher rates than would occur if the shredder residue was left sitting in water or was otherwise not exposed to leachate. While the substances present in shredder residue, and the constitution of leachate can vary widely, many of the POPs and other substances that can leach out of shredder residue (at increased rates due to exposure to leachate) are potentially damaging to the environment and human health."

## 6. Potential Technologies/Applications for the Beneficial Use of Shredder Residue

### 6.1 Introduction

Within this chapter, the range of post-shredder technologies/options for ASR are discussed across the following categories:

- physical and mechanical upgrading of ASR;
- ASR direct to energy processes;
- thermochemical treatment of ASR to produce fuels; and
- incorporation of ASR into manufactured products.

### 6.2 Physical and Mechanical Upgrading of ASR

#### 6.2.1 Introduction

The physical and mechanical upgrading of ASR can be seen as an extension of the shredding process. Recovery of all recyclable materials from ASR in a single step is not feasible due to its heterogeneity. The various post-shredder technologies that have been developed are designed to treat the residual material stream remaining after de-pollution, dismantling and shredding of an ELV. In currently operating technologies, the applied techniques to separate and concentrate the different types of materials are similar - air classification, magnetic and eddy current separation and screening or trommel separation.<sup>130</sup>

The largest difference among post-shredder technologies stems from the techniques used for the separation of plastics. Different steps of float/sink separation are most commonly used, as this is a well-established technique for the separation of mixed plastics, where the density differences of the plastics makes them respectively sink or float in a tank filled with a liquid of suitable density. Other techniques for plastic separation, not (only) exploiting the difference in density, have been developed and applied in several post-shredder technologies, for instance froth flotation, thermo-mechanical sorting or static hydrodynamic separation.<sup>131</sup>

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<sup>130</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>131</sup> Ibid.

It has been suggested that increasing the recycling of plastics from ASR is key to achieve the European reuse and recycling target of 85% by 2015, as it is expected that in this way an additional 6-10% of the total ELVs mass can be recycled. The quality of the recycled plastics remains a major issue in this context. Plastics should however not only be separated and recycled because of their intrinsic value - their occurrence can also cause problems in some subsequent treatment methods. For instance in pyrolysis, polyurethane is difficult to crack, PVC can contaminate the pyrolysis gas with methylchloride, rubbers form tars and major quantities of a carbonaceous residue, whereas polyethylene and polypropylene tend to form waxes.<sup>132</sup>

Outlined in the table below is a summary of the major technologies that have been developed for the physical and mechanical separation/upgrading of ASR. Separate sections are subsequently provided to discuss these and other similar technologies.

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<sup>132</sup> Ibid.

**Table 39: Overview of Major Post-Shredder Technologies**

Name of Technology Developer→	Argonne	Galloo	MBA Polymers	Salyp	Stena	WESA- SLF	VW-Sicon
Process							
Separation Techniques							
Air Classification	X	X	X	X	X	X	X
Magnetic Separation	X	X	X	X	X	X	X
Eddy Current Separation	X	X	X	X	X		X
Screening		X		X	X	X	X
Trommel Separation	X	X		X	X		
Optical Sorting				X			X
Manual Sorting					X		
Drying						X	
Float/Sink Separation		X		X	X		X
Froth Flotation	X						
Thermo-mechanical Sorting				X			
Wet Grinding			X				
Hydrocyclone			X				
Static, Hydrodynamic Separation Tanks		X					
Heavy Media Separation					X		
Status of Development	Operating Plants	Operating Plants	Operating Plants	Operating Plants	Operating Plants	Operating Plants	Operating Plants
Overall Recovery Rate	90% of polymers >6 mm 90% of metals >6 mm	90%	Not Given	86%	80%	92%	95%

Source: Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

## 6.2.2 Argonne National Laboratory<sup>133/134</sup>

The Argonne National Laboratory in the U.S. has developed a physical separation process for shredder residue as well as separate technologies to recover materials from separated shredder residue. One of these technologies has been designed to recover flexible polyurethane foam, while another technology has been developed to recover plastics. The main benefits of the Argonne process include:

- saving raw materials by recycling plastics from the waste stream;
- capable of processing polymer concentrate with mixed wood and rubber fractions;
- reduces greenhouse gases and uses no hazardous materials;
- recovered plastics are a fully compatible replacement for virgin plastics;
- using recycled instead of virgin plastics results in cost savings over 25%; and
- manufacturers can purchase plastics recovered from the Argonne process for half the cost of virgin plastics.

Argonne's physical separation and recovery technologies are described below.

### 6.2.2.1 Physical Separation Process for Shredder Residue

The physical separation concentrates the shredder residue into four fractions - foam, ferrous and non-ferrous metals, polymers, and fines. Larger pieces of metals, rocks, and foam are screened by a trommel separator and separated from the residue stream. The remaining shredder residue is then shredded to smaller pieces and put into a two-stage trommel. Small particulates are removed first and in the second stage a fraction containing plastics, rubber, residual metals, and small foam pieces falls through the slots in the trommel. A larger fraction consisting mainly of polyurethane foam exits the trommel and is passed over a magnetic pulley and an eddy current separator to recover residual ferrous and non-ferrous metals. The polymer-rich fraction is treated in the same way to recover and separate residual metals. The polymer-rich fraction is then granulated to an average particle size of 0.5-1 cm and put on a vibrating screen for further processing. The cyclone and air classification removes small residual polyurethane pieces, dust, and other fines.

The fractions recovered from the mechanical separation process are all able to be reused or recycled in some way. The figure below shows the material flow of 10,000 pounds of ASR in Argonne's mechanical separation plant. The bulk separation of the residue results

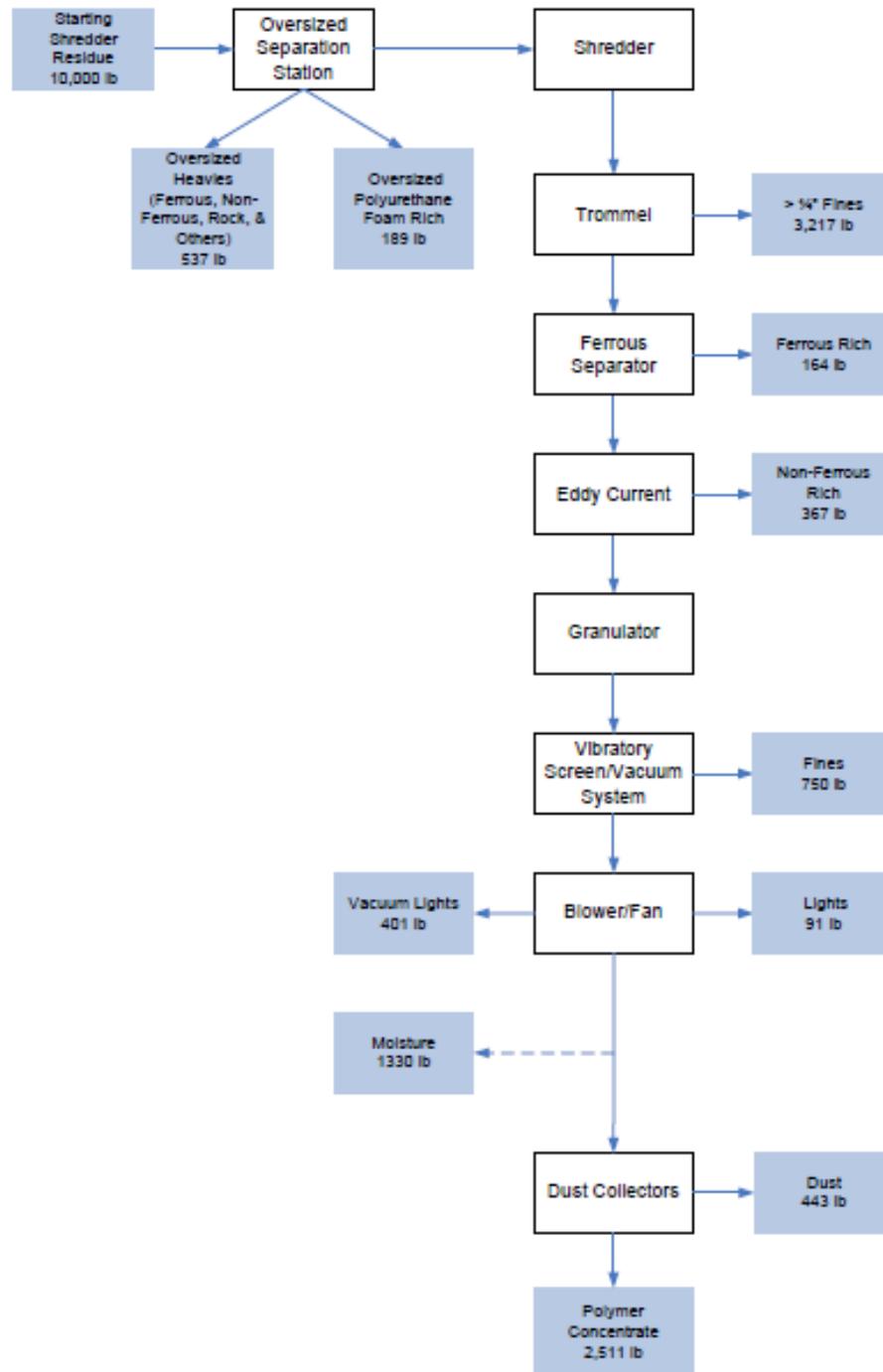
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<sup>133</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>134</sup> Moakley, J., et. al. (May, 2010), *An Evaluation of Shredder Waste Treatments in Denmark – Alternative Methods to Landfilling Auto Shredder Residue in Compliance with the Strict Environmental Quota by the European Union*.



in a polymer concentrate that is about 45% of the ASR weight and 10% by weight polyurethane foam fraction. The remaining 45% by weight is grouped into an oxides fraction and includes metals, small pieces of glass, dirt, and some organics. Argonne has a patented polyurethane foam cleaning system (see further description below) which allows for the use of the foam in producing carpet padding for automobiles. The oxide fraction has use in the cement industry. The polymer concentrate is processed at the froth flotation plant (see further discussion below) to recover and separate the plastics.



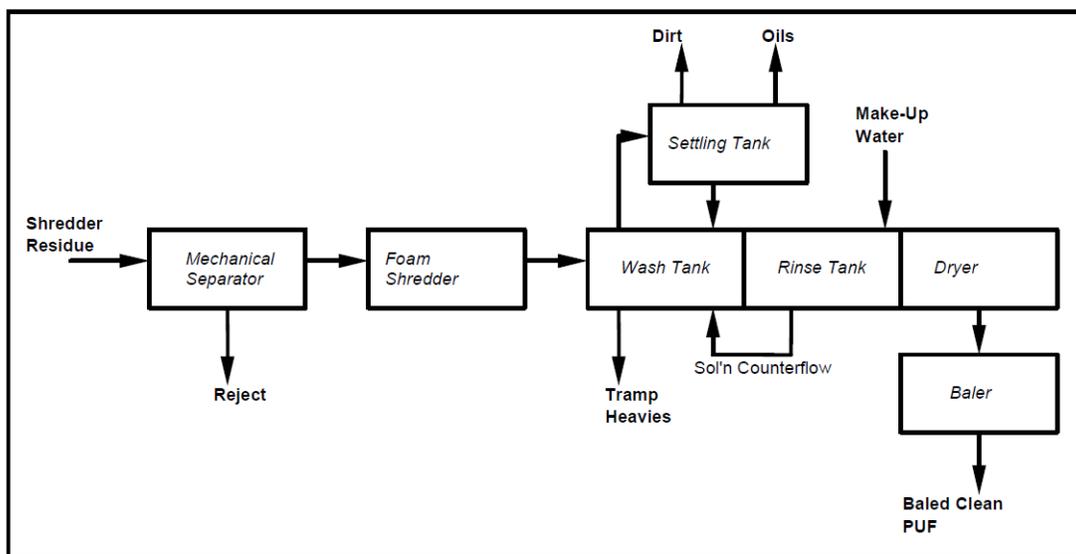
**Figure 2: Material Flow Sheet of the Argonne Mechanical Separation Plant Based on 10,000 Pounds of Shredder Residue**

Source: Moakley, J., et. al. (May, 2010), *An Evaluation of Shredder Waste Treatments in Denmark – Alternative Methods to Landfilling Auto Shredder Residue in Compliance with the Strict Environmental Quota by the European Union.*

### 6.2.2.2 Recovery of Flexible Polyurethane Foam

Argonne National Laboratory has developed a continuous process for the recovery of flexible polyurethane foam from shredder residue. Economic analysis of the process indicates a potential payback of less than two years for a plant producing about 1,000 tons/year of foam. Samples of clean foam produced through the process were shipped to three major foam processors, all of which indicated that the quality of the recovered foam met their requirements. In addition, tests of the recovered foam by an independent testing laboratory showed that the recycled foam met the specifications for several automotive applications, including carpet padding, headliner, and sound-suppression support materials. The acoustic performance of the recycled foam was equivalent to that of the conventional fiber pad.

The Argonne process consists of two parts, specifically the separation of the foam from the shredder residue and subsequently the cleaning of the foam once it was recovered. The overall process consists of six basic unit operations: (i) shredder residue screening and polyurethane foam recovery; (ii) sizing; (iii) washing; (iv) rinsing; (v) drying; and (vi) baling.



**Figure 3: Block Flow Diagram of the PUF Recovery Process**

Source: Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

Up to 50% of the weight of the foam (approximately 30%, on average), as recovered from shredder residue, is made up of moisture, entrained dirt, sand, automotive fluids, metal dust, metal oxides, and other contaminants. The heart of the Argonne system is patented linear continuous washing, rinsing, and drying equipment which essentially

consists of three linear conveyors. In each of the three conveyors, the foam is compressed sequentially and released to mechanically assist in the washing, rinsing, and drying of the foam. The residence time for drying the foam in this equipment is less than 15 minutes, while in the conventional rotary drum dryer, drying time is over 3 hours. The pilot plant also included a continuous ultra-filtration unit to remove oils and fine dirt particles that may be suspended in the wash water from the wash tank. This step was necessary to keep the water in the wash tank clean. Approximately two barrels of oily wastewater would be produced each day and would have to be disposed of by a waste handler.

### **6.2.2.3 Recovery of Plastics**

Argonne National Laboratory has developed two processes for the recovery of individual plastics from shredder residue: (i) froth flotation; and (ii) selective dissolution.

The basic principle of froth flotation is to place the plastics mixture in a solution that can selectively enhance or retard the hydrophobicity or hydrophilicity of one or more of the targeted plastics, so they can be separated from the mixture. One part of the polymer concentrate sinks while the other floats, thus enabling simple separation. Since ABS and HIPS have the same density, surface modification is used to enable air bubbles to attach to the hydrophobic HIPS molecules, thus lowering their apparent density and causing them to float while the hydrophilic ABS molecules sink. Therefore, HIPS molecules are easily separated from the ABS fraction. The recovery of pure fractions allows for the recycling of plastics into reusable products for the automobile industry instead of using virgin plastic materials.

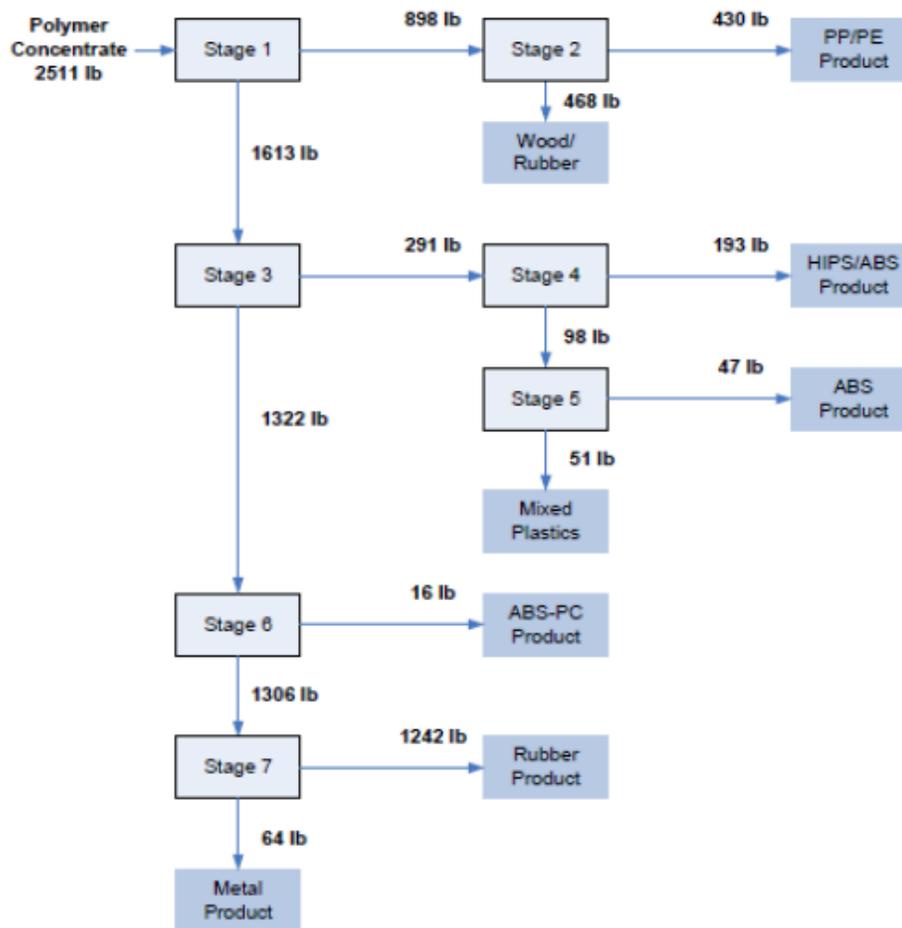
The flotation process consists of six main steps:

1. separate the polymers as a concentrate from shredder residue.
2. granulate the polymer concentrate to a particle size of 1/4–3/8 inch.
3. concentrate the plastics targeted for recovery from the polymer concentrate into more manageable fractions with a minimal number of species in each fraction.
4. recover targeted plastics from the concentrated fractions.
5. polish the recovered targeted species to increase purity, value, and marketability.
6. clean the plastics products.

Steps 3 through 6 consist of the following operations after the polymer concentrate is granulated to the appropriate particle size:

1. Separation of the “light” materials, including polyolefins. The conditions in this stage of the process can also be set to force over 90% of the wood to float with “lights,” so that it can be dealt with only once. This fraction contains appreciable amounts of different rubber species.

2. Separation of the “heavies,” such as metals, glass, rocks, rubber, and glass-filled nylons from the sinkers of step 1.
3. Separation of the polyolefins from the “lights” produced in step 1.
4. Separation of ABS, ABS/PC, PC, PS, PVC, and other plastics from the floaters of step 2.
5. Washing of the plastics concentrate produced by the mechanical separation process to remove dirt and contaminants.



**Figure 4: Material Flow Sheet of the Argonne Plastic Separation Plant Based on 10,000 lb of Shredder Residue**

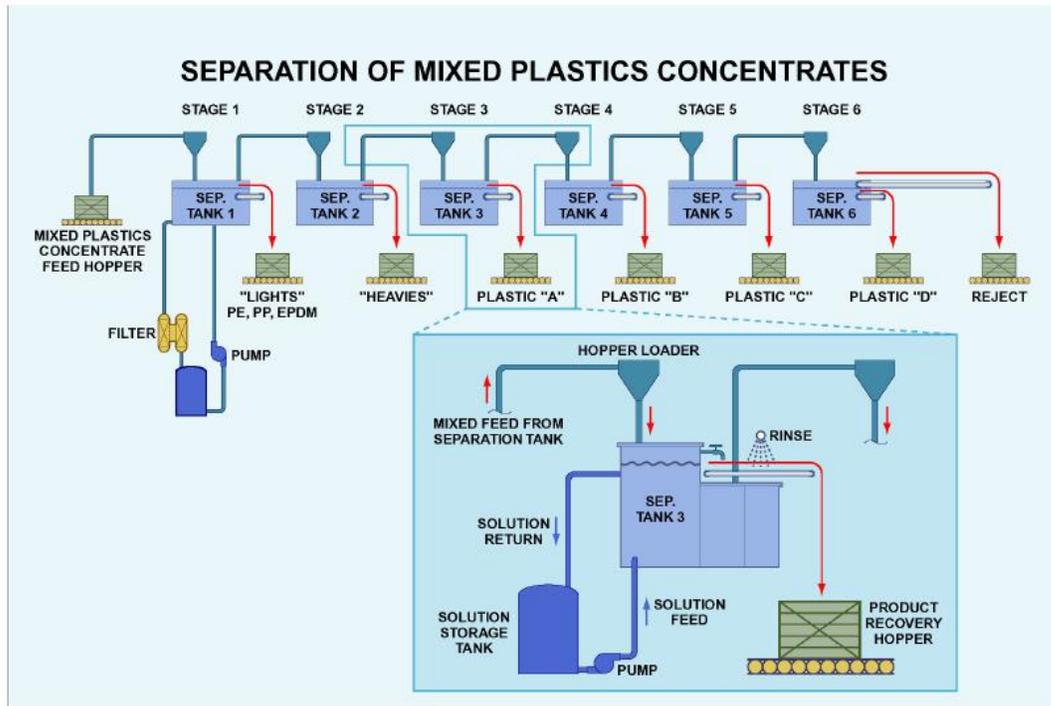
Source: Moakley, J., et. al. (May, 2010), *An Evaluation of Shredder Waste Treatments in Denmark – Alternative Methods to Landfilling Auto Shredder Residue in Compliance with the Strict Environmental Quota by the European Union.*

The main fractions recovered from the process are polypropylene, polyethylene, acrylonitrile butadiene styrene, and high-impact polystyrene. The polypropylene and polyethylene

fractions are recovered at a greater than 90% yield and are more than 95% pure. The properties of the pure and clean plastic fractions have been proven to be very similar to the properties of various grades of commercially marketed virgin materials. Thus the fractions have been successfully used to make spare tire covers, steering column covers, battery trays, and knee bolsters.

Argonne built a six-stage 1,000-lb/hour pilot plant to test the froth flotation process. The plant has been used to process about 20,000 pounds of polymer concentrate from shredder residue. Argonne produced a polyolefin (PP and PE) product and a rubber-rich fraction. Solution conditions for the recovery of other plastics are being tested. The plant was also used to process scrap plastics from electronics, home appliances, and floor care equipment. About 5,000 pounds of PP/PE have been produced. This fraction contains >95% PE and PP. Samples of the recovered PP/PE fraction were analyzed to determine its physical properties. The main impurity in the recovered material is rubber. Overall, the properties of the recovered sample compare well with those of commercially available olefinic polymers. Interestingly, removing the rubbery impurities, most of which are EPDM-based, did not have a big impact on overall properties. Larger samples of the recovered PP/PE material were mixed with recycled PP (PP regrind) copolymer (25% recovered and 75% regrind) and pelletized in standard equipment. The test led to the following observations:

- This initial test proved that an excellent pellet can be made by blending the recovered material with regrind that is presently being recycled.
- The general appearance of the final pellet was excellent. The supplemental material was black, which produced an excellent black pellet (no additional colors were visible).



**Figure 5: Schematic Diagram of Argonne's Froth Flotation Pilot Plant**

Source: Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

The Argonne process also recovered a filled ABS concentrate (70% ABS), an unfilled ABS/PS concentrate (60% ABS and PS), and a PC-ABS/PC concentrate (85%). Laboratory tests showed that these fractions can be upgraded to >90% purity. The basic Argonne process also produced a rubber fraction that was over 80% mixed rubber. The remainder of that fraction was made of mixed heavier plastics and a small amount of wood. Samples of this material were being tested to evaluate their suitability as construction materials.

Argonne's technologies have been licensed to Salyp in Belgium where a successful full-scale commercial demonstration plant is in operation.

### 6.2.3 Galloo

Galloo, headquartered in France, operates a number of materials recycling facilities, including 15 shredder operations throughout France and Belgium. Galloo has developed a process that includes bulk separation of shredder residue to recover residual metals and

plastics in the shredder residue. This process has been implemented at three of their sites. The basic steps in Galloo's process are as follows:<sup>135</sup>

1. shredder residue is ground to an average particle size of about 25 mm (1 inch).
2. a series of mechanical separation processes (including trommels and air classifiers) are used to produce a plastics concentrate.
3. a series of density separation stages are used for further separation. These include stages at specific gravities of 1.6, 1.25, 2.2, and 3.2.
4. proprietary gravity separation processes are used to separate plastics having specific gravity values between 0.9 and 1.5.

The outputs from the bulk separation of shredder residue after residual metals are recovered include the following fractions:<sup>136</sup>

- mineral fraction (40%) — currently disposed of in landfills, but reportedly being evaluated for road construction.
- light fraction (30%) — primarily foam and textiles; Galloo is working with an automotive company to investigate the feasibility of using this fraction for exterior sound insulation. Use of this material for interior applications would require that the material be cleaned to remove residual oils and other automotive fluids that are typically absorbed onto this material during the primary shredding operation.
- heavy combustible fraction (15%) — primarily rubber, wood, and other polymers; this fraction has a relatively high calorific value mainly because of the rubber content. This material has been used as a cement kiln fuel, but the market is limited because of the availability of other lower cost (higher value) fuels to the cement industry, such as waste solvents.
- plastics fraction (10%) — the plastics fraction from the three sites is apparently processed in a wet separation system.
- remaining residues (5%) — this fraction contains PVC, non-ferrous metals, and stone and rock. This fraction is processed in a heavy-media separation plant to recover the non-ferrous metals. Stone and rock are used in road construction, and the residual is disposed of in landfills.

The plastics fraction collected from the three bulk separation processing sites is sent to the Galloo Plastics recycling unit in France which has a commercial process for recovering polyolefins (i.e. polypropylene and polyethylene) as well as some polystyrene and ABS. Density and gravity separation processes are used to separate the different plastics fractions. To recover the polyolefin and polystyrene fraction, "static hydrodynamic" separation tanks are used and the recovered plastics fractions are then compounded and pelletized. Special filters are in place to eliminate residual contaminants and clean the plastic fractions. Based on

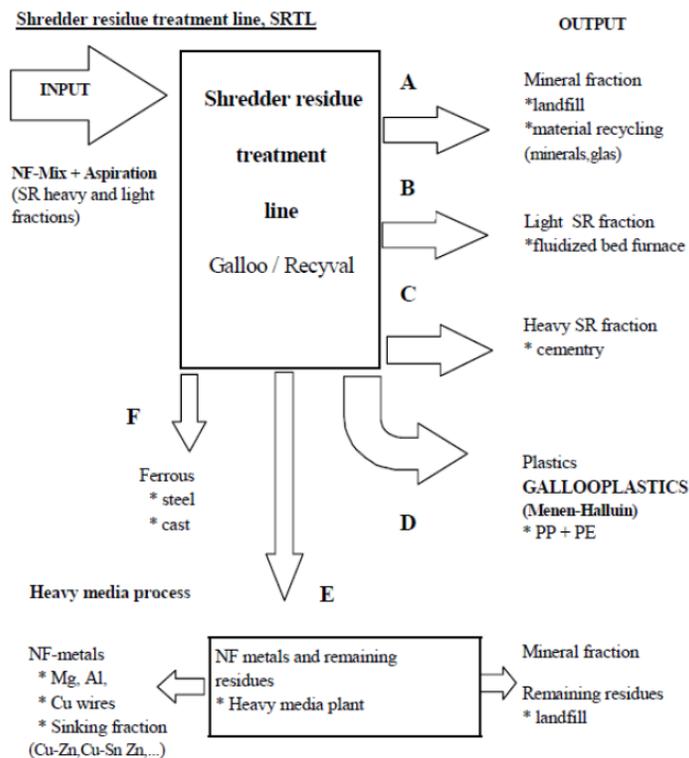
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<sup>135</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>136</sup> Ibid.

a 2002 test performed with 200 Peugeot and Renault vehicles, the Galloo Plastics process can recover about 50% of the polyolefin fraction.<sup>137</sup>

Galloo has stated that it plans to expand its plastics recovery process to recover other automotive plastics. The Galloo plastics recovery plant produces an estimated 20,000 tons/year of polyolefin pellet — all of which is consumed by Peugeot Citroen. The market for the polystyrene pellet has not been disclosed. Recovered polypropylene from the Galloo process is used in making wheel wells and battery cases for Peugeot vehicles.



**Figure 6: Galloo Shredder Residue Treatment Line**

Source: Moakley, J., et. al. (May, 2010), *An Evaluation of Shredder Waste Treatments in Denmark – Alternative Methods to Landfilling Auto Shredder Residue in Compliance with the Strict Environmental Quota by the European Union.*

### 6.2.4 MBA Polymers

MBA Polymers (located in Richmond, California) has developed a commercial-scale process employing physical and wet-density (froth flotation) separation techniques that focus on the recovery of recyclates from manufacturing scrap and from post-consumer electronic and appliance plastics concentrate. MBA Polymers has conducted research and

<sup>137</sup> Moakley, J., et. al. (May, 2010), *An Evaluation of Shredder Waste Treatments in Denmark – Alternative Methods to Landfilling Auto Shredder Residue in Compliance with the Strict Environmental Quota by the European Union.*

large-scale test runs on recovering post-consumer automotive plastics from shredder residue and from mixed plastics recovered in dismantling field trials. MBA Polymers conducted an 18,000-kg trial using plastics concentrates from Salyp. MBA Polymers processed the material on its pilot lines in Richmond, California. Five materials grades were recovered: (i) polyolefin “A”; (ii) polyolefin “B”; (iii) filled polypropylene; (iv) ABS; and (v) HIPS. Therefore the technology has been proven to be able to separate polyolefins, ABS and HIPS from plastics concentrate. The total yield of these products was estimated to be about 48.5% of the plastics-rich polymer concentrate. This yield is approximately 88% of the amount of these plastics predicted from characterization of the feed material. The products were characterized and extruded on a small laboratory extruder and subsequently molded and tested. The properties of the recovered plastics were reported to be “encouraging.” It is expected that most of the products could be used in some type of durable good applications without modification. The company has recently established two joint ventures on the basis of its plastics separation technology - one plant is operating in China and another one is in Austria.<sup>138/139</sup>

## 6.2.5 Salyp

Salyp NV (a Belgian company) developed a process to mechanically separate shredder residue to produce a polymer concentrate, followed by: (i) thermoplastics sorting for recovery of plastics from the plastics concentrate; and (ii) polyurethane foam cleaning for foam recovery. Salyp built a pilot plant, which operated for about a year. The basic Salyp process consists of the following steps:<sup>140</sup>

1. The shredder residue is conveyed to a two-stage trommel. In the first stage, fines (<1/4 inches) are removed. In the second stage, thin planar and semi-planar pieces are removed through slots. This fraction consists primarily of plastics, rubber, some metals, and some small foam and fiber pieces.
2. Oversized material exits the trommel. This material consists primarily of flexible polyurethane foam and contains some fabrics, fibers and plastics that are generally larger than what can fit through the trommel’s slots. It also contains some metals.
3. The oversized material is passed over a magnetic pulley to recover the ferrous metals and over an eddy current separator to recover the non-ferrous metals.
4. Foam is recovered from the oversized material.
5. The fraction that passes through the slots, which is the polymer-rich fraction, is also passed over a magnetic pulley to recover the ferrous metals and over an eddy current separator to recover non-ferrous metals.

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<sup>138</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>139</sup> Moakley, J., et. al. (May, 2010), *An Evaluation of Shredder Waste Treatments in Denmark – Alternative Methods to Landfilling Auto Shredder Residue in Compliance with the Strict Environmental Quota by the European Union*.

<sup>140</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

6. The de-metalized polymer-rich material is then granulated to an average particle size of about 5/8 inch and processed on a vibrating screen to remove fines and an air classifier to remove residual polyurethane foam pieces, dust, and other lights.
7. Wood is removed from the granulated material by using an optical (colour) sorter.
8. The material is then washed, and in the process, some of the heavy plastics, residual metals, and glass are removed.

Tests were conducted on the Salyp process for the automated recovery of plastics from shredder residue. One hundred tons of shredder residue was supplied by three different shredders. The tests demonstrated that a clean and wood-free plastics concentrate can be produced by mechanical separation.<sup>141</sup>

Salyp has also conducted work on developing a thermoplastics-sorting system using infrared energy to heat and dry a washed stream of mixed thermoplastics. The mixed plastics are irradiated until one type of plastic in the mix is softened, but not melted. Following the heating stage, the mixed-plastic stream is fed through a set of rollers. The softened plastic sticks to the roller and is removed from the stream. The remaining plastics continue through the process and move to the second heating stage, during which another plastic is selectively softened and removed. The remaining mixture moves to the next stage and so on until, theoretically, all desired plastics are separated. However, when this process was applied to mixtures of plastics derived from shredder residue, the purity was unacceptably low. Part of the reason for low purity is that the number of plastic species in the mixture was large and the softening temperatures of some of these plastic species overlapped.<sup>142</sup>

Salyp also licensed the Argonne technology for cleaning polyurethane foam. A full-scale (500-lb/hour) system for cleaning foam from shredder residue was installed at Salyp's facility in Belgium. Salyp was able to recover a relatively clean polyurethane foam product from shredder residue. The production capability of the equipment met design throughput expectations.<sup>143</sup>

#### 6.2.6 WESA-SLF<sup>144</sup>

In this process the shredder residue is separated into three size fractions: (i) fine (<1.2 mm); (ii) middling (>1.2 mm but <7 mm); and (iii) oversized (>7 mm). The oversized material is then reduced to less than 20 mm, and a magnet is used to recover ferrous metals. The shredded material is then reduced to <7 mm and combined with the middling fraction (<7 mm) and dried to less than 2% moisture. The dried material is air classified to separate foam and fluff, screened in a multi-level sieve, and then separated into three fractions - copper, minerals and mixed metals, and organic materials. Ferrous metals are

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<sup>141</sup> Ibid.

<sup>142</sup> Ibid.

<sup>143</sup> Ibid.

<sup>144</sup> Ibid.

also recovered from the mixed-metals fraction by using a magnet. A 4-ton per hour plant has been built in Germany.

### 6.2.7 VW-SiCon<sup>145</sup>

A mechanical separation process for shredder residue has been developed by the German company SiCon GmbH (in partnership with Volkswagen). The VW-SiCon process employs a multitude of mechanical treatments. After magnets remove the ferrous fraction and the residual non-ferrous metals are also removed from the ASR, the remaining residue stream undergoes a combination of crushing, chopping, hammering, blowing, mixing, screening and separation. This ensures that the ASR is separated according to optical characteristics and properties such as density, particle size and shape, and magnetic content. This process results in the generation of a separate plastic granule, fiber, and sand fraction, which are then transported in plastic tubes to refinement units.

Agreements are in place with various companies and plants so sale of the fractions generated by the VW-SiCon process is assured. The recovered metal fractions are sold to smelters. Meanwhile non-metallic end-products of the process include hard plastics and rubber in the shredder granules fraction, foams and textile fibers in the shredder fibers fraction, and glass, rust, iron particles, and heavy metals in the shredder sand fraction.

The shredder granulate is a mixed plastics fraction that has a low chlorine and metal content. Thus, it can be used instead of heavy oil as a reducing agent in blast furnaces. In addition, the polyfloat technology (see below) allows for the separation of the mixed plastics and further use as a raw material for making new plastics products. The plastics can also be manufactured into a fuel that burns with the same calorific value as pulverized coal. The shredder fibers fraction is a mix of textile fibers and seat foam that is mainly used instead of coal dust to filter sewage sludge or as a reducing agent. Research has also shown that the properties of the fraction may allow the use of fibers as a substitute fuel. The shredder sand fraction makes up a substantial fraction of the ASR and includes glass, fine iron particles, rust, fine copper wires, and dust. The fraction can be used in metallurgical applications, to fill old mine shafts or as a building material for landfills. A potential use being researched involves separating the shredder sand fraction at high temperatures. The sand melts while oil and other contaminants burn. This leaves residual metals and melted black glass, which can be used in countertops and floors. Overall the SiCon system can recover 80% of shredder residue and the process has been suggested to be environmentally friendly since it does not use any water.

The joint venture with Volkswagen started in 1998, when VW chose SiCon's system for mechanical processing of shredder residue. The first full-scale commercial plant using the

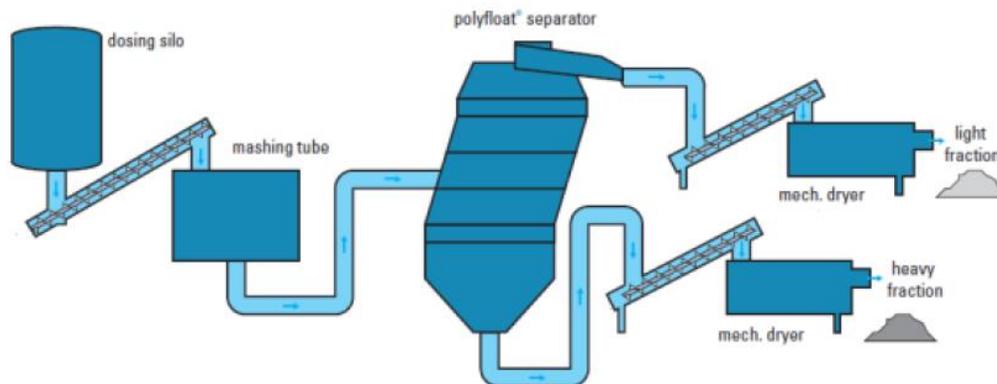
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<sup>145</sup> Moakley, J., et. al. (May, 2010), *An Evaluation of Shredder Waste Treatments in Denmark – Alternative Methods to Landfilling Auto Shredder Residue in Compliance with the Strict Environmental Quota by the European Union*.

VW-SiCon technology was opened in Belgium in 2005. Plants are now in operation in Germany, Belgium, Austria and France, with a combined capacity of over 200,000 tonnes of shredder residue/year (and likely additional plants have been constructed recently). The SiCon technology was also being installed at a new plant in the Netherlands, which was expected to start full operation in 2011, with a capacity of 100,000 tonnes/year. Recently, SiCon joined with Green EnviroTech and Thar to implement the technology in the U.S.<sup>146</sup>

In addition to the VW-SiCon process, SiCon is developing other shredder residue treatment processes including FinesTuning for treating the SLF sieve fraction, ReEnvision for the production of hydrogen and syngas from shredder residue, and polyfloat to separate plastics fractions.

The polyfloat technology allows for the separation of mixed plastics and further use as a raw material for making new plastic products. The technology separates plastic fractions based on density by using a fluid density system. The plastics are 99% pure and the fraction yields are over 98%. The company builds polyfloat turnkey systems up to 5,000 kg/hour that include storage, feeding, drying, and electronic control.



**Figure 7: Polyfloat Process Overview**

Source: Moakley, J., et. al. (May, 2010), *An Evaluation of Shredder Waste Treatments in Denmark – Alternative Methods to Landfilling Auto Shredder Residue in Compliance with the Strict Environmental Quota by the European Union.*

<sup>146</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue.*

## 6.2.8 Other Physical and Mechanical ASR Separation Processes

### 6.2.8.1 *Recovery Plastics International*

Recovery Plastics International (RPI) has developed a physical and wet “skin-flotation” process for the separation of plastics from shredder residue. As opposed to froth-flotation technology, skin-flotation technology uses a plasticizer to modify the surface of certain plastics, which would then allow the modified plastics to be selectively recovered. Large-scale pilot runs were conducted at RPI’s Salt Lake, Utah facility. RPI was reportedly able to recover a polyolefin fraction that met specifications for non-appearance automotive parts. Chrysler Corp. used materials supplied by RPI in the production of Chrysler’s CARE cars to demonstrate the feasibility of using recycled plastics in automotive applications. RPI was reportedly able to effectively recover polyolefins from its facility with a residual PCB concentration of less than 2 ppm.<sup>147</sup>

### 6.2.8.2 *Toyota*

Toyota began development of technology for recycling shredder residue in 1993. In 1998, the first Toyota shredder residue recycling plant went on-line, and it had a design capacity of approximately 15,000 ELVs per month. In 2000, the plant demonstrated an overall vehicle recycling rate of 90%. In 2002, Toyota constructed a recycle/recovery pilot plant and has been conducting pilot experimentation to establish new recovery technologies for shredder residue. Processes developed by Toyota include: (i) dry separation of shredder residue; and (ii) production of soundproofing products from polyurethane foam and fabrics.<sup>148</sup>

### 6.2.8.3 *Scholz AG*<sup>149</sup>

Scholz AG developed a high-tech post-shredder technology that is being utilized at their Leipzig-Espenhain plant in Germany. The post-shredder technology has been in operation since 2005. The Scholz plant classifies the heavy shredder fraction as mainly consisting of non-magnetic metals, metal-bearing composites, and plastics composites. The light shredder fraction is classified as including fibrous material, paints, polyurethane foams, plastics, rubber, and glass. A test in 2008 shredded ELVs, resulting in the generation of 110 tonnes of the light shredder fraction and 145.6 tonnes of the heavy

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<sup>147</sup> Ibid.

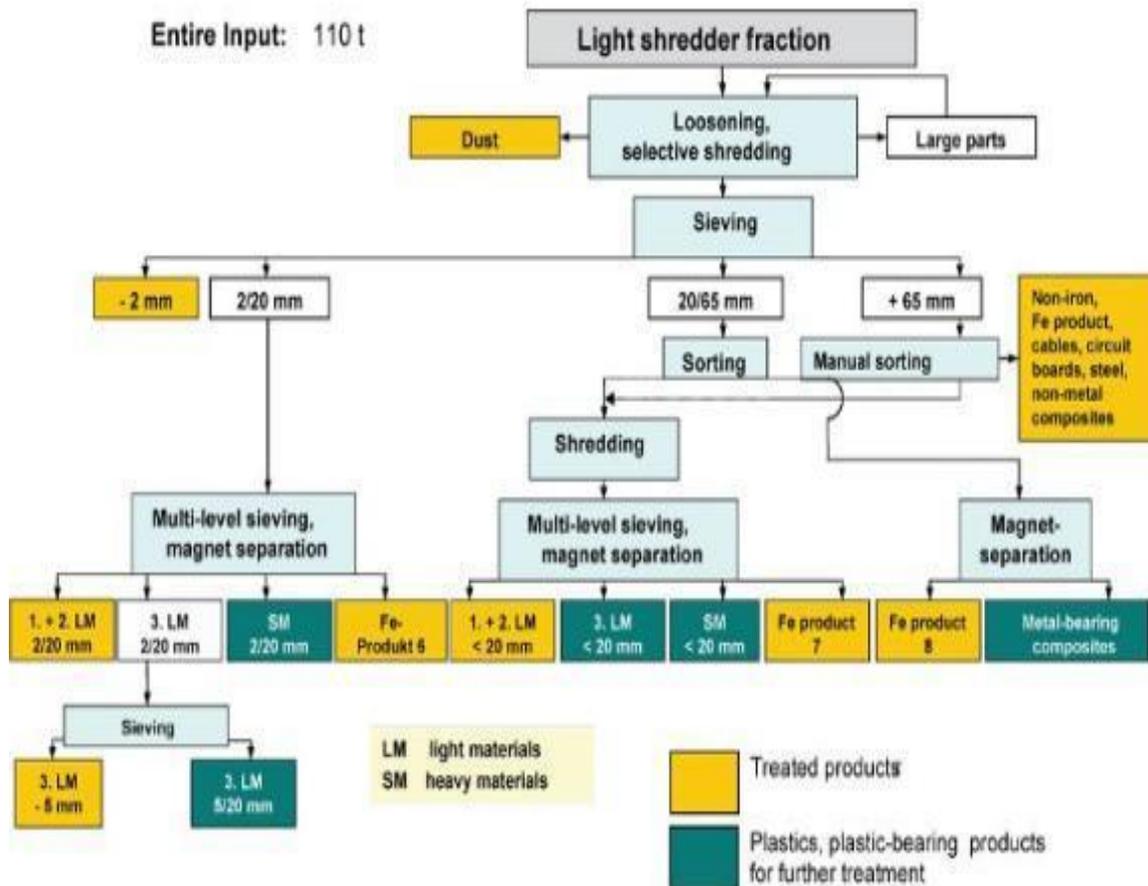
<sup>148</sup> Ibid.

<sup>149</sup> Moakley, J., et. al. (May, 2010), *An Evaluation of Shredder Waste Treatments in Denmark – Alternative Methods to Landfilling Auto Shredder Residue in Compliance with the Strict Environmental Quota by the European Union*.

shredder fraction. The two tables below provide process flow diagrams for the application of their post-shredder technology to the light and heavy shredder fractions.

## Treatment of the light shredder fraction

### Flow chart of the Scholz process

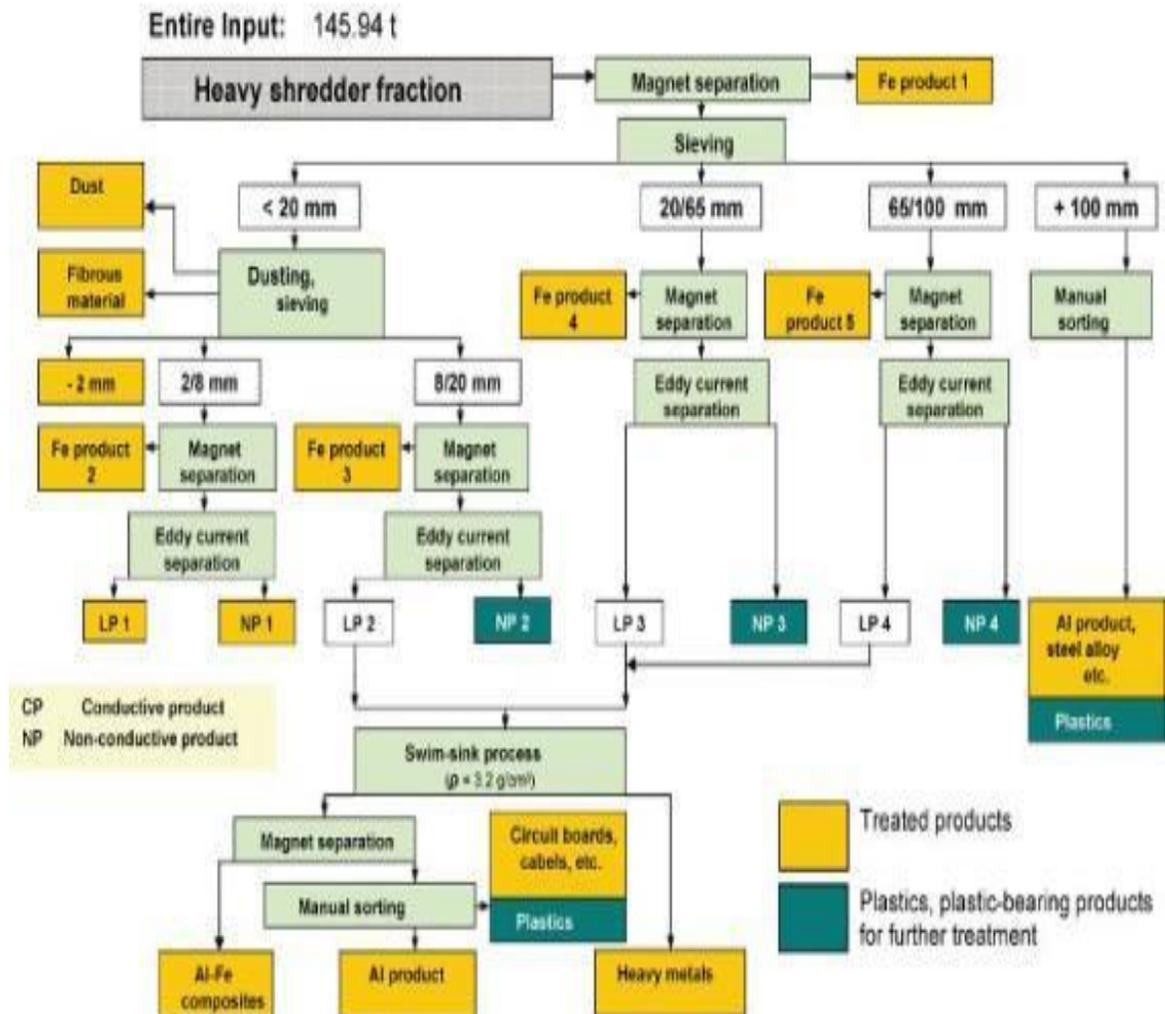


**Figure 8: Treatment of the Light Shredder Fraction Using the Scholz Process**

Source: Moakley, J., et. al. (May, 2010), *An Evaluation of Shredder Waste Treatments in Denmark – Alternative Methods to Landfilling Auto Shredder Residue in Compliance with the Strict Environmental Quota by the European Union.*

# Treatment of the heavy shredder fraction

## Flow chart of the Scholz process



**Figure 9: Treatment of the Light Shredder Fraction Using the Scholz Process**

Source: Moakley, J., et. al. (May, 2010), *An Evaluation of Shredder Waste Treatments in Denmark – Alternative Methods to Landfilling Auto Shredder Residue in Compliance with the Strict Environmental Quota by the European Union.*

By using shredding, sieving, magnetic separation, and sorting and classification technologies, the Scholz technology allowed the recovery of the following products from the light shredder fraction: (i) directly recyclable metals; (ii) metal-bearing composites (including cables and circuit boards for further treatment); (iii) substitute fuels (non-metal composites varying in particle size); (iv) plastics and plastics composites for further treatment; and (v) mineral products (< 2mm). Meanwhile the products recovered from the

heavy shredder fraction with the use of sieving, magnetic separation, and eddy current separation included: (i) metals (directly recyclable Fe, Al and Cu metals, steel alloys, Al-Fe composites); (ii) metal-bearing composites (Cu-Fe products, cables, circuit boards, and composites suitable for further treatment); (iii) substitute fuels; (iv) plastics of various sizes; (v) dust and fibrous material (<20 mm); and (vi) mineral particles (<2 mm).

#### **6.2.8.4 Witten Process<sup>150</sup>**

The University of Witten in Germany developed a mechanical separation process for producing an organic-rich fraction from shredder residue that is primarily used as a fuel in cement kilns and similar applications. The process consists of the following steps:

1. Ferrous metals are recovered by using a magnet.
2. A hammer mill is used to size reduce the material, and a screen is used to remove fines.
3. Air classification is used to separate fibrous from non-fibrous material. The two streams are processed separately.
4. A screening jig is used to separate residual metals.
5. Fibrous material is size-reduced in a “cutting mill,” and then a screening jig is used to separate residual metals and fines.
6. A conveyor dryer is used to dry the material.

The process produces the following streams:

- 3–8% of the shredder residue is a ferrous metals fraction containing about 80–95% iron.
- 8–23% of the shredder residue is a mixed Fe/Cu/Al fraction.
- about 25% of the shredder residue is a low-density organic fraction containing between 10% and 20% ash. Its heating value is between 9,480 and 11,200 Btu/lb.
- 15–25% of the shredder residue is a higher-density organic fraction containing between 15% and 25% ash. Its heating value is between 10,770 and 13,785 Btu/lb.
- 25–35% of the shredder residue is a high-ash (75–85% ash) fraction.

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<sup>150</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

#### 6.2.8.5 *Sortec Process*<sup>151</sup>

Sortec designed a 40,000-ton/yr plant to recover metals and an organic fraction from shredder residue. The process consists of the following steps:

1. screening to remove fines (< 0.25 inches) and to recover large metallic pieces.
2. size reduction to less than about 1 inch.
3. magnetic separation of ferrous metals.
4. size reduction to less than 0.25 inches by using fixed/rotating knife granulators.
5. drying on a conveyor belt to <2% (by weight) moisture.
6. screening into five fractions followed by air classification to remove heavies. The light fractions are the organic fraction. The heavies are the non-ferrous fraction.

The ash content of the organic fraction is expected to be between 10% and 30%, and its water content is 2%. Its heating value is between 7,325 and 12,925 Btu/lb.

#### 6.2.8.6 *Nimco Process*<sup>152</sup>

This ASR separation and recycling system comprises four major components. The first component is the initial size and separation of ASR into three separate fractions. The second component comprises a grit processing subsystem. The third component is a rubber and plastics recovery subsystem. The fourth component is a polyurethane foam separation and cleaning subsystem.

#### 6.2.8.7 *Thermo-bath Process*<sup>153</sup>

This process was developed by Japanese researchers. It consists of heating ASR in an oil bath using coal-tar based oil. ASR is heated quickly in the oil bath at 280°C, and by gravity, the organic plastic is easily separated, which floats. The floating plastics can be fed into blast furnaces as a reducing agent and the metal can be recycled. A pilot plant has been built in Japan where experiments were conducted concerning ASR recycling. The material balance obtained from the experiment shows that ASR is easily separated into floating material and sediments within a time of 20 minutes. From oil bath separation, about 65% of material in floating and 24% in sediments is obtained. The floating part contains 92% organic, 8% ash and 0.5% chlorine while the sediment part contains 16% organic, 39% iron 14% copper, and 31% of sand and glass.

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<sup>151</sup> Ibid.

<sup>152</sup> Ibid.

<sup>153</sup> Nourredine, M. (2007), *Recycling of Auto Shredder Residue*, published in the Journal of Hazardous Materials.

## 6.3 ASR Direct to Energy Processes

### 6.3.1 Introduction

ASR is difficult to recycle because of its heterogeneous composition, however its high heating value (generally ranging from 14-30 MJ/kg<sup>154</sup>) makes thermal treatment with recovery of energy or its use as a fuel supplement in industrial processes feasible.<sup>155</sup> ASR can be a cost-effective fuel since ASR's fuel value is nearly half that of coal (and greater than that of solid biomass<sup>156</sup>) and it will burn without the need for supplemental fuel. In addition, due to the increased use of polymers in vehicles and other durable goods, the heating value of shredder residue is increasing.<sup>157</sup> As such, co-incineration of ASR with other wastes (e.g. MSW) in waste-to-energy installations or application as (energy) feedstock in the iron and steel and cement manufacturing industries may constitute a cost effective and more sustainable alternative to landfilling of ASR. Moreover, thermal treatment of ASR considerably reduces volume and mass, with only the resulting inert ash that must be landfilled.<sup>158</sup> The main problem associated with its use as a fuel is its content of heavy metals as zinc and copper.<sup>159</sup>

ASR incineration treatment is the second most adopted ASR end-of-life management system in Europe after landfilling. At present, European countries thermally treat ASR only in co-combustion with MSW mainly due to difficulties associated with the composition of ASR. ASR presents some physical and chemical parameters that can result in difficulties in the incineration process, for instance the high heating value of plastic matter in the ASR, the significant presence of inert matter in the ASR and the presence of problematic materials that can lead to unwanted emissions (e.g. PVC or residual oils). Typically ASR/MSW co-combustion rates in Europe range from 3%-11%.<sup>160</sup>

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<sup>154</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>155</sup> Cossu, R. & Lai, T. (2013), *Washing Treatment of Automotive Shredder Residue*, published in Waste Management.

<sup>156</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>157</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>158</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>159</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>160</sup> Ciacci, L., et. al. (2010), *A Comparison Among Different Automotive Shredder Residue Treatment Processes*, published in the International Journal of Life Cycle Assessment.

It has been reported that up to approximately 6% ASR can be co-fired with MSW without major problems and without making changes to the incinerator. Another study of the co-firing of up to 8.4% ASR with MSW indicated no operational problems, while CO emissions were reduced. However, the concentrations of dioxins/furans and Cd, As, Pb, and Zn increased by up to a factor of 6. However the plant's emission control systems was able to handle the increase. The grate ash also showed increased levels of Zn, Cu, Sb, Ni, Pb, and Sn, but the ash still passed the governing leachability test.<sup>161</sup>

It should be noted that in Europe, ASR incineration cannot be considered as a long-term alternative to landfilling ASR since this end-of-life strategy does not allow the achievement of the 85% recycling target established by the European Community.<sup>162</sup>

Two categories of ASR direct to energy processes are described in this section, specifically: (i) co-incineration with other waste; and (ii) use of ASR as fuel in metallurgical processes. However, first a brief discussion is provided on the most appropriate sized fraction of ASR for use in energy recovery processes.

#### ***6.3.1.1 Most Appropriate ASR Fraction Size to Use for Energy Recovery***

Based on the heating value and metal content of different sized ASR fractions, as well as pollutant concentration in the gases evolved when samples are subjected to combustion, the 50–100 mm size fraction of ASR would be the most suitable for use as waste fuel. In past tests, the fines fraction presented a low heating value (LHV: 15 MJ/kg dry sample) and had a high amount of PCDD/PCDFs formed during the combustion experiments (800 pg-iTEQ/g dry sample), likely associated with the high metals content in this fraction. These results suggest that the fines fraction would be the least suitable to be used as waste fuel – both from an energetic and an environmental point of view.<sup>163</sup>

From the point of view of toxic pollutants emissions, the ASR in general as well as the 20–50 mm fraction of ASR behaved similarly, although the latter had a higher low-heating value (18.7 vs 23.7 MJ/kg dry sample) making it more suitable to be used as waste fuel. Thus, based on the above considerations, the material obtained after removal of the fines fraction from the ASR would be suitable for use as waste fuel. In this case, a high heating value, low metal content and low concentration of toxic pollutants resulting from incineration, would be expected.<sup>164</sup>

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<sup>161</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>162</sup> Ciacci, L., et. al. (2010), *A Comparison Among Different Automotive Shredder Residue Treatment Processes*, published in the International Journal of Life Cycle Assessment.

<sup>163</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

<sup>164</sup> Ibid.

### 6.3.1.2 *Upgrading ASR for Utilization as Fuel*<sup>165</sup>

While ASR has a favourable calorific value (14–30 MJ/kg), its high ash content, elevated chlorine and heavy metal concentrations may limit its use as fuel substitute. Advanced secondary recovery techniques can segregate ASR in order to isolate combustible materials with low ash content and with low contaminant concentrations. The finest fraction of ASR generally have the highest ash and mineral oil content, combined with the lowest calorific value. Screens, shaker tables, rotary drums or float/sink separation techniques can be applied to remove this fine sized fraction and therefore improve the fuel characteristics of ASR. In order to improve the ease of transportation and storage, the ASR density can be increased by pelletization.

Chlorinated plastic components such as PVC or (halobutyl) rubber are the main sources of the high chlorine concentrations found in ASR. PVC removal from ASR is a simple way of lowering its overall chlorine concentration. Density separation, using a bath density of 1,100–1,200 kg/m<sup>3</sup>, can remove the majority (up to 68%) of chlorinated plastics (density of about 1,400 kg/m<sup>3</sup> or more) from the combustible materials of ASR. Another technique to decrease the chlorine content of ASR plastics is by combining the thermal treatment of ASR (heating to 300°C) to remove chlorine from PVC, followed by washing of the char to remove soluble chlorides. It is estimated that overall de-chlorination of ASR has reached 81% when these process have been applied after density separation. The use of thermal energy to reduce chlorine concentration is however debatable due to the high energy costs. Other recently studied de-chlorination techniques of ASR include the extraction of chlorine with calcium hydroxide or with a sodium hydroxide/ethylene glycol mixture. At ambient temperature, only inorganic chlorine is removed, however when the temperature is increased to 100–200°C, organic chlorine can also be extracted. A ball mill reactor can be used to improve contact between the ASR and the solution and thus enhance the extraction efficiency.

In some cases heavy metals must be removed from ASR before recycling or energy recovery in order to meet regulatory limits of the final application. Certain heavy metals can easily be removed by mechanical separation. The ASR fraction smaller than 0.5 mm has been suggested to contain the highest Cr, Ni, Pb and Zn concentrations. It has been estimated that removing this fraction can reduce the overall concentration of these elements in the ASR by more than 77%. It has been further demonstrated that Cr, Cd and Pb concentrations in ASR could be reduced by at least 83% by eddy current separation of non-ferrous metals. Further heavy metal removal can be obtained by washing ASR with an acid extraction agent. This technique can also be used to recover Zn from the ASR

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<sup>165</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

fraction smaller than 0.5mm, as it is one of the most abundant metals in this fraction and it has a fair market value.

### 6.3.2 Co-Incineration of ASR with Other Waste

In general ASR is not suited for mono-incineration, due to possible carry-over of unburned fines and melting characteristics. A mixture with lower calorific wastes enhances the incineration potential and efficiency in waste-to-energy plants, while still maintaining the advantages of considerable mass and volume reduction, along with recovery of energy. Co-incineration of ASR can be conducted in various incinerator types, such as grate furnaces, fluidized bed combustors, rotary kilns and cement kilns.<sup>166</sup>

#### 6.3.2.1 Grate Furnaces

Co-incineration of ASR with MSW in a grate furnace has the advantage that the technique is well known and that grate furnaces, using best available techniques for energy recovery and flue gas cleaning, are operational in many countries globally. Many of the pilot and full-scale studies have determined that using ASR as fuel in these furnaces can be both economically and environmentally sound, on condition that best available techniques (BAT) are applied.<sup>167</sup>

In Switzerland, up to 10% ASR was co-incinerated with MSW to assess the technical feasibility and environmental impact. The co-incineration was reported to meet the regulatory environmental limits. As such, Switzerland has been reported to be the first country globally to treat all of its shredder residue, including ASR, by thermal processing. Co-incineration tests of ASR and MSW have also been conducted in Germany, Spain and Sweden. The largest waste incineration facility in Sweden successfully co-incinerated up to 20% ASR with MSW. It was shown that flue gas emissions did not change significantly compared to the incineration of MSW only. PCBs appeared to be the most critical organic pollutants as their concentration increased by a factor of 3–5 in the flue gases and by a factor of 5 in the bottom ashes (when ASR was co-incinerated), however all regulatory limits were still met. Some past studies have compared co-incineration of ASR with MSW, co-incineration in a cement kiln and co-incineration with hazardous waste and concluded that co-incineration of ASR with MSW was most appropriate.<sup>168</sup>

It is generally recommended that high percentages of ASR not be co-incinerated with MSW. However past work has demonstrated that up to 31% ASR can be co-incinerated with MSW, without significantly changing the composition of the flue gases, the plant

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<sup>166</sup> Ibid.

<sup>167</sup> Ibid.

<sup>168</sup> Ibid.

operation, the burnout of the waste or the potential use of the bottom ashes. However, the concentrations of Zn, Pb, Sn, Sb and Co in the fly and boiler ashes increased significantly. For instance, the respective concentrations of Pb and Zn were up to 18 and 16 times higher than the average baseline level. For higher amounts of ASR, over 40%, problems of bridging and plugging of the conveyer transfer chutes and additional problems in the feed system have been reported.<sup>169</sup>

In many countries, bottom ashes from MSW incineration are used as a secondary raw material in building applications. Therefore, it is important to monitor toxic components (e.g. heavy metals, persistent organic pollutants) in the bottom ashes when ASR is co-incinerated, as ASR generally contains higher amounts of these components than MSW. The legal concentration limits for toxic elements in bottom ashes used in building applications will therefore limit the amount of ASR that can effectively be co-incinerated.<sup>170</sup>

### 6.3.2.2 *Fluidized Bed Combustors*

Recent studies have focused on the co-incineration of ASR in a fluidized bed combustor. Good practice in such installations is to incinerate low calorific waste streams such as waste water treatment sludge along with high calorific, non-recyclable waste from industrial sources, such as carpets, textiles, refuse derived fuel and ASR, in order to maintain temperatures of approximately 650°C in the sand bed and of about 900°C in the freeboard.<sup>171</sup>

Nissan modified a fluidized bed combustor at its Oppama plant (located in Japan) to recover energy from ASR. Energy recovery began in 2003<sup>172</sup> and full-scale operation amounting to the co-incineration of 4,800 tonnes of ASR per year along with other waste from Nissan plants, started in 2005. Nissan was the first car manufacturer to thermally treat its own ASR with energy recovery.<sup>173</sup> Thermal energy generated during incineration is converted into steam that is effectively used for humidification and other purposes in the pre-painting processes at the plant. Since ASR generates large quantities of heat, controlling the temperature during incineration has been difficult. Another problem has been that unburned substances tend to stick to the inner walls of the incinerator and the

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<sup>169</sup> Ibid.

<sup>170</sup> Ibid.

<sup>171</sup> Ibid.

<sup>172</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>173</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

evaporation pipes of the boiler. These problems have been resolved through optimum temperature control.<sup>174</sup>

During an extensive trial, heavy ASR was added to the usual waste feed of a fluidized bed combustor in Antwerp, Belgium - Europe's largest fluidized bed combustor for waste-to-energy conversion. During the trial, the input waste stream consisted of 25% ASR, 25% refuse derived fuel and 50% wastewater treatment sludge, whereas the usual waste feed consisted of 70% refuse derived fuel and 30% wastewater treatment sludge. NO<sub>x</sub> and SO<sub>2</sub> emissions did not change significantly, nor did emissions of persistent organic pollutants (POPs), despite the increased input. The POPs in the input streams were destroyed during incineration and the formation of new POPs during the cooling of the flue gas appeared to a great extent independent of the POP concentrations in the input. The increased Cu and Fe concentrations in the fly ash and boiler ash enhanced de novo synthesis of PCDD/PCDFs. During the co-incineration trial, the amount of bottom ashes generated per ton of incinerated waste was at most 48% higher than with the usual waste feed. The concentrations of heavy metals in these ashes increased on average by 10%, but still complied with local legal requirements for use as secondary raw materials (road construction), except for copper. The total heavy metal concentration in the flue gas also increased (by about 60%) during the co-incineration of ASR, but remained well below the local regulatory limits. Fly and boiler ash and flue gas cleaning residue, corresponding to 16.5% (by weight) of the original input, were landfilled after appropriate treatment. It was concluded that co-incineration of heavy ASR with refuse derived fuel and wastewater treatment sludge is a valid method to increase the reuse and recovery rate of end-of-life vehicles. The quality of the generated ashes was found to determine the proportion of ASR that can effectively be co-incinerated.<sup>175</sup>

### 6.3.2.3 Rotary Kilns

A rotary kiln enables the processing of solid, liquid and gaseous waste streams and is generally applied for the thermal treatment of hazardous industrial wastes such as POP-containing waste, medical waste, chemical waste, sludge, etc. The use of a small-scale rotary kiln incinerator for on-site power generation from ASR has been investigated. This investigation determined that the heavy metal and inorganic emissions in the flue gases were acceptable. The ASR volume and mass was reduced by 80% and 55%, respectively. Some samples of the ashes exceeded the regulatory limits on lead leaching, but addition of sodium silicate, lime or cement type reagents resulted in reduced leaching.<sup>176</sup>

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<sup>174</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>175</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>176</sup> Ibid.

A rotary kiln is very robust and is thus also suitable for co-incineration of ASR with hazardous waste. Thermal recovery in a rotary kiln is however often more expensive than in a grate furnace or fluidized bed combustor due to both the more intensive flue gas cleaning and the additional treatment and disposal of the ashes, while in general less energy is recovered.<sup>177</sup>

#### **6.3.2.4 Cement Kilns**

A cement kiln is a rotary kiln with a length that can amount to 200 meters. To guarantee that quality standards of clinker are met, extensive chemical analysis of any waste materials used as fuel are required and pre-treatments should be conducted before using a waste as an alternative fuel or resource. ASR is a potential alternative fuel and mineral feedstock for cement production since approximately 50% (by weight) of ASR consists of combustible matter such as plastic or rubber, and another 40% (by weight) is made up of silicates, calcium, aluminum and iron (i.e. raw materials used to produce clinker). However an existing study has reported strong negative effects on the quality of the clinker when ASR was used in a cement production process in Switzerland. When the fuel contained 50% ASR, instead of the regular fossil fuel mix, the concentrations of Cl, Pb, Cd, Cu and Zn in the clinker increased by one order of magnitude or more. In this instance, the Swiss product specification for clinker was not met for Cl, Cd, Cu, Pb and Zn. In general, upgrading and purification of ASR is required before its use as fuel substitute in high percentages in a cement kiln. This required pre-treatment is, however, often uneconomic or impractical. Other problems related to co-incineration of ASR in cement kilns are increased ash formation, clogging of the fuel injection zone, volatilization of mercury and increased concentrations of hazardous elements in the cement kiln dust.<sup>178</sup>

#### **6.3.2.5 Potential Problems When Co-incinerating ASR with Waste**

##### **6.3.2.5.1 High Concentrations of Chlorine in ASR**

High concentrations of chlorine in waste result in high concentrations of hydrogen chloride in the combustion gases, which may reduce the service life of incineration equipment due to chemical corrosion and fouling and/or the materials and maintenance cost for the incinerator. Traditional acid components, such as hydrogen chloride, are therefore removed from combustion gases by wet, semi-wet, dry or semi-dry scrubbing, using lime, hydrated lime, sodium bicarbonate, sodium carbonate or limestone as a solid, in suspension or in solution. Wet scrubbers are more efficient, but have the disadvantage of producing wastewater. In many recent thermal treatment plants, a dry contactor/reactor

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<sup>177</sup> Ibid.

<sup>178</sup> Ibid.

and filter are therefore followed by a wet gas scrubber.<sup>179</sup> Although the technology for scrubbing hydrogen chloride exists, the scrubbing of chlorinated compounds could be expensive, especially when they are present in high concentrations, which may be the case for shredder residue.<sup>180</sup>

EU-Directive 2000/76/EC sets stringent regulations on the operating conditions of waste incinerators depending on the chlorine content of the waste. For instance, a gas temperature of at least 850°C and a residence time of at least 2 seconds are required for waste containing less than 1% (by weight) chlorine. For waste containing more chlorine, a gas temperature of at least 1,100°C and a residence time of at least 2 seconds are imposed. As ASR can contain up to 4% (by weight) chlorine, de-chlorination techniques for ASR, are intensively researched in order to make ASR more suitable for co-incineration in installations that operate at temperatures lower than 1,100°C.<sup>181</sup> For instance, shredding plants could potentially sieve the ASR in order to eliminate that size fraction that is particularly high in chlorine content.<sup>182</sup> These de-chlorination techniques add cost to the treatment of ASR.

#### 6.3.2.5.2 Potential Increase in POP Emissions

Co-incineration of ASR may lead to the increased release of POPs (e.g. PCDDs/PCDFs, PCBs and PAHs) due to the elevated concentrations of chlorine, POP-precursors and POPs contained in the ASR.<sup>183</sup> Therefore, operation of shredder residue incinerators is expected to be subject to a complicated permitting process that may call for costly chemical analysis.<sup>184</sup>

Several studies have investigated the influence of co-incineration of ASR on POP emissions. It is generally believed and confirmed based on studies that the incoming POPs are destroyed during incineration and that upon cooling of the flue gases new POPs form. There have been conclusions that the POP-output of an incineration process is to a

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<sup>179</sup> Ibid.

<sup>180</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>181</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>182</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

<sup>183</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>184</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

great extent independent from the POP concentration in the incinerated waste.<sup>185</sup> Some literature on PCDD/PCDF emissions from the industrial combustion of ASR mixed with other fuels has indicated that adding ASR to refuse derived fuel and wastewater treatment sludge (i.e. the usual waste feed) in a real-scale fluidized bed combustor increased the concentration of PCDD/PCDFs in the flue gas.<sup>186</sup>

New formation of PCDD/PCDFs upon cooling of the flue gas occurs via the heterogeneous pathway either through the precursor mechanism or through de novo synthesis. Formation and chlorination of PCDD/PCDFs via the precursor pathway can be enhanced by the presence of ash particles, copper and iron. As ASR contains high concentrations of both copper and iron, this could enhance the formation of PCDD/PCDFs in the flue gas when ASR is co-incinerated with wastes containing lower amounts of these elements. Past research has found that a waste mix containing 25% ASR, 25% refuse derived fuel and 50% wastewater treatment sludge contained 7.5 times more copper than a 70% refuse derived fuel and 30% wastewater treatment sludge mix (i.e. the usual feed). In this case, the concentrations of the individual PCDD/PCDF congeners increased mainly in the fly and boiler ash.<sup>187</sup>

Another study determined that PCB concentrations increased by a factor of 3-5 in the flue gases and by a factor of 5 in the bottom ash, when ASR was co-incinerated with MSW compared to the sole MSW incineration. Other studies have reported similar increases of the total PCB concentration of incinerator outputs.<sup>188</sup> Incineration is more expensive if the shredder residue contains elevated levels of PCBs. Some regulations require that PCBs be incinerated at very high temperatures (about 1,100°C), but high-temperature incinerators are costly to build and maintain. Supplementary fuel would also be required to attain such temperatures, which would increase operating costs.<sup>189</sup>

#### 6.3.2.5.3 Increased Concentration of Heavy Metals in Flue Gases

Another important environmental concern related to co-incineration of ASR is the increasing concentration of heavy metals in the flue gases and in the solid residues. As has been noted, ASR is rich in certain heavy metals, such as copper, nickel, lead and zinc. Before incineration, the concentrations of heavy metals can be reduced by advanced

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<sup>185</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>186</sup> Edo, M., et. al. (2013), *Viability Study of Automobile Shredder Residue as Fuel*, published in the Journal of Hazardous Materials.

<sup>187</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>188</sup> Ibid.

<sup>189</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

secondary recovery techniques.<sup>190</sup> However if the concentration of these metals increase in the flue gases and ash residue when ASR is co-incinerated, issues arise in terms of needed costly treatment technologies and/or reduced marketable ash products.

Bottom ashes originating from MSW incinerators are in many countries used as secondary raw material for building applications. Incineration of high quantities of ASR may increase the heavy metal concentrations in the bottom ashes to such an extent that the limit values for leaching are no longer met, thus limiting the use of bottom ashes as secondary raw material or imposing more intensive treatment of the ashes. Especially the high amount of copper present in ASR, mainly transferred into the bottom ash, may limit the application of this ash as a raw material. A possible way to decrease copper leaching below the limit value, is extraction with solutions of organic complexants, like ammonium citrate, or acid washing with dilute hydrogen chloride solutions. Another possibility is heating the bottom ashes (at about 400°C) in order to destroy fulvic and humic acids that form extractable complexes with copper.<sup>191</sup>

The fly and boiler ashes are most often landfilled, possibly after an appropriate treatment. Especially the higher concentrations of Cd, Pb and Zn might require removal or stabilization of these heavy metals before landfilling. Possible methods for the reduction of heavy metal leaching from these ashes include separation, solidification, chemical stabilization, encapsulation, sintering or vitrification. Therefore the economic aspects of the treatment of the different ashes will determine the proportion of ASR effectively co-incinerated.<sup>192</sup>

Increased concentrations of heavy metals in the ash could result in the ash being classified as hazardous waste in some jurisdictions, which would then require that the ash be fixed and/or post-processed to recover the metals.<sup>193</sup>

### 6.3.3 Use of ASR as Fuel in Metallurgical Processes

ASR could be used as fuel in both ferrous and non-ferrous metallurgical processes. Outlined below is a description of ASR use in both blast furnaces (i.e. ferrous) and non-ferrous metallurgical processes.

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<sup>190</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>191</sup> Ibid.

<sup>192</sup> Ibid.

<sup>193</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

### 6.3.3.1 Blast Furnaces

A blast furnace is a reactor used in the iron and steel industry that transforms iron ore into molten iron. Auxiliary fuels have been used by the primary iron and steel industry, both for their energy content as well as to act as reducing agents. This was found possible due to the high intrinsic stability of the blast furnace process.<sup>194</sup> The plastics and other organics in shredder residue that are basically hydrocarbon-based materials are used to partially replace the coke, natural gas, oil, or coal supplied to the blast furnace. It has been estimated that between 1.1 and 1.5 tons of the organic fraction of ASR would be required to replace a ton of coke in the blast furnace. Therefore, from an economics point of view, it appears to be a good potential application, if it could replace some of the coke. This application would also reduce the environmental concerns associated with coke ovens. The advantages are less obvious if it is used to replace coal, natural gas, or oil.<sup>195</sup>

Several simulations, lab scale and industrial tests have been conducted in order to analyze the possible use of ASR in blast furnaces both as auxiliary fuel and as auxiliary reducing agent. Most of these studies concluded that, due to the presence of certain chemical components as well as due to the physical nature of ASR, it is only cost-effective to co-combust small proportions (up to 3%). Injecting higher amounts of ASR leads to disturbances in the operation of the blast furnace and can only be considered after suitable pre-treatment. Important parameters that influence the use of ASR in blast furnaces are the physical properties, the calorific value, the chemical composition and the concentration of non-ferrous metals.<sup>196</sup>

Some research has set the following criteria for the organic fraction of ASR for use in blast furnaces - moisture content below 7.5%, particle size between 3.2 and 6.4 mm and ash content below 10%. Besides these criteria, also the chlorine, copper, lead and zinc concentrations are limiting factors. Chlorine can accumulate in the blast furnace dust, part of which is recycled in the furnace. When the chlorine accumulates, the concentration of hydrogen chloride in the off gas might exceed regulatory limits. The concentration of copper in the hot metal is a very important parameter and has to be maintained below certain limits as copper makes the steel brittle. Besides copper, also heavy metals such as lead and zinc were found problematic for the iron making process, since they generally increase coke and energy consumption and cause productivity losses due to the formation of scaffolds in the blast furnace. Intensive advanced secondary recovery of ASR is

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<sup>194</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>195</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>196</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

generally necessary to comply with the requirements of a specific blast furnace plant. As this may be quite expensive, the use of ASR as an alternative fuel in blast furnaces is often not economically viable.<sup>197</sup>

Other noted risks associated with using ASR in blast furnaces are as follows:<sup>198</sup>

- The economic and environmental advantages depend on the replacement ratio. In general the ASR replacement ratio with coke is in the range of 0.71–0.79.
- The ability of hammer mills to produce a product smaller than 0.25 inches and the ability of the screens and air classifiers to reduce the ash content in the organics material to less than 10% are of concern. Failure to do so could result in unacceptable metallic contamination of the steel;
- The high chlorine content of the shredder residue may lead to unacceptable corrosion rates. The high chlorine content could also lead to the emission of chloride particulates into the air;
- Separating the organic material from shredder residue could leave behind a residue with nearly double the concentration of some of the heavy metals in shredder residue. As a result, this material might have to be classified as hazardous waste, which will increase its disposal cost substantially;
- The amount of shredder residue that is available near integrated steel plants is very small compared with the amount of coke, natural gas, and other fuels used by these plants. Therefore, these plants may be reluctant to use this material and risk impacting their operations or the quality of their products, unless they are paid for accepting it. This added cost may eliminate some of the economic benefits;
- Accommodating the higher chlorine in the material requires modifying the blast furnace;
- Metals, if not removed from the material, can cause severe problems, including abrasion in injection systems and reduction of furnace capacity for producing quality hot metal; and
- Copper and lead can build up in the furnace and degrade its productivity.

It should be noted that the Thermobath® process has been developed which is a thermal pre-treatment process, facilitating ASR injection into a blast furnace. It separates ASR in floats (plastics) and sediments (metals, glass and sand) on the basis of their different specific density, using an oil bath at 280°C. The floating plastics can be injected into the blast furnace as auxiliary fuel and as reducing agent, while the remaining metals can be recycled in the steel-making process.<sup>199</sup>

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<sup>197</sup> Ibid.

<sup>198</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>199</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

### 6.3.3.2 *Pyro-metallurgical Non-ferrous Metal Production Processes*

Due to price increases in copper and fossil fuels, electronic scrap smelters have become interested in certain ASR fractions. Co-smelting of ASR or of its ash from preceding energy recovery treatments (incineration, pyrolysis or gasification) in non-ferrous metal plants may be considered as a low cost recycling route, as no complex, energy consuming mechanical pre-treatment is necessary. In order to be of economic interest for copper smelters, the waste mixture should contain over 5% (by weight) of copper, which is in general not the case for ASR or its ashes. A possible solution is the co-smelting of ASR and shredder residues from electric and electronic scrap (ESR), resulting in a waste stream with sufficient concentrations of copper (mainly due to the ESR) and with an elevated heat content (mainly due to the ASR). Typical impurities or hazardous metallic components present in ASR and ESR, such as Pb, Sn and Zn, do not require any special measures or pre-treatment. Only the presence of aluminum can cause problems in the smelting process - due to its high reactivity, its presence leads to slag splashing.<sup>200</sup>

## 6.4 Thermochemical Treatment of ASR to Produce Fuels

Thermochemical treatment refers to processes that convert ASR components under the application of heat into liquids and/or gases. A solid residue by-product is generated through these processes, containing a carbonaceous char, mineral ash and metals that were present in the ASR feedstock. The liquids and the gas produced through thermochemical conversion have mostly been found suitable for use as fuel. Their use as a feedstock for the production of petrochemicals is considered to have less potential. The by-product char generated through these processes has been found to be difficult to recycle due to its high concentration of heavy metals and minerals, and is therefore typically forwarded to landfill. Within thermochemical treatment technologies, pyrolysis and gasification are generally considered as the most relevant emerging technologies for ASR (and other waste streams) and are therefore discussed in more detail below. With new ELV regulations in Europe and increasing landfill costs, ASR pyrolysis and gasification are being extensively researched at present.<sup>201</sup>

### 6.4.1 Pyrolysis

Pyrolysis is the thermal decomposition of organic material in an oxygen-deficient environment. Pyrolysis is commonly operated at moderate temperatures (400–600°C) and either in the absence of oxygen, or with such low levels of oxygen that feedstock combustion does not significantly occur. The products generated through pyrolysis processes are a solid residue, condensable organic vapours called pyrolytic liquids, and

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<sup>200</sup> Ibid.

<sup>201</sup> Ibid.

gases. The type and relative quantities of different products generated through pyrolysis is typically a function of the composition of the feedstock and operating conditions, primarily temperature, pressure, and residence time. As an example, the major products of pyrolysis when polyethylene was used as a feedstock were hydrogen, benzene, methane, ethylene, and propane. The major products from polyvinyl chloride were benzene, acetylene, styrene, and hydrogen chloride and the major products from polystyrene were styrene, benzene, toluene, and methyl-styrene. It is anticipated that pyrolysis of shredder residue would yield products similar to those produced by the pyrolysis of a mixture polyethylene, polyvinyl chloride, polypropylene, and polystyrene.<sup>202/203</sup>

High-temperature pyrolysis, low-temperature pyrolysis, and pyrolysis at different pressures, including sub-atmospheric pressure, have been attempted for processing shredder residue. In all cases, the pyrolysis process produces oil, gas, and a char/solid residue. Several pyrolysis tests conducted on shredder residue in Switzerland in the 1990s yielded the following observations:<sup>204</sup>

- iron represents up to 25% of the solid product;
- copper content in the solid product was as high as 5%, and the major part of the copper is present as fine copper filaments in elementary form;
- the concentration of PAHs was reduced by more than 90%, and the PCB concentration was reduced by more than 99%; and
- because of the presence of heavy metals (i.e. cadmium, nickel, and zinc), the solid product could not be disposed of in landfills as a result of limitations on the metals content of waste to be disposed of in landfills in the country.

It is noteworthy that all pyrolysis processes that have been developed mix ASR with other wastes, such as MSW or biomass to regulate the variations in material characteristics and calorific value. The main problems with pyrolysis relate to both the difficulty of pyrolyzing some of the ASR components, and the difficulty in handling products being formed. For instance, polyurethane is difficult to crack, PVC can contaminate the pyrolysis gas with methyl chloride, rubbers form tars and major quantities of carbonaceous residue, whereas polyethylene and polypropylene tend to form waxes.<sup>205</sup>

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<sup>202</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>203</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

<sup>204</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>205</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

It is generally believed that pyrolysis reduces the environmental burden of a thermal process, by operating at low temperature and in the absence of oxygen. The reducing atmosphere avoids the formation of products of incomplete combustion or post-combustion synthesis (such as PCDD/PCDF), whereas the low temperature operation avoids the volatilization of heavy metals and/or their oxides or salts. Existing literature provides evidence that emissions in the exhaust gas (dioxins, HCl, NO<sub>x</sub>, SO<sub>x</sub>, dust and CO), and leaching test results of both slag and flue gas cleaning residue (Cr(VI), Cd, Pb, As, Hg and Se) complied with the corresponding Japanese standards. The occurrence of dioxins, furans and dioxin-like PCBs in the solid residue from a pyrolysis and melting process, as well as the fate of brominated flame retardants and heavy metals in such a process indicate that the pyrolysis-melting process is efficient in the reduction and/or fly ash recovery of possible toxic chemicals.<sup>206</sup>

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<sup>206</sup> Ibid.

**Table 40: Advanced Pyrolysis Processes Developed/Tested for Shredder Residue**

Process	Description
Siemens-KWU	Process was commercialized for pyrolysis of MSW and is operating in Furth, Germany. The plant also conducted one trial using 30 tons of shredder residue. The process uses an indirect heated rotary kiln operating at 450°C to convert the feed material to a pyrolysis gas and coke. Solids (including the char) are discharged from the kiln for recovery of metals. The pyrolysis gas and solid char are then combusted in an incinerator for steam production. Slag from the combustor meets the requirements for Class 2 landfills. Slag pH, phenol content, and residual antimony exceeded the limits for disposal in a Class 1 landfill. The technology reportedly has been licensed to Mitsui & Co., Ltd. (Tokyo, Japan), which is marketing the technology.
Baltrec AG	Process involves pyrolysis of the organic fraction of shredder residue followed by mechanical separation of the metals (iron and copper) from the residual solids. Pyrolysis tests for shredder residue in a 400-kg/h reactor at 600°C were conducted (large chunks of metal and foam were removed from the shredder residue prior to introduction into the process). The feed material was pressed into 10-cm x 5-cm cylinders. It was reported that about one-half of the iron and copper in the solids remaining after pyrolysis can be recovered from the >2-mm fraction.
Takuma	A plant with a rotary pyrolysis reactor with a capacity of 90 tonnes of ASR/day is operating in Kanemura, Japan. In this process, the shredder residue is first pyrolyzed, and then the residual solids are sorted to recover metals. About 1 tonne of copper and 8 tonnes of mixed metals are produced daily. The remaining char is then combusted in a combustion chamber (along with the gases produced by the pyrolysis process), and the heat is recovered in a steam boiler to produce electricity. The process generates 20 ton/h of 48 bar saturated steam and nearly 2 MWh of electricity. The emission data of the exhaust gas (dioxins, HCl, NO <sub>x</sub> , SO <sub>x</sub> , dust and CO), and leaching test results of both slag and flue gas cleaning residue (Cr(VI), Cd, Pb, As, Hg and Se) comply with the Japanese standards.
Citron-Oxyreducer Process	A large-scale plant is in operation (Le Havre, France), and it has processed over 20,000 tonnes of shredder residue. The plant can accept pieces up to 7 cm and can handle materials with up to 50 ppm of PCBs and up to 100 ppm of mercury. The organic materials in the shredder residue, plastics, and other materials are pyrolyzed at high temperatures. The product gases are then used as agents to reduce some of the metal oxides and hydroxides to their elemental state. The low-boiling metals (zinc, lead, cadmium, and mercury) evaporate, and then the zinc, lead, and cadmium are re-oxidized at about 1,200°C in the gas phase to produce solid oxides and destroy dioxins. The gases are then quenched at 80°C. The mercury stays in the metallic form as a vapour in the oxy-reducer reactor and is condensed during the quenching process and removed by means of a wet electrostatic precipitator and a scrubber. The high-boiling oxides (FeO <sub>2</sub> , Al <sub>2</sub> O <sub>3</sub> , CaO, and SiO <sub>2</sub> ) are discharged from the oxy-reducing reactor. The chlorine in the waste is converted to sodium and potassium chlorides.
PKA Process	Comprises a modular pyrolysis and gasification concept. Pre-processing involves separation, screening and shredding of the different feedstock (MSW, ASR, spent tires, plastic waste, contaminated soil). Pyrolysis occurs at 500–550°C for about 45–60 minutes in an indirect heated rotary kiln. The main product is a CO/H <sub>2</sub> rich fuel gas. Char and ashes are treated by separating ferrous and non-ferrous metals, then dried to below 10% moisture and milled to <2mm before being used as fuel, as activated carbon or raw material in brick plants.
PyroMelt	Combines pyrolysis and slagging combustion in a sequential mode, yielding a vitrified granular slag. The feedstock consists of MSW, hazardous waste, ASR and post-consumer plastic waste. The process gas (500–600°C) is subjected to multiple scrubbing steps using pyrolysis oil, cooling the gas to 120–150°C. The char is cooled to 50°C and jointly burnt with a slurry of dust and heavy pyrolysis oils in a melt furnace.
ConTherm®	The ConTherm® technology pyrolyzes shredded fuels such as MSW, ASR and up to 50% post-consumer plastics at 500–550°C in a 100,000 ton/year rotary kiln, combusting the gas directly in a pulverised coal-fired boiler. Residues from the process are screened and sorted to recover materials, mainly metals. A coal mill is attached to the main processing line to treat the char fraction.

Sources:

Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.  
 Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

## 6.4.2 Gasification

Gasification is a high-temperature thermochemical process that can convert the organic content of a material, such as shredder residue, into a gaseous mixture of primarily CO, H<sub>2</sub>, CO<sub>2</sub>, and light hydrocarbons. In addition to the organic feed material, water and air (or oxygen) are supplied to the reactor. However, the amount of air or oxygen that is supplied is limited to achieve partial oxidation of the organic feed in order to raise the reactor temperature to the desired value, which is normally between 500-1,500°C, depending on the process. Three types of gasification reactors are commonly used: (i) moving bed; (ii) fluidized bed; and (iii) entrained flow reactors. Gasification of shredder residue can produce the following products, after further purification and processing: (i) a gaseous mixture made of CO, H<sub>2</sub>, and light hydrocarbons; and (ii) reduced metals (e.g., iron, copper, and aluminum), as a result of the reducing environment in the reactor. The use of air in the process introduces nitrogen in the gases that are produced, thereby considerably reducing the calorific value of the syngas because of the dilution. The high-temperature processes also produce vitrified ash, which is non-leachable.<sup>207/208</sup>

As gasification is achieved in a partially oxidizing atmosphere, it does not achieve the same environmental advantages of pyrolysis. However, the use of a sequential gasification and combustion system (at very high temperatures) as reported in the literature demonstrated that atmospheric emissions were considerably below the legal limits (in Japan).<sup>209</sup>

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<sup>207</sup> Ibid.

<sup>208</sup> Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

<sup>209</sup> Vermeulen, I., et. al. (2011), *Automotive Shredder Residue (ASR): Reviewing its Production from End-of-Life Vehicles (ELVs) and its Recycling, Energy or Chemicals' Valorisation*, published in the Journal of Hazardous Materials.

**Table 41: Gasification Processes Developed/Tested for Shredder Residue**

Process	Description
VOEST-ALPINE Process	Developed by VOEST-ALPINE of Austria. Tests were conducted with shredder residue blended with mixed plastics, waste oils, and fuel oil. The amount of actual shredder residue used relative to the oils and mixed plastics was approximately 25%. Products resulting from gasification of the mixture showed several dioxin species present in minute quantities. The product gas had a calorific value of about 100 Btu/ft <sup>3</sup> . This low-Btu industrial fuel gas would have to be used on-site because it would not be economical to transport it in pipelines.
TwinRec Process	The TwinRec process was developed by Ebara Corporation in 2000, and now over 14 process lines are in operation. The process is based on fluidized-bed gasification with ash melting. SEINAN, a large shredder in Japan, has been operating a combined material and energy recycling “TwinRec” plant since 2000. Shredder residue from five shredding plants and three non-ferrous-separation plants is brought to the plant and fed to the TwinRec gasifier without any pre-treatment. As of January 2002, the plant had processed 95,000 tons of shredder residue. The plant recovers ferrous and non-ferrous metals (including copper and aluminum). The fine inert residue is vitrified in the process and used in road construction. Zinc and lead-rich fly ash from the process are sent to the zinc industry for further processing. The energy content of the shredder residues is used to produce steam, which is then used for power generation.
SVC Process	Using this gasification process, SVC (Siemens Venture Capital GmbH) has recycled shredder residue (along with other wastes containing organic material, such as MSW) for many years. Tests on shredder residue were conducted using a ratio of 30% shredder residue/70% other solid and liquid wastes. Raw shredder residue cannot be fed into the gasifier and must be preprocessed to produce a fuel puck to feed the material into the gasifier. Several reactors, having different throughputs are in operation, and over 1 million tons of different types of waste have been gasified. The mixed-waste material is processed into high-purity methanol. SVC is working to increase the relatively low ratio of shredder residues used in its mixed feed. This task requires removal of the fines from shredder residue before gasification. SVC reports that, even though the technology is well demonstrated, it cannot compete economically with landfills in Germany. The SVC commercial gasification facility currently processes 450,000 tons/year of solid waste and 50,000 tons/year of contaminated oil and oil-water emulsions in a Lurgi moving-bed gasifier. The feed to the plant contains about 10–20% (by weight) shredder residue after removing the metals. It is estimated that about 211 kg of methanol is produced from every tonne of shredder residue fed to the plant.
RESHMENT® Process	This process is based on a smelting cyclone. Initially, large pieces of metals are recovered, and the rest of the material is size-reduced to less than 5 mm. The size-reduced material is then fed to the cyclone furnace, which is maintained at about 2,000°C - the result is the vitrification of the ash. Oxygen is also provided to the furnace to assist in oxidizing the decomposition products of the organics. In the process, the metal oxides are also reduced to their elements, and the elements are melted. The iron/copper molten material is separated by gravity to leave behind a molten mixture of minerals, glass, and some molten metals. The evolved gases are sent to an afterburner and then to heat recovery, and a cleaning-and-scrubbing system downstream of the thermal treatment module controls the emissions. Its energy is used to produce electricity. The process recovers 98% of the cadmium, 92% of the zinc, 91.5% of the iron, 89.5% of the copper, 82% of the lead, and 35% of the aluminum from the material. In 2003, this technology was chosen for Europe’s first plant to thermally treat shredder residue. The design capacity of the plant was 105,000 tons/yr, including 55,000 tons/yr of shredder residue. Plant start-up was scheduled for 2007. It is unknown if the plant was built.
Plasma Processes	Another form of gasification that has been used experimentally on shredder residue is plasma gasification. This process takes place at very high temperatures (~5,000–10,000°C) and atmospheric pressure. In the process, the organic material is converted to a gas rich in CO and H <sub>2</sub> . The inorganic residue is melted into a slag that, when cooled, solidifies into a potentially useable construction material. The slag normally passes the toxicity characterization leaching procedure test.
Montello Process	This process separates fine inorganic material from shredder residue and processes the balance of the shredder residue in a rotary kiln to preheat iron scrap charged to an electric arc furnace. The scrap iron is preheated to about 550°C by the gasification of the organic fraction of the shredder residue. The shredder residue is fed to the rotary kiln gasifier with the scrap iron at a ratio of 1 ton of shredder residue to 4 tons of iron and steel scrap. Off-gases from the gasifier are completely combusted in an afterburner/incinerator, and the resultant heat is available for the recovery and production of steam for energy recovery or electricity generation. The process technology is designed to be co-located with a mini-mill.





Process	Description
PyroArc Technology	This technology, developed in Norway, was initially developed as a waste-incineration process incorporating a gasifier followed by plasma combustion of the gasifier off-gases. The temperature in the first stage (gasifier) is about 1,000°C, and in the plasma reactor, the temperature is as high as 5,000°C. Quench and cooling of the combustion gases follows for removal of particulates and acid gases. It also produces steam for co-generation. Inorganics in the feed material are recovered as molten slag and metal from the gasifier bottom. The developers report an energy recovery efficiency of 65–70%. A total of 400 tons of shredder residue have been processed only in a pilot-plant. In these trials, product gases after plasma combustion and gas cleanup met environmental standards. Slag from the gasifier met the leach requirements that would allow the slag to be used as a construction aggregate.
Dry Distillation/Gasification	This process was developed in Japan. Dried and compressed wafers of organic material in shredder residue are fed to a batch “dry distillation furnace,” in which gasification occurs as the wafers are brought in contact with a gas that is up to 1,100°C and contains up to 7% O <sub>2</sub> . The residence time is between 30 and 60 minutes. The wafers are also doped with 1.2% calcium hydroxide for capturing chlorine in the feed material. The product gas from the gasification process is further refined in a secondary reactor that is heated by using an external fuel, such as liquefied petroleum gas. The best results have been reported obtained at process temperatures between 500-700°C, which resulted in a gas having a heating value of about 15.5 MJ/kg. At temperatures above 700°C, copper in the ash started to oxidize at higher rates. About 50% of the feed material was lost (converted to gas) during gasification.
Thermoselect Process	This process was tested for treatment of shredder residue, although it is used mostly for processing MSW. The process has four stages: waste compaction, pyrolysis, gasification, and water and gas cleanup. In 2002, a large trial, using over 1,000 tons of shredder residue, was conducted in which mixtures of shredder residue (up to 45% by weight) and MSW were used. In the process, mixtures of shredder residue and MSW are fed in discrete packages into a degassing channel, and the waste spends about 1–2 hours in the channel. The material is dried, and the organics are converted to gas and char. The material then enters a high-temperature fixed-bed oxygen-blown gasifier reactor in which the residence time is about 2–4 seconds. The gaseous products leave at about 1,200°C, and the mineral/metal molten slag leaves at about 1,600°C as a two-phase flow because of the difference in the density of the minerals and the metals. The molten material is then quenched by using water. Because the thermal conductivity of the minerals is different than that of the metals, the quenching process produces two products, minerals and metals that can be separated by a magnet. The product gas stream is cleaned by first very rapidly quenching with water. The gases are scrubbed in an acidic scrubber to remove HCl, HF, and heavy metals. The gases are then scrubbed in an alkaline scrubber to remove residual acid liquid droplets. The gases are subsequently de-sulphurized and dried. No changes in the operating procedures were required to accommodate the shredder residue, and no significant changes were observed in the output streams. All emissions remained well within the limits. No refractory wear beyond that observed when processing MSW was apparent.
Changing World Technologies	This is a two-stage thermal conversion/depolymerization process that converts organic material into fuels, gases, and solids. A study focused on two different types of shredder residue was conducted. Results indicated that the process was able to convert the shredder residue samples to three product fractions - an oil, a gas, and a carbon char. On the basis of the results of this initial testing, a test on about 600 kilograms of shredder residue was undertaken. The results are as follows: (i) tests demonstrated the ability of the process to convert shredder residue into oil and solid product streams; (ii) PCBs in the shredder residue dissolved in the hot oil and were eventually destroyed during hydrolysis. As a result, their concentration was reduced from 35–65 ppm to less than the detection limit of 2 ppm; (iii) thermal cracking of the hydrolyzed oil at about 500°C produced hydrocarbon fuels, a fuel-gas, and a solid carbon product in ratios of 84%, 10%, and 6%, respectively. Fractional distillation of the cracked fuel produced gasoline (12%), kerosene (38%), diesel (32%), heavy oil (15%), and gas (3%); and (iv) economic analysis of the process was conducted on the basis of a plant that has a design capacity of 103,800 tons/yr. On the basis of these assumptions, the plant would generate annual revenues of approximately \$14 million. The average net free cash flow for the first 3 years would be approximately \$4.6 million.

Sources:

Argonne National Laboratory (September, 2010), *End-of-Life Vehicle Recycling: State of the Art of Resource Recovery from Shredder Residue*.

## 6.5 Incorporation of ASR into Manufactured Products

It is very difficult to mechanically separate the fine sized fraction (<20mm) of ASR into ferrous and non-ferrous metals, plastics, etc. In addition, this fraction generally exhibits the worst combustion characteristics. Therefore several studies have investigated the potential of directly incorporating the fine sized ASR fraction into such products as composites, concrete or asphalt. However most of these applications are still at the research phase and further investigation is necessary before real scale application is possible. Additional details on some of these end-products that could contain ASR are as follows:<sup>210</sup>

- Composites – tests have been conducted to produce rigid composites from ASR using isocyanate-based binders. Another study investigated the dual-injection moulding process to incorporate ASR into composites. A skin of virgin polymer was moulded over the core material, containing ASR. Polypropylene was used as skin material, while the core consisted of a 50/50 (by volume) mixture of polypropylene and ASR granules. The properties of this composite were found acceptable to manufacture low strength components such as housings, casings and covers or for products where the mechanical strength can be provided by large cross-sections.
- Concrete – the fine-sized fraction of ASR typically contains approximately 30% organic matter, as well as inorganic substances such as quartz, calcite, magnetite, hematite, anhydrite. If calcium sulfoaluminate cement is used, ASR can be directly incorporated into the concrete. Heavy metals, such as zinc and lead, were found to be successfully integrated and immobilized into the structure. This ASR-concrete mixture can be used for various applications including road construction.
- Binder and/or aggregate in asphalt - incorporation of the fine-sized fraction of ASR in asphalt reduces the oxidation of the asphalt and increases the elastic memory, thus preventing fatigue cracking. Past research has shown that granules, produced by mixing ASR with binding materials (lime or cement), fly ash and a densifying agent, were a suitable aggregate in asphalt mixes. The optimum ASR to fly ash ratio was determined to be 1 to 1.

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<sup>210</sup> Ibid.

## 6.6 Conclusions

Even though it contains valuable material as plastics, copper wires and up to 5% of remaining metals, shredder residue is usually landfilled. This is mainly a consequence of the high pollutant content as well as of the lack of cost-effective sorting technologies, suitable for the separation of valuable materials from the shredder residue.<sup>211</sup> There are several factors that contribute to the desire to manage ASR in a manner other than landfills, for instance:<sup>212</sup> (i) the amount of material that is generated annually; (ii) the recyclable materials content (such as plastics and metals); (iii) the high heat value of ASR (more than 13 MJ/kg); and (iv) its potential hazardousness due to the presence of oils, hydrocarbons, PCBs and heavy metals.

Post-shredder technologies are innovative processes dealing with the residual material, specifically shredder residue. Post-shredder technologies can be distinguished into two main categories: (i) those based on physical and mechanical sorting of the waste into different fractions that can be recycled and sold; and (ii) those based on the thermal treatment of the waste to recover chemical building blocks or fuel for energy production.<sup>213</sup> It has been suggested that a net environmental performance improvement appears to be ensured by those scenarios which include the application of post-shredder technologies.<sup>214</sup>

Europe appears to be much more progressive than North America in terms of developing and implementing technologies/options to address shredder residue other than landfilling. This is likely primarily attributed to European Commission Directives which mandates that options other than landfills be implemented. It is likely that until similar regulations are established in North America, landfills will still predominate in terms of the management of shredder residue.

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<sup>211</sup> Morselli, L. et. al. (2010), *Automotive Shredder Residue (ASR) Characterization for a Valuable Management*, published in Waste Management.

<sup>212</sup> Ibid.

<sup>213</sup> Ibid.

<sup>214</sup> Ciacci, L., et. al. (2010), *A Comparison Among Different Automotive Shredder Residue Treatment Processes*, published in the International Journal of Life Cycle Assessment.

## 7. Discussion of the Potential for Future Sampling of SR by Environment Canada

### 7.1 Sampling Standards

There were no standard test methodologies specific to auto shredder residue in Canada or the U.S. identified through Internet literature research or industry interviews. Contacted parties include SGS International, Argonne National Laboratory, Environmental Analytical Laboratories, Saskatchewan Research Council and W. Z. Baumgartner & Associates, Inc.

In the U.S., individual state environmental agencies are free to choose methods that are deemed appropriate and or may elect to specify no testing method for ASR. Many states do not specify a test method and place the onus on the individual shredders to select a method deemed appropriate for the given parameter and to perform the tests themselves. These tests are intended to ensure that the waste being sent to standard landfills does not contain contaminants above the federal threshold for “toxic” waste as specified in the regulation 40 CFR 261. Some laboratories or experts have developed testing procedures for ASR such as W. Z. Baumgartner & Associates Inc., based in Franklin, TN. Baumgartner and Associates have performed extensive work in the auto shredder industry including multiple projects with Argonne National Laboratory. They have written testing procedures that have been adopted by states such as Arizona, Minnesota, Wisconsin, Massachusetts, Kentucky, and Pennsylvania.<sup>215</sup> The following sections provide descriptions on some identified ASR testing methodologies.

#### 7.1.1 40 CFR 761

40 CFR 761 is a U.S. Environmental Protection Agency regulation on polychlorinated biphenyls (PCBs) in manufacturing, processing, distribution in commerce, and use prohibitions. It covers a variety of PCB-containing materials including PCB-containing wastes from the shredding of automobiles, household appliances, or industrial appliances. In the regulation, Subpart R is the *Sampling Non-Liquid, Non-Metal PCB Bulk Product Waste for Purposes of Characterization for PCB Disposal in Accordance With Section 761.62, and Sampling PCB Remediation Waste Destined for Off-Site Disposal, in Accordance with Section 761.61*. It specifies testing methods for PCBs in wastes including sample collection and sample sorting. This method tests for extractable PCB under simulated landfill conditions.<sup>216</sup> One common testing procedure under this

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<sup>215</sup> Interview with W. Z. Baumgartner & Associates, December, 2013.

<sup>216</sup> USEPA. 40 CFR Part 761 - *Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution In Commerce, And Use Prohibitions*

regulation is U.S. EPA Method 1311: Toxicity Characteristic Leaching procedure (TCLP). This method tests for the extractable levels of various contaminants under simulated landfill conditions.

### 7.1.2 W. Z. Baumgartner & Associates

This methodology has been adopted by several states including Arizona, Minnesota, Wisconsin, Massachusetts, Kentucky, and Pennsylvania. It specifies the sampling procedures and test methods to be used in order to analyze for TCLP metals (lead, cadmium, and other metals), PCBs, semi volatiles, and volatiles. This method differs from the 40 CFR 761 method since it tests for total PCB content.<sup>217</sup>

### 7.1.3 Quebec

Quebec has no prescriptive testing methodology for auto shredder residue but since it does allow ASR to be disposed of in landfills, the ASR must meet the regulations set forth in *Règlement sur l'Enfouissement et l'Incineration de Matières Résiduelles (REIMR) Q-2, r. 19*. This is Quebec's regulation on the disposal and incineration of waste. It contains limits on water permeability and particle size that any material must meet before it can be used as landfill cover.

### 7.1.4 Arizona Department of Environmental Quality and Solid Waste Management

The Arizona Department of Environmental Quality and Solid Waste Management has a methodology for ASR sampling based on the method created by W. Z. Baumgartner & Associates. It specifies how sampling should be conducted over an eight hour period of normal shredder operation. Seven 2,000 gram samples are to be collected from the shredder, which must then be subdivided into twenty 100 gram samples. Further steps including screening, manual particle resizing, and re-distribution are required in order to achieve representative ASR samples. Arizona specifies that the samples must be tested for extractable arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, cadmium, and lead. The samples are deemed toxic if they exceeded the limits set forth in 40 CFR 261.24. The limit for PCB concentration in the waste is 50 mg/kg.<sup>218</sup>

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<sup>217</sup> Interview with W. Z. Baumgartner & Associates, December, 2013.

<sup>218</sup> Arizona Department of State, *Title 18. Environmental Quality, Chapter 13. Department of Environmental Quality Solid Waste Management*. Available at: [http://www.azsos.gov/public\\_services/Title\\_18/18-13.htm](http://www.azsos.gov/public_services/Title_18/18-13.htm)

## 7.2 Laboratories Capable of Testing

It is expected that a large number of chemical analysis laboratories are capable of testing ASR using the testing methodologies described above. The table below lists some common analytes that are tested for in ASR analysis.

**Table 42: Typical Testing Criteria for ASR**

Test Criteria	Description
TCLP Metals	As, Ba, Cd, Cr, Pb, Hg, Se, Ag
TCLP Volatiles	Benzene, carbon tetrachloride, chlorobenzene, Methyl ethyl ketone, Vinyl chloride
TCLP Semi-volatiles	Cresols, Hexachlorobutadiene, 6 Nitrobenzene, Pentachlorophenol,
Polychlorinated Biphenyls (PCB)	
Pesticides	Endrin, Lindane, 2,4,5-TP (Silvex), Chlordane,

Source: Arizona Department of State, *Title 18. Environmental Quality, Chapter 13. Department of Environmental Quality Solid Waste Management.* Available at: [http://www.azsos.gov/public\\_services/Title\\_18/18-13.htm](http://www.azsos.gov/public_services/Title_18/18-13.htm)

The TCLP method is a common test method for testing a variety of wastes such as municipal solid waste, industrial waste, and mining waste. According to the method, if an analysis of any one of the liquid fractions of the TCLP extract indicates that a regulated compound is present at such high concentrations that even after accounting for dilution from the other fractions of the extract, the concentration would be above the regulatory level for that compound, then the waste is hazardous and it is not necessary to analyze the remaining fractions of the extract.<sup>219</sup>

Most major environmental testing laboratories are expected to have the capability of performing this test although many may not have performed tests on shredder residue in the past. Laboratories that specialize in soil testing and contaminated site testing are expected to be capable of handling this type of analysis. Many of the above substances are routinely tested by these labs. The laboratories identified below are some of the major labs known to be capable of performing TCLP tests on waste material.

<sup>219</sup> USEPA. (1992). *Method 1311, Toxicity Characteristic Leaching Procedure.*

### Canada

- SGS;
- Maxxam Laboratories;
- Exova;
- Environmental Analytical Laboratories, Saskatchewan Research Council;
- ALS Environmental;
- National Laboratory for Environmental Testing (NLET); and
- EMSLCanada, Inc.

### USA

- Environmental Monitoring & Technology Inc.; and
- TestAmerica Laboratories Inc.

## 7.3 Issues

One of the issues identified surrounding testing ASR residue in the U.S. was the method for testing polychlorinated biphenyls (PCBs). The U.S. EPA method does not specify the extraction method that must be used. As a result, a commonly used test method is *U.S. EPA Method 1311: Toxicity Characteristic Leaching Procedure (TCLP)*, which typically involves an aqueous extraction step in order to simulate typical extraction conditions in a landfill.<sup>220</sup> PCBs are strongly hydrophobic (water-repelling) substances and have negligible solubility in water. Instead, PCBs tend to strongly adsorb onto soil, plastic particles, or partition into an oil/grease phase present in the material. As a result, this methodology does not capture real PCB contents of a material but only the extractable PCB levels. Many aqueous TCLP tests will not detect any PCBs but a test using a hexane extraction will produce significant levels. Some concerns were expressed that while testing for extractable PCBs is good in theory (because it simulates real-world conditions), future regulations may require total PCB testing.<sup>221</sup> A similar situation may occur when testing for flame retardants and plasticizers that may also be hydrophobic in nature. Different test procedures are required to analyze for these types of organic compounds.

Testing of ASR is further complicated by the fact that the material is highly heterogeneous and includes such varied materials as plastics (foams, rubbers, PVC), glass, dirt, fluids (oils, greases) and some small metal particles. Establishing methods to obtain a well-mixed, representative sample can be difficult. Some tests, such as a total metals test, are further complicated because they require a small sample quantity (such as 1 gram). It is often difficult to obtain a representative 1 gram sample of ASR due to the highly irregular particle sizes and densities. As a result, such tests often require 20 or

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<sup>220</sup> Ibid.

<sup>221</sup> Interview with W. Z. Baumgartner & Associates, December, 2013.

more individual 1 gram tests to be aggregated, which can increase the testing costs significantly.

## 7.4 Priority Chemicals for Testing in Shredder Residue

Based on the results of this study, there are many CMP chemicals that have not been tested for their concentration in shredder residue. All identified literature that has specified the concentration of specific chemicals in shredder residue was outlined earlier in this report. Therefore Environment Canada should review the list of priority CMP substances to identify those that are considered to be of most importance for testing in shredder residue.

It is suggested that CMP II substance groupings such as phthalates, certain organic flame retardants and methylenediphenyl diisocyanates would be good candidates for analysis. These substances have not been tested for their concentration in shredder residue, based on the available literature reviewed during this study (except for one phthalate). An earlier table in the report provided commentary on the likelihood of CMP I substances (that have been declared toxic) being present in auto shredder residue. Environment Canada is encouraged to review this table along with the priorities for the management of these chemicals in Canada to determine which of these substances should be selected for testing in shredder residue.

## 7.5 Conclusions

The research conducted for this study did not identify any standard test methodologies as jurisdictions are often free to choose their own test method. One identified test method (developed by W. Z. Baumgartner & Associates) is used as a basis by several U.S. state environmental agencies as a template for their test methods. According to Argonne National Laboratory, it is one of the only and most rigorous test methods for ASR.

There is no single test suitable to ASR, rather, the types of tests performed depend on the exact substances of interest. Polychlorinated biphenyls are a commonly tested substance along with the Toxicity Characteristic Leaching Procedure (TCLP) to identify metals and volatiles. Most large environmental testing laboratories are capable of performing the various tests on ASR as they involve the same equipment and instruments as other testing of wastes, soils, and other material. Common tests and previous ASR studies do not capture many of the CMP II group substances. As a result, specialized tests for phthalates, certain organic flame retardants, and methylenediphenyl diisocyanates would be good candidates for analysis. The ASR testing methodologies are unique because they must produce a very small representative sample of ASR, a highly heterogeneous and variable material, which can be difficult.



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