Supporting Information for the manuscript:

Scarce Metals in Conventional Passenger Vehicles and End-of-Life Vehicle Shredder Output

Rolf Widmer[1], Xiaoyue Du[1], Olaf Haag[2], Eliette Restrepo[1] and Patrick A. Wäger[1]*

*E-mail: rolf.widmer@empa.ch

Table of Figures

Table of Tables

Table of Lists

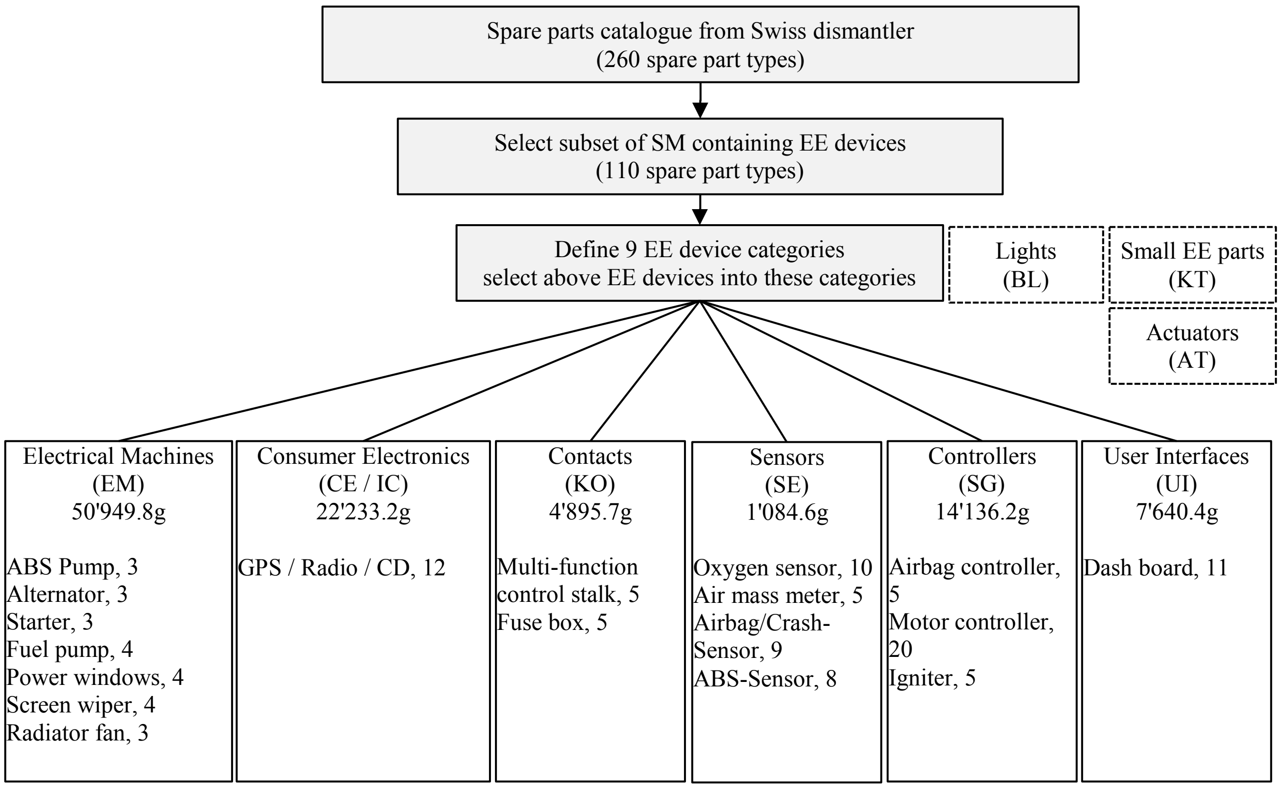


Figure SI 1: Selection procedure for EE devices from spare parts.

The considerations for the selection of device categories are documented in the report "Verwertung von Seltenen Technologiemetallen aus der Automobilelektronik in der Schweiz: Systemübersicht und Probenahmekonzept" (download).

excerpts:
The primary goal of this measurement campaign is to find evidence for the occurrence of the SM in the various components in order to gain an overview of SM in automotive electronics. It is not intended to acquire representative SM mass fractions for EE components from ELVs. Therefore, the following guidelines regarding the sampling result:

1. The number of analyzed components will be adjusted to the available parts in VASSO's spare parts store and is kept low. To allow meaningful statements about SM content in the electronic components, the number of analyzed components would have to be significantly higher (hundreds instead of dozens).
2. (For budget reasons) The number of samples to be analyzed is also kept small. For a more representative study the measurement of three, if not of 5 or more samples per sampled material would be necessary. In this measurement campaign, however, only 1 sample per material is measured.

The 3 categories which were neglected are:
Components from the device categories "Lighting" (BL), "Small parts" (KT) and "Actuators" (AT) were not selected. The reasons are as follows:

BL: The lamps used are commonly incandescent lamps, i.e. the SM content is low or known (contain W filaments with a total mass of a few hundred milligrams). Regarding the SM xenon technology might be of interest, however, according to VASSO still (almost) no bulbs of this type are found.

KT: Compared to EEE in vehicles their masses and the SM content are very low.

AT: These components are difficult to extract and thus not available for sampling.

119 EE devices from 6 out of 9 pre-defined EE device categories were picked from the spare part dealer's stock. The total mass was approximately 103 kg of which half accounted for Electrical Machines EM. 17 different types of EE components were extracted from the parts in the 119 EE

devices. The sampling plan of EE components, including the devices that provided the components for the final samples is presented in Table SI 1 below.

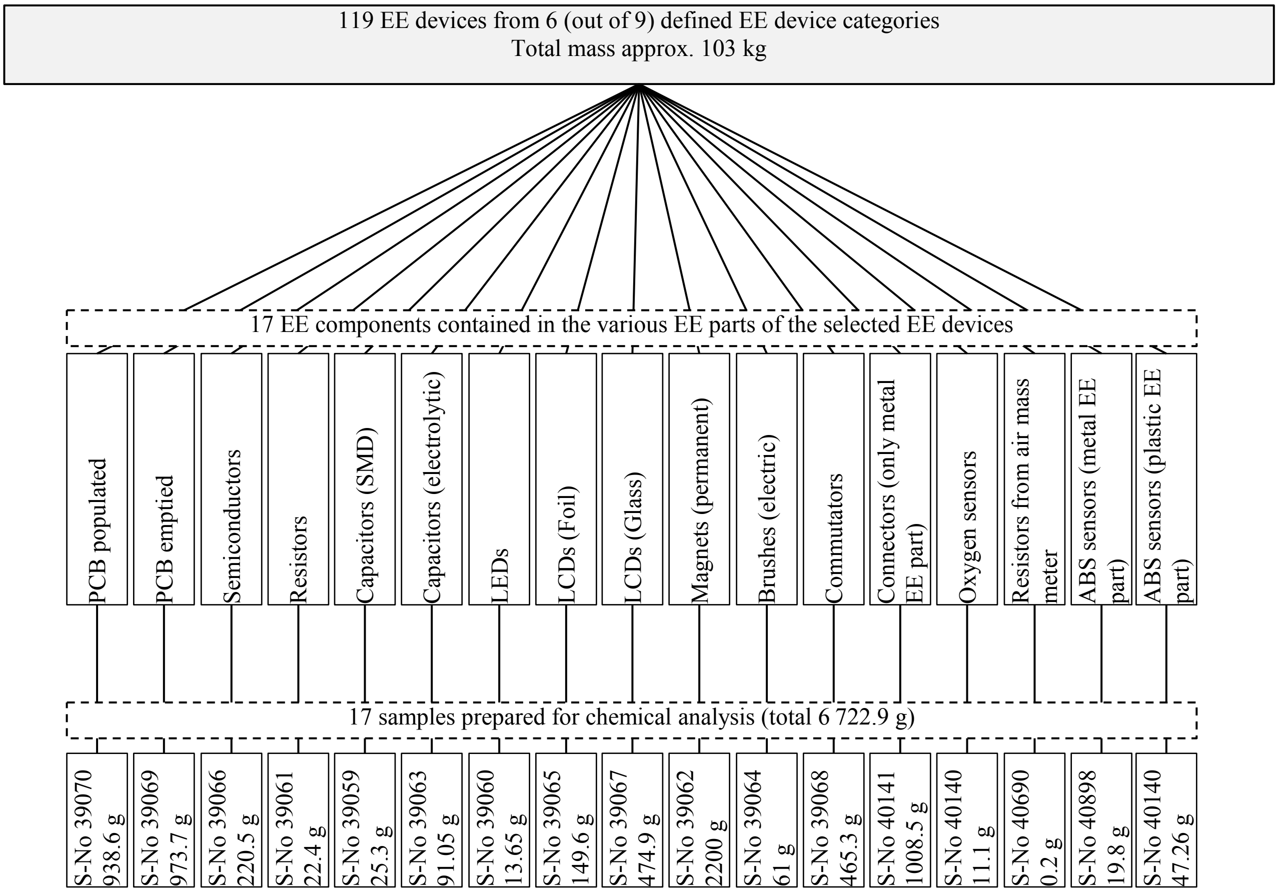


Figure SI 2: Selection procedure of EE components from 9 defined EE device categories

Table SI 1: Sampling plan of EE components

		17 sampled EE component types - Each consisting of multiple components - Each type was one sample for chemical analyses																
			Correspond to a populated PCB															
EE device category	**EE devices from which the EE components were extracted**	PCB populated	PCB emptied	Semiconductors	Resistors	Capacitors (SMD)	Capacitors (electrolytic)	LEDs	LCD Displays (Foil)	LCD Displays (Glass)	Magnets (permanent)	Brushes (electric)	Commutators	Connectors (only metal EE part)	Oxygen sensors	Resistors from air mass meter	ABS sensors (metal EE part)	ABS sensors (plastic EE part)
Electrical Machines (EM)	ABS pump										X	X	X	X				
	Alternator																	
	Starter motor										X	X	X					
	Fuel pump										X	X	X	X				
	Power windows										X	X	X	X				
	Wiper Motor										X	X	X	X				
	Radiator fan motor										X	X	X	X				
Consumer Electronics (CE)	GPS / Radio/ CD	X	X	X	X	X	X	X	X	X	X	X	X	X				
Contacts (KO)	Multi-function control stalk													X				
	Fuse box													X				
Sensors (SE)	Oxygen sensor													X	X			
	Air mass meter													X		X		
	Airbag / crash sensor													X				
	ABS sensor																X	X
Controllers (SG)	Airbag controller	X	X	X	X	X	X							X				
	Ignition controller																	
	Motor controller	X	X	X	X	X	X							X				
User Interface (UI)	Instruments	X	X	X	X	X	X	X			X	X	X	X				
Sample mass (in grams)		**938.6**	**973.7**	**220.5**	**22.4**	**25.3**	**91.1**	**13.7**	**149.6**	**474.9**	**2200.0**	**61.0**	**465.3**	**1008.5**	**11.1**	**0.2**	**19.8**	**47.3**

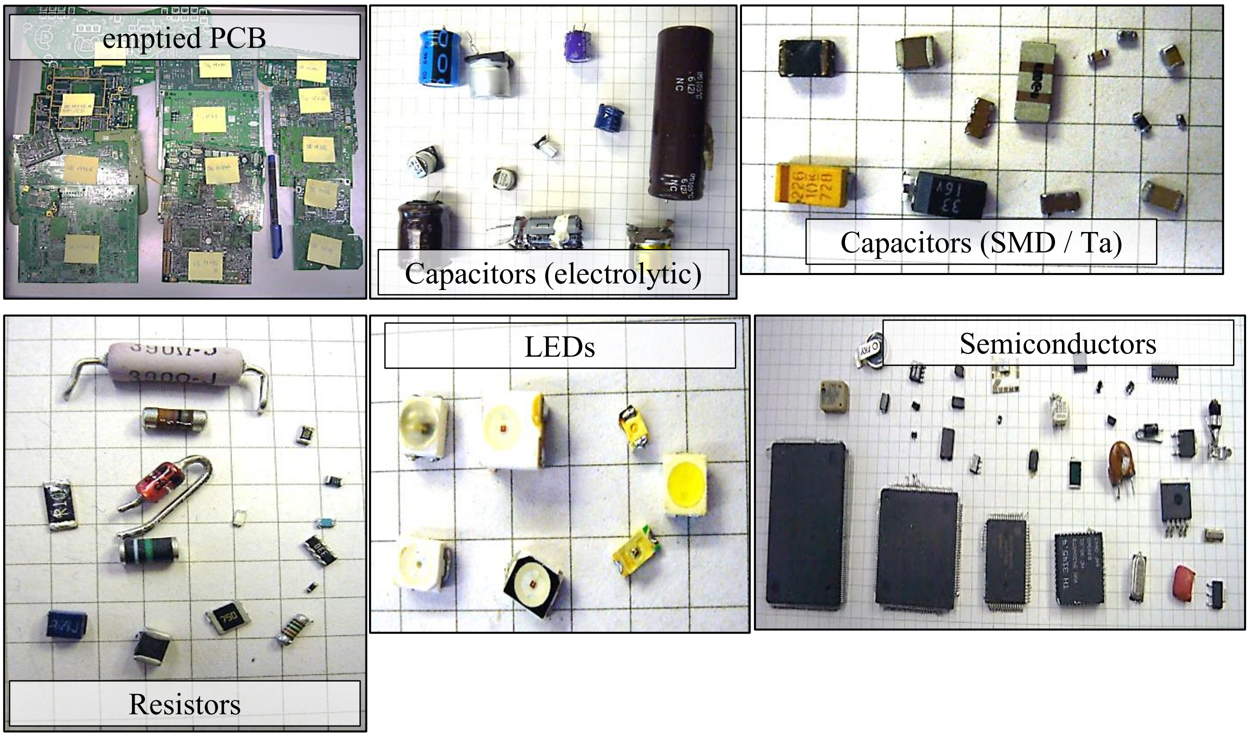


Figure SI 3: Photos of sampled EE components: emptied PCB and removed electronic components

Figure SI 4: Photos of sampled EE components: components from electrical motors.

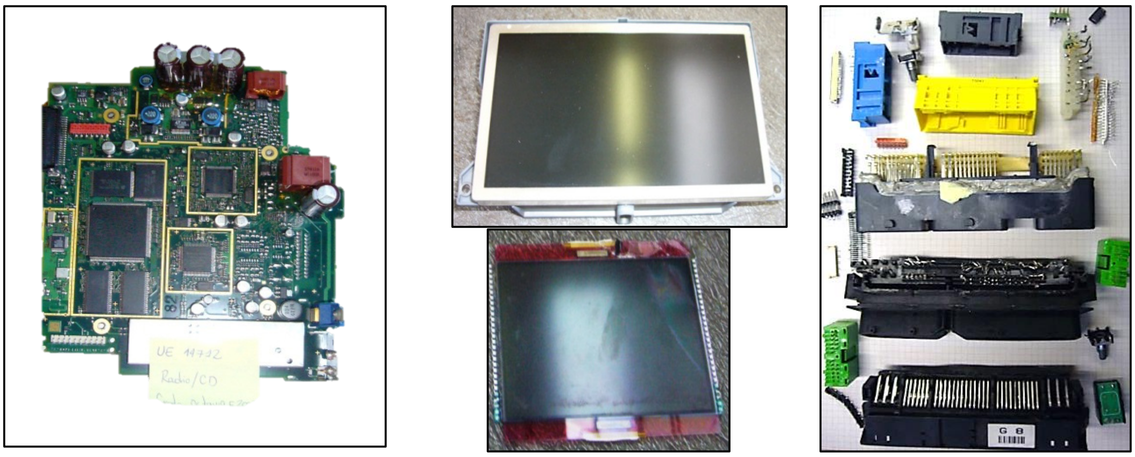


Figure SI 5: Photos of sampled EE components: populated PCB, LCD glass and foil and metal part of connectors.

Figure SI 6: Photos of sampled EE components: ABS sensor's plastic and metal part, sensor element in lambda probe (removed in picture) and resister from air mass flow meters.

List SI 1: Preparation of EE component samples for chemical analysis

- SMD capacitors, resistors, LED and sensor element in lambda probe (4 samples) were comminuted with a cryogenic mill under liquid nitrogen cooling. The comminution process was repeated until all the material passed through a 0.5 mm sieve.
- Populated and depopulated (emptied) PCB, integrated circuits (semiconductors) and commutators (4 samples) were treated with liquid nitrogen, sheared, and then crushed with a jaw crusher. Following, the material was submitted to a vibrating disc mill until it reached a particle size smaller than 0.5 mm.
- Electrolytic capacitors (1 sample) were crushed in a jaw crusher and then passed through a cutting mill until the particle size of the material was smaller than 0.5 mm. Then, the material was reduced to a particle size of less than 0.12 mm by a centrifugal mill.
- The metal part of the connectors (1 sample) was consecutively passed through a vibrating disc mill, a cutting mill and a centrifugal mill until its particle size was reduced to less than 0.12 mm.
- The LCD glass (1 sample) was first crushed in a jaw crusher and then separated into two fractions with particle sizes larger than 1 mm and smaller than 1mm. The fraction >1 mm was further reduced to less than 0.12 mm with a cutting and a centrifugal mill. The fraction >1 mm, which consisted of a mixture of glass and plastics, was reduced to less than 0.1 mm in a ball mill. In a last step, the fractions were recombined in one sample.
- Resistors from air mass meters were comminuted to a size less than 0.5 mm by means of a mortar.
- Magnets were first broken into pieces with a 60 ton press and then reduced to a particle size of less than 0.5 mm with a sequence of jaw crusher and ball mill.
- Electric brushes were reduced to a particle size of less than 0.5 mm with a jaw crusher and a ball mill.
- The EE particle size of LCD foils was reduced to 6 mm by means of a hole punch.
- The EE particle size of the plastic EE part of ABS sensors was reduced with a centrifugal mill in several loops until less than 0.12 mm.
- The size of the metal part of ABS sensors could not be reduced by means of the equipment available and hence was digested as such.

List SI 2: Chemical analysis for both experiments

- For a first screening a subset of 13 metals (Ag, Co, Ga, Ge, La, Mo, Nb, Rb, Sb, Sn, Sr, W and Zr) was semiquantitatively analyzed. The analyses were carried out using an X-ray fluorescence (XRF) spectrometer and the Turbo-Quant method (fundamental parameter calibration). The spectrometer was calibrated for samples of not geological origin. For each of the selected samples, an aliquot of the homogenized sample was introduced into an XRF cuvette and located into the automatic sampler where it was measured one time.

- Five different digestion methods were used in the quantitative analysis:
  1. Total microwave digestion: was used for samples consisting of non-elemental metal and other materials to determine mass fractions of all investigated elements except Ag. In a first stage the material was digested in a microwave vessel with a mixture of nitric acid (67-69%, p.a.), hydrochloric acid (37%, p.a.) and hydrofluoric acid (48%, p.a.) at 220°C and a maximum 400 psi. In a second stage, saturated boric acid was added to the remaining hydrofluoric acid and the material was further digested at 160°C.
  2. Metal microwave digestion with hydrofluoric acid (HF): was used for samples consisting of elemental metal to determine mass fractions of all investigated elements except Ag. In a first stage, the material was digested in a microwave vessel with a mixture of hydrochloric acid (37%, p.a.) and nitric acid (67-69%, p.a.) in a 1:3 ratio at 180°C and maximum pressure of 300 psi. In a second stage, hydrofluoric acid (48%, p.a.) was added and the material was digested at 220°C and 300 psi. In a third stage, saturated boric acid was added to the remaining hydrofluoric acid and the material was digested at 180°C and a maximum of 100 psi.
  3. "Plastics" microwave digestion: An extra of hydrogen peroxide was added to the total microwave digestion when organic matter was present in the sample in order to avoid overpressure due to formation of nitrogen oxides in the presence of nitric acid.
  4. Aqua-regia microwave digestion: was used for samples consisting of non-elemental metal and other materials to determine of Ag mass fractions. The material was digested in a microwave vessel with a mixture of hydrochloric acid (37%, p.a.) and nitric acid (67-69%, p.a.) in a 1:3 ratio. Temperature was sequentially increased to 170°C under unmonitored pressure.
  5. Aqua-regia open digestion: was used for samples consisting of non-elemental metals and other materials to determine Ag mass fractions, as well as for metallic samples that were not possible to homogenize to determine mass fractions of all elements except Ta, W and Zr. The material was digested in an open vessel with a mixture of hydrochloric acid (37%, p.a.) and nitric acid (67-69%, p.a.) in a 1:3 ratio at 150°C.
- For each sample, a single or several parallel digestions from the above were carried out depending on the material of the sample and the metals to be analyzed. A sub-sample of about 0.5 g of material from the homogenized sample was taken for the microwave digestions and of about 1 to 3 g for the aqua-regia open digestion.
- Out of the 31 metals, 29 metals (except Co and Sn) were measured with an Agilent 7500ce Octopole Reaction System Inductively Coupled Plasma Mass Spectrometer (ORS-ICP-MS) and a Thermoelement 2 High-Resolution Sector Field Inductively Coupled Plasma Mass Spectrometer (HRSF-ICP-MS). Co and Sn were measured with a Varian 735-ES Inductively Coupled Plasma Atomic Emission Spectroscope (ICP-OES). Linear calibrations were performed in accordance with the mass fraction ranges of the elements analyzed.
- The final mass fraction result for each element in each sample was the average of the measurements of the different digested sub-samples, respectively, total microwave and metal microwave digestions for all elements, except Ag and aqua regia digestions for Ag.
- Because In has no undisturbed isotope its mass fraction was calculated via the Sn mass fraction and the Sn-isotope ratio. For this, and additional measurement of the mass fraction of Sn was carried out using ORS-ICP-MS and HRSF-ICP-MS and the value of In was corrected accordingly.
- The combined uncertainty of the mass fraction value, taking into account the contributions of sample preparation, digestion and measurement, is estimated to be approximately between 12% and 24%. For elements in very small mass fractions, the uncertainty may increase 2% to 3% (Bachema, 2011).

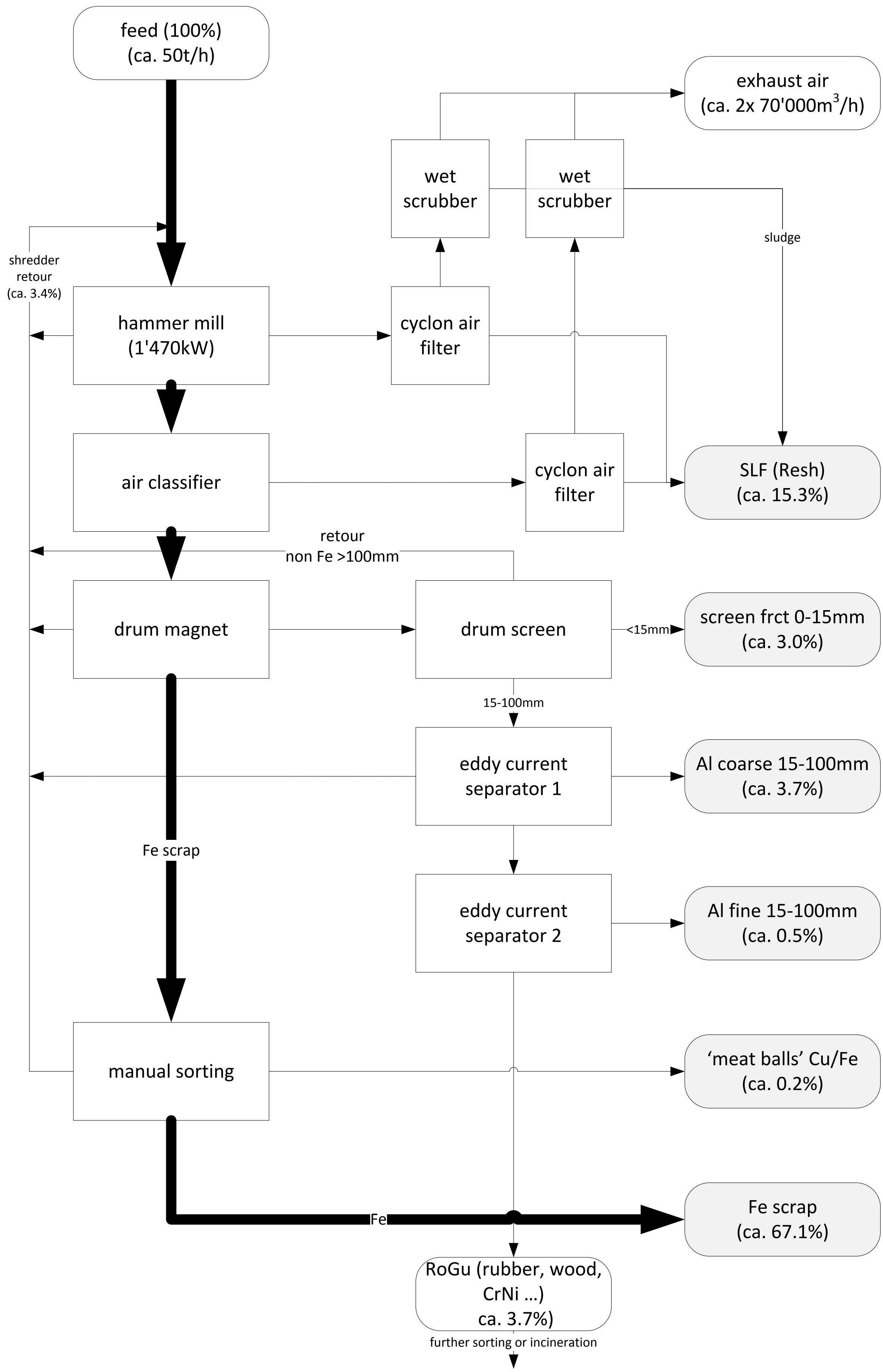

feed (100%)
(ca. 50t/h)
exhaust air
(ca. 2x 70'000m3/h)
wet
scrubber
wet
scrubber
sludge
shredder
retour
(ca. 3.4%)
hammer mill
(1'470kW)
cyclon air
filter
air classifier
cyclon air
filter
SLF (Resh)
(ca. 15.3%)
retour
non Fe >100mm
drum magnet
drum screen
<15mm
screen frct 0-15mm
(ca. 3.0%)
15-100mm
eddy current
separator 1
Al coarse 15-100mm
(ca. 3.7%)
Fe scrap
eddy current
separator 2
Al fine 15-100mm
(ca. 0.5%)
manual sorting
'meat balls' Cu/Fe
(ca. 0.2%)
Fe
Fe scrap
(ca. 67.1%)
RoGu (rubber, wood,
CrNi ...)
ca. 3.7%)
further sorting or incineration

Figure SI 7: Flow sheet of the shredding process; share of shredder fraction masses are shown in percent of the total batch test output mass.

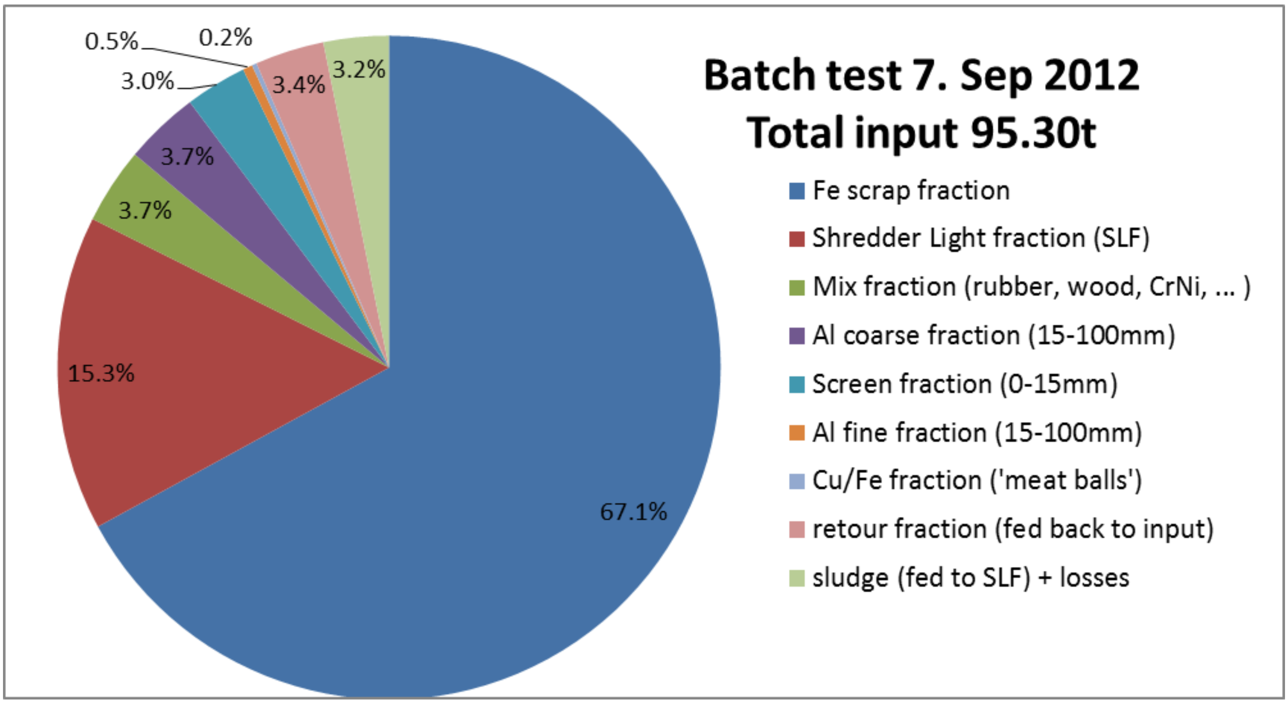


Figure SI 8: Mass distribution over the shredder fractions.

Figure SI 9: Snapshots of the shredder fractions considered in mass balance.

1) Fe scrap (or coarse) fraction, 2) Shredder Light fraction (SLF), 3) Mix (or RoGu) fraction (mainly, rubber, wood, CrNi, ...), 4) Al coarse fraction (15-100mm), 5) Screen fraction (0-15mm), 6) Al fine fraction (15-100mm), 7) Cu/Fe (or 'meat ball') fraction and 8) the retour fraction (fed back to input). Not shown is the sludge from the wet scrubber, which is fed to the SLF and of course also not shown are the losses.

List SI 3: Sampling of shredder fractions

The purpose of the sampling process was to collect as representative as possible samples of all the shredder fractions. Depending on the process and materials, different sampling procedures were applied.

Shredder light fraction (SLF): all material was dumped in a pile on the open ground, then mixed and divided into four smaller piles by a material handler. 2 x 60 Liter Euro stacking container material was collected by randomly shoving it from the output pile.

Screen fraction: 2 containers were collected by extracting single scoops in regular time intervals from existing material stream.

Coarse and a fine aluminum fraction: 1 container each of the material was randomly hand-picked from the collecting container at the end of the process.

Iron scrap fraction: 1 container of randomly grabbed material was hand-picked by four persons off the running conveyor belt.

Mixed material fraction: 1 container of material (mainly rubber, plastic and wood (ca. 60%) but also non Fe metals such as CrNi, Cu cables and PCB) was randomly shoved from the output pile at the end of shredding process.

Scrubber sludge fraction: 1 glass jar of (approx. 0.5 Liter) material was collected from the sump of the wet scrubber for each: the floating froth, the top and the bottom water layer.

"meat balls" fraction: (mainly rotors and stators) this material was not sampled.

List SI 4: Chemical analysis of the metal surface of the Al and Fe coarse fractions

1. The Al coarse and Fe scrap fractions (2.5±0.05 kg each sample) were washed in 1% HNO3.
2. the washed Al and Fe pieces were ground and analysed to establish the SM mass fraction in their volume (the inside of the metal pieces, also referred to as "core", "matrix" or "solvent")
3. The eluate was filtered and produced 3 fractions: 1) "grob": the scrubbed off layer on the filter, "fein": the filter itself containing particles >0.45µm and 3) the filtered eluate.
4. All 3 fractions were prepared and analysed to establish the SM mass fractions in each.
5. The cumulated mass fraction w_x^{all} (in mg/kg) of the SM x in all 3 fractions is calculated with the following equation:

$$w_x^{all} = \frac{m_x^{grob} + m_x^{fein} + m_x^{lösung}}{m_{total}}$$

with:
m_{total} the initial mass of the Al coarse and Fe scrap fractions to be washed (in g)

and using

$$m_x^{grob} = w_x^{grob} \times m_{grob}$$

with:
m_x^{grob} the mass of metal x in the scrubbed off layer on filter (in µg)
w_x^{grob} the mass fraction of metal x in the scrubbed off layer on filter (in mg/kg or ppm)
m_{grob} the mass of the scrubbed off layer on filter (in g)

$$m_x^{fein} = w_x^{fein} \times m_{fein}$$

with:
m_x^{fein} the mass of metal x in the filter (in µg)
w_x^{fein} the mass fraction of metal x in the filter (in mg/kg or ppm)
$m_{fein} = m_{filter\_after} - m_{filter\_before}$ the mass of the material deposited in the filter during filtering (in g)

$$m_x^{lösung} = c_x^{lösung} \times v_{lösung}$$

with:

$m_x^{lösung}$	the mass of metal x in the eluate (in µg)
$c_x^{lösung}$	the concentration of metal x in the eluate (in mg/L)
$v_{lösung}$	the volume of the scrubbed off the eluate (in mL)

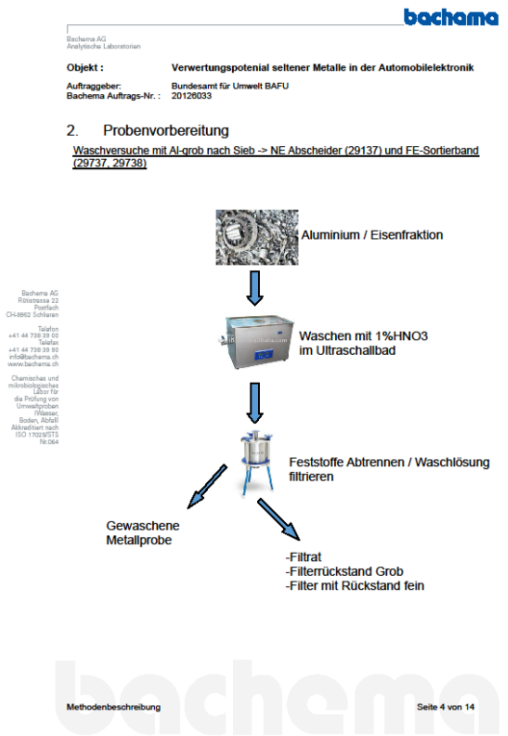
For the Al coarse fraction only one, for the Fe scrap fraction two valid measurements resulted; for the latter the average value was used. In case of measured values below detection levels the values for the calculations were set to zero. In case all measured values below detection levels the result of the calculations were set to "below threshold (b.t.)"

The terms "concentration" and "mass fraction" are defined in general and physical chemistry. A comprehensive overview is given in e.g. "Quantities, Units and Symbols in Physical Chemistry", page 77, second edition, published by the INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY, 1993". A brief summary is given in the following table:

Concentration type	Symbol	Definition	SI unit	other unit(s)
mass concentration	ρ_i or γ_i	m_i/V	kg/m³	g/100mL (= g/dL)
molar concentration	c_i	n_i/V	mol/m³	M (= mol/L)
number concentration	C_i	N_i/V	1/m³	1/cm³
volume concentration	ϕ_i	V_i/V	m³/m³	
Related quantities	**Symbol**	**Definition**	**SI unit**	**other unit(s)**
normality		c_i/f_{eq}	mol/m³	N (= mol/L)
molality	b_i	$n_i/m_{solvent}$	mol/kg	
mole fraction	x_i	n_i/n_{tot}	mol/mol	ppm, ppb, ppt
mole ratio	r_i	$n_i/(n_{tot} - n_i)$	mol/mol	ppm, ppb, ppt
mass fraction	w_i	m_i/m_{tot}	kg/kg	ppm, ppb, ppt
mass ratio	ζ_i	$m_i/(m_{tot} - m_i)$	kg/kg	ppm, ppb, ppt

Since different methods were used to chemically analyze and measure the content of SM in various matrices the authors were careful not to mingle the terms: whenever the SM is contained in a mass the term "mass fraction" is used, whenever the SM is contained in a volume the term "concentration" is used.

List SI 5: List of the applied procedures and their detailed description for the sample preparation



bachama

Bachema AG
Analytische Laboratorien

Objekt : **Verwertungspotenial seltener Metalle in der Automobilelektronik**

Auftraggeber: Bundesamt für Umwelt BAFU
Bachema Auftrags-Nr. : 20126033

2. Probenvorbereitung

Waschversuche mit Al-grob nach Sieb -> NE Abscheider (29137) und FE-Sortierband (29737, 29738)

Aluminium / Eisenfraktion

Waschen mit 1%HNO3
im Ultraschallbad

Feststoffe Abtrennen / Waschlösung
filtrieren

Gewaschene
Metallprobe

-Filtrat
-Filterrückstand Grob
-Filter mit Rückstand fein

Bachema AG
Rütistrasse 22
Postfach
CH-8952 Schlieren

Telefon
+41 44 738 39 00
Telefax
+41 44 738 39 90
info@bachema.ch
www.bachema.ch

Chemisches und
mikrobiologisches
Labor für
die Prüfung von
Umweltproben
(Wasser,
Boden, Abfall)
Akkreditiert nach
ISO 17025/STS
Nr.064

Methodenbeschreibung Seite 4 von 14

The list is embedded in this document (requires AcroExch to open it) or available as a pdf-document upon requested from the corresponding author.

Table SI 2: 31 SM mass fractions w_x (in mg/kg, g/t or also ppm) measured in the 17 EE components

Element	ABS sensors (metal EE part)	ABS sensors (plastic EE part)	Brushes (Electric)	Electrolytic Capacitors	SMD Capacitors	Commutators	Connectors (only metal EE part)	LCD Displays (Foil)	LCD Displays (Glass)	LEDs	Magnets	Sensor element in lambda probe	PCB populated	PCB without components	Resistors	Resistors from Air mass meter	Semiconductors
Ag	134.0	20.9 *	239.0	165.0	4 270.0	60.1*	902.0	<0.1	7.5	582.0	0.2	1.0	412.0	5.9*	3 980.0	6 630.0	508.0
Au	<0.1	1.7	0.1	1.4	108.0	0.6	57.2	<0.1	22.4	764.0	<0.1	2.1	121.0	33.0	61.1	<0.1	1 230.0
Be	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	4.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Ce	<0.5	7.9	2.3	4.5	19.0	6.2	2.6	<0.5	4.2	12.2	1.4	11.8	13.6	20.4	13.9	0.7	1.2
Co	11.3	1.7	2.3	4.8	99.0	3.9	33.0	31.7	4.0	5.3	3 500.0	3.0	122.0	6.9	71.7	25 600.0	274.0
Dy	<0.1	0.3	0.3	0.2	2 860.0	0.4	0.2	<0.1	0.4	5.2	12.1	1.7	10.6	1.2	31.3	<0.1	2.3
Ga	1.5	3.5	<1.0	22.6	1.8	3.9	2.1	<1.0	3.9	391.0	9.5	1.8	14.1	7.2	5.4	<1.0	1.9
Gd	<0.1	1.4	0.2	0.5	280.0	0.6	0.2	<0.1	5.8	13.0	24.8	1.1	4.3	3.0	10.3	0.3	2.1
Ge	4.2	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	16.0	<1.0	<1.0	<1.0	1.7	63.3	<1.0
In	n.a	n.a	<1.0	<0.1	3.0	n.a	3.0	<0.5	198.0	<0.1	n.a	<0.1	<0.1	n.a	<0.1	n.a	11.9
La	0.5	5.2	0.9	2.3	2 550.0	3.3	1.3	<0.1	2.9	2.8	7 180.0	4.0	22.2	11.6	164.0	2.9	13.7
Li	<10	<10	<10	<10	13.0	<10	<10	<10	<10	<10	<10	<10	31.0	22.0	453.0	<10	<10
Mo	45.5	0.8	14 700.0	26.4	21.4	8.4	30.0	<0.25	19.6	<0.25	18.5	10.2	6.6	3.4	14 100.0	3.6	148.0
Nb	3.0	2.3	0.8	6.4	4 350.0	2.2	3.2	<0.5	0.9	3.0	15.8	18.7	15.4	5.5	33.1	0.9	24.9
Nd	<0.1	55.9	7.4	6.7	11 400.0	4.5	1.9	<0.1	22.7	2.0	475.0	3.9	1 090.0	12.9	576.0	1.3	51.6
Pd	<0.5	7.1	0.6	<0.5	2 350.0	<0.5	0.6	<0.5	<0.5	61.6	14.7	49.9	25.4	6.6	316.0	156.0	18.3
Pr	<0.1	2.3	1.2	0.6	658.0	0.7	0.3	<0.1	0.6	0.5	28.2	1.0	16.6	2.7	38.6	<0.1	2.6
Pt	<1.0	<1.0	<1.0	<1.0	29.6	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	7 520.0	<1.0	<1.0	1.4	<1.0	1.8
Rb	<0.2	4.7	0.8	3.3	0.3	2.0	1.2	<0.2	15.8	2.1	<0.2	7.7	2.4	2.6	0.3	<0.2	0.5
Re	<0.1	<0.1	0.2	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	0.2
Ru	2.0	<0.1	0.3	<0.1	1.2	0.2	4.0	<0.2	<0.1	<0.1	1.1	7.7	0.4	<0.1	6.1	2.3	0.5
Sb	1.1	14.5	224.0	250.0	1 070.0	665.0	543.0	137.0	1 430.0	59.3	0.4	<0.1	807.0	12.7	385.0	2 050.0	5 900.0
Sm	<0.1	0.6	5.0	0.3	133.0	0.4	0.3	<0.1	0.4	0.3	0.4	0.9	1.3	1.6	6.4	5.8	0.3
Sn	5 390.0	194.0	1 820.0	4 990.0	52 600.0	1 370.0	10 600.0	<1	453.0	53 600.0	22.1	288.0	21 500.0	20 200.0	74 100.0	20 400.0	14 700.0
Sr	22.1	415.0	7.5	34.2	2 380.0	156.0	53.5	<5.0	22 700.0	255.0	84 100.0	34.3	314.0	526.0	20.9	1 440.0	101.0
Ta	n.a	0.0	<0.5	1.1	32 500.0	0.0	<0.5	<0.5	5.4	<0.5	<0.5	2.2	469.0	0.0	6.2	n.a	1 710.0
Tb	<0.1	0.4	0.3	0.3	67.5	0.2	<0.1	<0.1	1.0	14.1	1.8	0.2	3.0	0.7	1.3	0.1	2.3
Te	<0.5	<0.5	1.6	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	3.4	<0.5	<0.5	1.2	<0.5	1.6
W	n.a	0.8	122.0	62.0	389.0	0.8	5.1	<1.0	15.8	0.8	2.9	0.6	6.3	1.0	6.3	n.a	233.0
Y	<0.1	1.6	1.7	0.5	1 030.0	1.2	0.6	<0.1	3.5	111.0	0.8	25 400.0	40.6	3.8	23.1	2.3	1.4
Zr	n.a	5.0	7.4	16.4	16 900.0	17.5	2.7	<1.0	194.0	19.4	1.2	380 000.0	563.0	58.3	227.0	n.a	118.0

< ###: value below detection level

###*: value might be too low due to digestion with HF instead of aqua regia.

n.a. value not available for In due to the lack of samples for re-measurement of Sn correction and for Ta, W and Zr due to the lack of samples for new digestion with HF.

The accredited Lab of Bachema AG describes its uncertainty of measurement in "Forum1416Bestimmungsunsicherheit.pdf" (referenced in the main manuscript). It follows the ISO "Guide to the Expression of Uncertainty in Measurement" (GUM) and groups its applied analytical methods in 4 classes a) to d). For this research uncertainty class c) = 12%-24% applies. It reads: the relative combined standard uncertainty $u_{c,r}(y)$of output y of the measurand Y is:

$$u_{c,r}(y) = \frac{u_c(y)}{|y|} = 12\%$$

Given the expanded uncertainty $U = k \cdot u_c(y)$ and assuming a normal distribution density for the uncertainty and a confidence level $p = 95\%$ the coverage factor is $k_p = 2$ and the relative expanded uncertainty $U_{p,r}$

$$U_{p,r} = \frac{U}{|y|} = \frac{k_p \cdot u_c(y)}{|y|} = 24\%$$

Thus the measurand Y, the mass fraction w_x, is normally distributed with $\sigma/_{w_x} = 12\%$ and the measurement is with a confidence level of 95% in the confidence interval $w_x - 24\%, \dots, w_x + 24\%$. These uncertainty value includes the entire procedure for chemical analysis applied at the Lab taking into account sample preparation, digestion and measurement etc.. For values approaching the detection limit, the uncertainty may increase by a factor of 2 to 3.

Table SI 3: Some key indicators for the 31 SM in the EE components in one mid-range car.

SM	Max. mass fraction $\frac{w_x}{\mathrm{g/t}}$	17 EE components with max. mass fraction	Max. mass $\frac{M_x}{g}$	error $\frac{u_{c,r}(M_x)}{g/com}$	11 EE components with max mass	Total mass $\frac{M_x}{g/car}$	error $\frac{u_{c,r}(M_x)}{g/car}$
Ag	6'630.0	Resistors from Air mass meter	0.16	0.019	Printed Wiring Boards (populated)	1.3	0.16
Au	1'230.0	Semiconductors	0.046	0.0055	Printed Wiring Boards (populated)	0.22	0.027
Be	4.7	Connectors (only metal EE part)	0.00079	0.000095	Connectors (metal EE part)	0.0034	0.00041
Ce	20.4	PCB without components	0.0052	0.00062	PCB (populated)	0.028	0.0034
Co	25'600.0	Resistors from Air mass meter	2	0.24	Magnets	6	0.73
Dy	2'860.0	Capacitors (SMD + Tantalum)	0.007	0.00084	Magnets	0.036	0.0044
Ga	391.0	LEDs	0.0055	0.00066	Magnets	0.041	0.0049
Gd	280.0	Capacitors (SMD + Tantalum)	0.014	0.0017	Magnets	0.049	0.0059
Ge	63.3	Resistors from Air mass meter	0.0092	0.0011	Magnets	0.027	0.0032
In	198.0	LCD Displays (Glass)	0.0085	0.001	Printed Wiring Boards (populated)	0.022	0.0027
La	7'180.0	Magnets	4.1	0.5	Magnets	12	1.4
Li	453.0	Resistors	0.012	0.0014	Printed Wiring Boards (populated)	0.046	0.0055
Mo	14'700.0	Brushes (Electric)	0.37	0.044	Brushes (electric)	1	0.12
Nb	4'350.0	Capacitors (SMD + Tantalum)	0.0091	0.0011	Magnets	0.053	0.0064
Nd	11'400.0	Capacitors (SMD + Tantalum)	0.41	0.05	Printed Wiring Boards (populated)	2.4	0.29
Pd	2'350.0	Capacitors (SMD + Tantalum)	0.0096	0.0012	Printed Wiring Boards (populated)	0.064	0.0077
Pr	658.0	Capacitors (SMD + Tantalum)	0.016	0.002	Magnets	0.073	0.0087
Pt	7'520.0	Sensor element in lambda probe	0.0083	0.001	Sensor element in lambda probe	0.0083	0.001
Rb	15.8	LCD Displays (Glass)	0.001	0.00012	ABS sensors (plastic EE part)	0.0074	0.00088
Re	0.4	Resistors from Air mass meter	0.000005	0.0000006	Brushes (electric)	0.000013	0.0000015
Ru	7.7	Sensor element in lambda probe	0.00068	0.000081	Connectors (metal EE part)	0.0056	0.00067
Sb	5'900.0	Semiconductors	0.31	0.037	Printed Wiring Boards (populated)	1.9	0.23
Sm	133.0	Capacitors (SMD + Tantalum)	0.00049	0.000059	Printed Wiring Boards (populated)	0.0034	0.00041
Sn	74'100.0	Resistors	8.2	0.98	Printed Wiring Boards (populated)	41	4.9
Sr	84'100.0	Magnets	48	5.8	Magnets	140	17
Ta	32'500.0	Capacitors (SMD + Tantalum)	0.18	0.021	Printed Wiring Boards (populated)	0.7	0.084
Tb	67.5	Capacitors (SMD + Tantalum)	0.0011	0.00014	Printed Wiring Boards (populated)	0.0077	0.00092
Te	3.4	Sensor element in lambda probe	0.00004	0.0000048	Brushes (electric)	0.0001	0.000013
W	389.0	Capacitors (SMD + Tantalum)	0.0031	0.00037	Brushes (electric)	0.027	0.0033
Y	25'400.0	Sensor element in lambda probe	0.028	0.0034	Sensor element in lambda probe	0.091	0.011
Zr	380'000.0	Sensor element in lambda probe	0.42	0.051	Sensor element in lambda probe	1.3	0.15

For the SM mass fractions all sampled 17 EE components are used; however, for the SM masses subset of 11 EE components used for the mass projection for the hypothetical cars is used. In this case the de-populated PWB and all the de-soldered electronic elements (resistors, capacitors, ICs and LEDs) are not included.
Depending on chemical element and sample, mass fraction threshold is from <0.1 mg/kg to <1.0 mg/kg and for Li it is <10.0 mg/kg).
EE component masses required for projections of total masses have a precision of 100 mg.
Same uncertainty of measurement as described in Table SI2.

Estimation of missing mass due to dismantling ELV prior to shredding

The average car's mass according to the average unladen mass (Leermasse) of passenger vehicles in Switzerland, has risen continuously from 1'300 kg (1996) to 1'500 kg (2008) (http://www.bfs.admin.ch/bfs/portal/en/index/themen/11.html); we use the average unladen mass of

1'400 kg, which is probably an upper limit since Swiss consumers tend to buy heavier cars then car owners in most of the EU. The unladen mass represents a ready to drive car with all liquids 100% filled up except fuel which is taken as 90% full, all accessories such as spare wheel, toolset, safety equipment etc. and includes a 75 kg driver.
All CH car dismantlers prepare cars for shredding i.e. they remove the required parts. Many also remove additional parts for 2nd-hand sale. Some may export 2nd-hand parts such as engine blocks but we did not investigate the 2nd-hand spare parts exports and not checked if further dismantling had taken place e.g. removal of EE components. The quick check below suggests that some spare parts beyond the legal requirement may indeed have been removed. The spare parts of interest are e.g. fenders (which would not contain SM hot spots) or doors which might contain power windows with motors which might contain SMs e.g. Nd or La.

The following estimate shows that some of the expected mass might be missing:

with:
1'400 kg average unladen car mass
950 kg actual car mass shredded
75 kg driver

and removed parts prior to shredding (ref: http://www.bafu.admin.ch/veva-inland/11827/11830/index.html?lang=de):
required (total ca. 200kg):

- All liquids (fuel, oil, water, coolant, ...), in some cases with the tank (e.g. CNG) >>> 60 kg
- Batteries >>> 20 kg
- Wheels / tires >>> 100 kg
- Catalyst (incl. part of exhaust system) >>> 20 kg

parts lost prior to shredding (total ca. 60kg) (these "losses" are normally added to the shredder in a weekly clean-up of the scrap yard, however, this wasn't the case during this batch test.):

- most windows are lost when the ELVs are stacked for shredding >>> 20 kg
- most salient parts are rear mirror, screen wipers, etc. >>> 20 kg
- toolset, safety equipment, etc. >>> 20 kg

recommended parts if feasible for reuse or recycling (ref: http://www.bafu.admin.ch/veva-inland/11827/11830/index.html?lang=de) (total ca. ???kg):

- All other parts >>> (unknown)

1'400 kg - 950kg - 75kg - 200 kg - 60 kg = 115 kg

these recommended parts might sum up to the 115 kg difference in the quick calculation above.

Table SI 4: Number of EE devices in 5 hypothetical car models

Devices	High-end car	Low-end car	Mid-range car (used in this study)	Coupé high-end	Coupé low-end
ABS pump	1	0	1	1	0
Power windows	4	0	4	2	0
GPS navigation system*	2	0	1	2	0
Radio / CD*	2	1	1	2	1
Instruments (User Interface)	1	1	1	1	1
Airbag / crash sensor	1	0	1	1	0

Airbag controller	1	0	1	2	0
Oxygen sensor	2	1	1	1	1
ABS sensor	4	0	4	4	0
The following EE devices are in all hypothetical car models by default:					
Devices	**Number of EE devices**				
Fuel pump	1				
Alternator	1				
Starter motor	1				
Wiper motor (wind screen)	1				
Radiator fan motor	1				
Multi-function control stalk	1				
Fuse box	1				
Air mass meter	1				
Motor controller	1				

* In the case of GPS unit and radio the number of devices is used to represent the size and control options of the devices, not the actual devices installed in the vehicle. This simplification is based on the number of printed circuit boards in the devices, which are the ones contributing to the mass of critical metals in the calculation. A simple radio with 1 cassette unit contains 1 printed circuit board and it is represented here as 1 radio - a radio with more options such as CD and Bluetooth has 2 or more printed circuit boards and it is represented as 2 radios.

Table SI 5: Assembly of EE device with EE parts and EE components in one hypothetical mid-range vehicle

Sample Nr	EE components containing analyzed scarce metals	EE parts containing the EE components	average mass of EE component in EE part (in grams)	EE devices containing the EE parts	Number of EE parts per EE device	Our classification of EE devices	Subsystem (classification Alonso 2012)
39070	Printed Wiring Boards (populated)	Circuit Boards	40.00	ABS pump	1	Electromotors (EM)	Steering & Brakes
40141	Connectors (metal EE part)	Contacts/Connectors	169.00	ABS pump	1	Electromotors (EM)	Steering & Brakes
39062	Magnets	Electromotors	234.00	ABS pump	1	Electromotors (EM)	Steering & Brakes
39064	Brushes (electric)	Electromotors	6.29	ABS pump	1	Electromotors (EM)	Steering & Brakes
39068	Commutators	Electromotors	24.70	ABS pump	1	Electromotors (EM)	Steering & Brakes
40141	Connectors (metal EE part)	Contacts/Connectors	35.70	ABS sensor	1	Sensors (SE)	Steering & Brakes
40901	ABS sensors (plastic EE part)	ABS sensor	53.64	ABS sensor	1	Sensors (SE)	Steering & Brakes
40898	ABS sensors (metal EE part)	ABS sensor	22.47	ABS sensor	1	Sensors (SE)	Steering & Brakes
39070	Printed Wiring Boards (populated)	Circuit Boards	41.20	Air mass meter	1	Sensors (SE)	Electrical
40141	Connectors (metal EE part)	Contacts/Connectors	17.50	Air mass meter	1	Sensors (SE)	Electrical
40690	Resistors from air mass meter	Air mass sensor	0.10	Air mass meter	1	Sensors (SE)	Electrical
39070	Printed Wiring Boards (populated)	Circuit Boards	10.30	Airbag / crash sensor	1	Sensors (SE)	Interior
40141	Connectors (metal EE part)	Contacts/Connectors	11.60	Airbag / crash sensor	1	Sensors (SE)	Interior
39070	Printed Wiring Boards (populated)	Circuit Boards	75.80	Airbag controller	1	Controllers (SG)	Electrical
39064	Brushes (electric)	Electromotors	6.29	Alternator	1	Electromotors (EM)	Electrical
39068	Commutators	Electromotors	24.70	Alternator	1	Electromotors (EM)	Electrical
39070	Printed Wiring Boards (populated)	Circuit Boards	1.80	Fuel pump	1	Electromotors (EM)	Fuel & Exhaust
40141	Connectors (metal EE part)	Contacts/Connectors	10.40	Fuel pump	1	Electromotors (EM)	Fuel & Exhaust
39062	Magnets	Electromotors	137.40	Fuel pump	1	Electromotors (EM)	Fuel & Exhaust
39064	Brushes (electric)	Electromotors	6.29	Fuel pump	1	Electromotors (EM)	Fuel & Exhaust
39068	Commutators	Electromotors	24.70	Fuel pump	1	Electromotors (EM)	Fuel & Exhaust
39070	Printed Wiring Boards (populated)	Circuit Boards	379.40	Fuse box	1	Contacts (KO)	Electrical
40141	Connectors (metal EE part)	Contacts/Connectors	9.50	Fuse box	1	Contacts (KO)	Electrical
39070	Printed Wiring Boards (populated)	Circuit Boards	302.77	GPS navigation system	1	Consumer Electronics (UE)	Info & Controls
40141	Connectors (metal EE part)	Contacts/Connectors	2.75	GPS navigation system	1	Consumer Electronics (UE)	Info & Controls
39062	Magnets	Electromotors	6.60	GPS navigation system	1	Consumer Electronics (UE)	Info & Controls

Sample Nr	EE components containing analyzed scarce metals	EE parts containing the EE components	average mass of EE component in EE part (in grams)	EE devices containing the EE parts	Number of EE parts per EE device	Our classification of EE devices	Subsystem (classification Alonso 2012)
39065	LCD Displays (Foil)	LCD Displays	13.60	GPS navigation system	1	Consumer Electronics (UE)	Info & Controls
39067	LDC Displays (Glass)	LCD Displays	43.17	GPS navigation system	1	Consumer Electronics (UE)	Info & Controls
39070	Printed Wiring Boards (populated)	Circuit Boards	160.30	Instruments (User Interface)	1	User Interface (UI)	Interior
40141	Connectors (metal EE part)	Contacts/Connectors	10.00	Instruments (User Interface)	1	User Interface (UI)	Interior
39062	Magnets	Electromotors	4.90	Instruments (User Interface)	3	User Interface (UI)	Interior
39068	Commutators	Electromotors	2.00	Instruments (User Interface)	3	User Interface (UI)	Interior
39070	Printed Wiring Boards (populated)	Circuit Boards	147.70	Motor controller	1	Controllers (SG)	Electrical
40141	Connectors (metal EE part)	Contacts/Connectors	35.60	Motor controller	1	Controllers (SG)	Electrical
39070	Printed Wiring Boards (populated)	Circuit Boards	25.80	Multi-function control stalk	1	Contacts (KO)	Interior
40141	Connectors (metal EE part)	Contacts/Connectors	106.80	Multi-function control stalk	1	Contacts (KO)	Interior
39062	Magnets	Electromotors	4.80	Multi-function control stalk	1	Contacts (KO)	Interior
40141	Connectors (metal EE part)	Contacts/Connectors	12.80	Oxygen sensor	1	Sensors (SE)	Fuel & Exhaust
40140	Sensor element in lambda probe	Lambda sensor	1.11	Oxygen sensor	1	Sensors (SE)	Fuel & Exhaust
40141	Connectors (metal EE part)	Contacts/Connectors	16.90	Power windows	1	Electromotors (EM)	Closures
39062	Magnets	Electromotors	144.10	Power windows	1	Electromotors (EM)	Closures
39064	Brushes (electric)	Electromotors	6.29	Power windows	1	Electromotors (EM)	Closures
39068	Commutators	Electromotors	24.70	Power windows	1	Electromotors (EM)	Closures
40141	Connectors (metal EE part)	Contacts/Connectors	63.80	Radiator fan motor	1	Electromotors (EM)	Electrical
39064	Brushes (electric)	Electromotors	6.29	Radiator fan motor	1	Electromotors (EM)	Electrical
39068	Commutators	Electromotors	24.70	Radiator fan motor	1	Electromotors (EM)	Electrical
39070	Printed Wiring Boards (populated)	Circuit Boards	302.77	Radio / CD	1	Consumer Electronics (UE)	Info & Controls
40141	Connectors (metal EE part)	Contacts/Connectors	2.75	Radio / CD	1	Consumer Electronics (UE)	Info & Controls

Sample Nr	EE components containing analyzed scarce metals	EE parts containing the EE components	average mass of EE component in EE part (in grams)	EE devices containing the EE parts	Number of EE parts per EE device	Our classification of EE devices	Subsystem (classification Alonso 2012)
39062	Magnets	Electromotors/CD reader	6.60	Radio / CD	1	Consumer Electronics (UE)	Info & Controls
39065	LCD Displays (Foil)	LCD Displays	13.60	Radio / CD	1	Consumer Electronics (UE)	Info & Controls
39067	LDC Displays (Glass)	LCD Displays	43.17	Radio / CD	1	Consumer Electronics (UE)	Info & Controls
39062	Magnets	Electromotors	529.00	Starter motor	1	Electromotors (EM)	Electrical
39064	Brushes (electric)	Electromotors	6.29	Starter motor	1	Electromotors (EM)	Electrical
39068	Commutators	Electromotors	24.70	Starter motor	1	Electromotors (EM)	Electrical
40141	Connectors (metal EE part)	Contacts/Connectors	56.30	Wiper Motor	1	Electromotors (EM)	Electrical
39062	Magnets	Electromotors	157.00	Wiper Motor	1	Electromotors (EM)	Electrical
39064	Brushes (electric)	Electromotors	6.29	Wiper Motor	1	Electromotors (EM)	Electrical
39068	Commutators	Electromotors	24.70	Wiper Motor	1	Electromotors (EM)	Electrical

EE component masses, required for projections to total masses have a precision of 10 mg.

Table SI 6: 31 SM mass fractions w_x in mg/kg, g/t or also ppm) measured in the analyzed shredder fractions of m=100 cars

Element	SLF	Screen fraction	Sludge	Al fine	Mix	Fe scrap "core"	Fe scrap "crust"	Fe scrap Total	Al coarse "core"	Al coarse "crust"	Al coarse Total
Ag	10.8	70.3	13.0	22.7	13.0	0.5	0.0	0.5	6.9	0.0	6.9
Au	1.2	1.5	0.4	0.2	b.t.	b.t.	0.0	0.0	0.1	0.0	0.1
Be	b.t.	1.0	b.t.	0.6	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.
Ce	12.5	4.6	26.6	2.0	15.5	b.t.	0.0	0.0	2.0	0.0	2.0
Co	31.7	24.7	28.0	29.7	5.6	32.4	0.1	32.5	8.9	0.1	9.0
Dy	0.7	0.3	1.3	b.t.	0.1	b.t.	0.0	0.0	b.t.	0.0	0.0
Ga	4.1	30.0	3.2	55.6	b.t.	10.1	0.0	10.1	81.9	0.0	81.9
Gd	1.1	0.4	2.2	0.1	0.3	b.t.	0.0	0.0	0.2	0.0	0.2
Ge	b.t.	b.t.	b.t.	b.t.	b.t.	5.3	0.0	5.3	b.t.	0.0	0.0
In	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	0.0	0.0	b.t.	0.0	0.0
La	5.8	2.4	8.5	0.9	1.5	0.2	0.0	0.2	1.0	0.0	1.0
Li	15.0	b.t.	15.0	b.t.	b.t.	22.0	0.1	22.1	20.5	0.0	20.5
Mo	110.0	25.0	135.0	18.7	23.9	70.6	0.1	70.7	8.5	0.1	8.6
Nb	5.8	b.t.	1.1	b.t.	b.t.	32.2	0.0	32.2	0.3	0.0	0.3
Nd	11.8	3.8	19.0	1.1	1.9	0.2	0.0	0.2	1.1	0.0	1.1
Pd	2.7	6.4	1.2	2.8	1.0	b.t.	0.0	0.0	0.6	0.0	0.6
Pr	1.7	0.8	3.0	0.3	0.3	b.t.	0.0	0.0	0.2	0.0	0.2
Pt	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	0.0	0.0	b.t.	0.0	0.0
Rb	7.4	2.7	4.7	b.t.	1.6	b.t.	0.0	0.0	b.t.	0.0	0.0
Re	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.
Ru	0.3	0.3	0.4	0.3	0.3	0.2	0.0	0.2	b.t.	0.0	0.0
Sb	285.0	108.0	85.2	13.0	83.1	2.7	0.0	2.7	12.3	0.1	12.4
Sm	3.4	0.8	2.7	0.1	0.4	0.1	0.0	0.1	0.1	0.0	0.1
Sn	350.0	1380.0	403.0	1150.0	83.4	105.0	0.1	105.1	176.5	0.8	177.3
Sr	816.0	174.0	314.0	16.5	173.0	18.6	0.9	19.5	21.8	0.9	22.7
Ta	0.7	2.6		b.t.	27.5	b.t.	0.0	0.0	b.t.	b.t.	b.t.
Tb	0.1	b.t.	0.4	b.t.	b.t.	b.t.	0.0	0.0	b.t.	b.t.	b.t.
Te	1.4	0.7	b.t.	b.t.	4.6	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.
W	9.6	7.6		3.5	2.3	1.6	0.0	1.6	3.6	0.0	3.6
Y	3.5	1.1	5.6	0.4	0.7	b.t.	0.0	0.0	0.3	0.0	0.3
Zr	60.3	60.8		46.1	7.6	b.t.	0.0	0.0	29.6	0.0	29.6

b.t. below threshold (depending on chemical element and sample threshold is from <0.1 mg/kg to <1.0 mg/kg and for Li it is <10.0 mg/kg)

0.0 below 0.1 mg/kg

empty no valid measurement

Same uncertainty of measurement as described in Table SI2.

Table SI 7: 31 SM masses M_x^{out} (in grams) in the shredder fractions with shredder fraction mass in tons for m=100 cars

Element	SLF	Screen fraction	Sludge	Al fine	Mix	Fe scrap "core"	Fe scrap "crust"	Fe scrap Total	Al coarse "core"	Al coarse "crust"	Al coarse Total
shredder fraction mass	14.62	2.86	0	0.45	3.53	63.9			3.48		
Ag	157.9	201.1	37.2	10.2	45.9	32.0	0.1	32.1	24.0	0.1	24.1
Au	17.5	4.3	1.1	0.1	b.t.	b.t.	0.0	0.0	0.2	0.0	0.2
Be	b.t.	2.9	b.t.	0.3	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.
Ce	182.8	13.2	76.1	0.9	54.7	b.t.	1.5	1.5	6.8	0.1	6.9
Co	463.5	70.6	80.1	13.4	19.8	2070.4	4.1	2074.5	31.0	0.3	31.2
Dy	10.2	0.9	3.7	b.t.	0.4	b.t.	0.1	0.1	b.t.	0.0	0.0
Ga	59.9	85.8	9.2	25.0	b.t.	645.4	0.5	645.9	285.0	0.1	285.1
Gd	16.1	1.1	6.3	0.0	1.1	b.t.	0.2	0.2	0.5	0.0	0.5
Ge	b.t.	b.t.	b.t.	b.t.	b.t.	338.7	0.4	339.1	b.t.	0.0	0.0
In	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	0.0	0.0	b.t.	0.0	0.0
La	84.8	6.9	24.3	0.4	5.3	12.8	0.4	13.1	3.3	0.0	3.4
Li	219.3	b.t.	42.9	b.t.	b.t.	1'405.8	3.7	1'409.5	71.3	0.0	71.4
Mo	1'608.2	71.5	386.1	8.4	84.4	4'511.3	5.3	4'516.7	29.5	0.5	30.0
Nb	84.8	b.t.	3.1	b.t.	b.t.	2057.6	1.7	2059.3	1.0	0.0	1.0
Nd	172.5	10.9	54.3	0.5	6.7	12.8	1.2	14.0	3.7	0.1	3.8
Pd	39.5	18.3	3.4	1.3	3.5	b.t.	0.0	0.0	1.9	0.0	1.9
Pr	24.9	2.3	8.6	0.1	1.1	b.t.	0.6	0.6	0.7	0.0	0.7
Pt	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	0.0	0.0	b.t.	0.0	0.0
Rb	108.2	7.7	13.4	b.t.	5.6	b.t.	0.2	0.2	b.t.	0.0	0.0
Re	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.
Ru	4.4	0.9	1.1	0.1	1.1	12.8	0.5	13.3	b.t.	0.0	0.0
Sb	4'166.7	308.9	243.7	5.9	293.3	172.5	1.2	173.7	42.8	0.2	43.0
Sm	49.7	2.3	7.7	0.0	1.4	6.4	0.7	7.1	0.2	0.1	0.3
Sn	5'117.0	3'946.8	1'152.6	517.5	294.4	6'709.5	5.4	6'714.9	614.2	2.7	616.9
Sr	11'929.9	497.6	898.0	7.4	610.7	1'188.5	56.9	1'245.4	75.7	3.2	78.9
Ta	10.2	7.4		b.t.	97.1	b.t.	0.0	0.0	b.t.	b.t.	b.t.
Tb	1.5	b.t.	1.1	b.t.	b.t.	b.t.	0.0	0.0	b.t.	b.t.	b.t.
Te	20.5	2.0	b.t.	b.t.	16.2	b.t.	b.t.	b.t.	b.t.	b.t.	b.t.
W	140.4	21.7		1.6	8.1	103.5	0.1	103.6	12.5	0.0	12.5
Y	51.2	3.1	16.0	0.2	2.5	b.t.	0.2	0.2	1.0	0.0	1.1
Zr	881.6	173.9		20.7	26.8	b.t.	0.9	0.9	102.8	0.1	103.0

b.t. below threshold (see Table SI 6)
0.0 below 0.1 g
empty no valid measurement

Table SI 8: 31 SM masses M_x^{EEdev} (in grams) in the 6 EE device categories in n=100 hypothetical mid-range cars (rounded to 2 significant figures; precision 0.01 g)

	ConsumerElectronics (CE)	Contacts (KO)	Controllers (SG)	Electromotors (EM)	Sensors (SE)	UserInterface (UI)	Total
Ag	26.00	27.00	12.00	38.00	21.00	7.50	131.50
Au	7.60	5.60	2.90	2.60	1.70	2.00	22.40
Be	0.00	0.06	0.02	0.17	0.09	0.00	0.34
Ce	0.86	0.58	0.31	0.55	0.29	0.23	2.82
Co	12.00	7.00	2.80	570.00	1.60	7.10	600.50
Dy	0.66	0.44	0.24	2.00	0.07	0.19	3.60
Ga	0.90	0.60	0.32	1.80	0.20	0.24	4.06
Gd	0.34	0.19	0.10	4.10	0.06	0.11	4.89
Ge	0.02	0.01	b.t.	2.60	0.04	0.02	2.69
In	1.70	0.04	0.01	0.27	0.20	0.01	2.22
La	11.00	4.40	0.50	1'200.00	0.25	11.00	1'227.15
Li	1.90	1.30	0.69	0.13	0.16	0.50	4.68
Mo	0.61	0.63	0.25	97.00	1.00	0.17	99.66
Nb	0.96	0.67	0.36	2.80	0.22	0.27	5.28
Nd	67.00	44.00	24.00	82.00	6.80	18.00	241.80
Pd	1.60	1.00	0.57	2.50	0.30	0.43	6.40
Pr	1.00	0.69	0.37	4.70	0.14	0.31	7.21
Pt	b.t.	b.t.	b.t.	b.t.	0.83	b.t.	0.83
Rb	0.28	0.11	0.06	0.11	0.14	0.04	0.74
Re	b.t.	b.t.	b.t.	0.00	0.00	b.t.	0.00
Ru	0.03	0.06	0.02	0.34	0.09	0.01	0.56
Sb	62.00	39.00	20.00	41.00	15.00	14.00	191.00
Sm	0.08	0.06	0.03	0.12	0.03	0.02	0.34
Sn	1'300.00	990.00	520.00	530.00	360.00	360.00	4'060.00
Sr	330.00	54.00	7.20	14'000.00	12.00	130.00	14'533.20
Ta	28.00	19.00	10.00	2.00	2.40	7.50	68.90
Tb	0.19	0.12	0.07	0.31	0.02	0.05	0.76
Te	b.t.	b.t.	b.t.	0.01	0.00	b.t.	0.01
W	0.52	0.32	0.16	1.50	0.15	0.11	2.76
Y	2.50	1.70	0.91	0.36	3.10	0.65	9.22
Zr	36.00	23.00	13.00	3.10	45.00	9.00	129.10

b.t. below threshold
0.00 below 0.01 g
Same uncertainty of measurement as described in Table SI2

Table SI 9: 31 SM masses M_x^{core} (in grams) in the matrix of the Al coarse and Fe scrap fractions (rounded to 2 sign. figures) ranked relative to the ' "core" in % of Total'.

SM	Fe scrap "core"	Al coarse "core"	sum "core"	Total output	"core" in % of Total	mismatch $\frac{\Delta_x}{g}$	rel. mismatch δ_x
Ge	340.00	b.t.	340.00	340.00	100.0%	336.4	99.2%
Nb	2'100.00	1.00	2'101.00	2'100.00	100.0%	2'139.8	99.8%
Li	1'400.00	71.00	1'471.00	1'700.00	86.5%	1'695.5	99.7%
Ga	650.00	290.00	940.00	1'100.00	85.5%	1'097.7	99.6%

Co	2'100.00	31.00	2'131.00	2'700.00	78.9%	2'068.5	77.4%
Mo	4'500.00	30.00	4'530.00	6'300.00	71.9%	6'219.6	98.4%
Ru	13.00	b.t.	13.00	20.00	65.0%	19.2	97.2%
Sn	6'700.00	610.00	7'310.00	17'000.00	43.0%	13'139.8	76.4%
W	100.00	13.00	113.00	290.00	39.0%	285.2	99.1%
La	13.00	3.30	16.30	110.00	14.8%	-1'086.3	-954.1%
Ag	32.00	24.00	56.00	470.00	11.9%	340.3	72.2%
Sm	6.40	0.17	6.57	61.00	10.8%	60.5	99.4%
Sr	1'200.00	76.00	1'276.00	14'000.00	9.1%	95.0	0.7%
Zr	b.t.	100.00	100.00	1'200.00	8.3%	1'078.2	89.3%
Nd	13.00	3.70	16.70	210.00	8.0%	-34.7	-16.7%
Sb	170.00	43.00	213.00	5'000.00	4.3%	4'801.0	96.2%
Pd	b.t.	1.90	1.90	65.00	2.9%	58.1	90.0%
Gd	b.t.	0.52	0.52	19.00	2.7%	14.2	74.4%
Ce	b.t.	6.80	6.80	260.00	2.6%	257.1	98.9%
Pr	b.t.	0.70	0.70	30.00	2.3%	22.4	75.5%
Y	b.t.	1.00	1.00	58.00	1.7%	49.1	84.3%
Au	b.t.	0.17	0.17	22.00	0.8%	-0.3	-1.2%
Be	b.t.	b.t.	b.t.	3.10	b.t.	2.8	89.2%
Dy	b.t.	b.t.	b.t.	12.00	b.t.	7.9	68.5%
In	b.t.	b.t.	b.t.	0.04	b.t.	-2.2	-5244.8%
Pt	b.t.	b.t.	b.t.	0.02	b.t.	-0.8	-3789.5%
Rb	b.t.	b.t.	b.t.	120.00	b.t.	121.1	99.4%
Ta	b.t.	b.t.	b.t.	110.00	b.t.	44.9	39.1%
Tb	b.t.	b.t.	b.t.	1.50	b.t.	0.7	47.5%
Te	b.t.	b.t.	b.t.	39.00	b.t.	38.7	100.0%
Re	b.t.	b.t.	b.t.	b.t.	b.t.	-0.0	b.t.

b.t. below threshold

To show correlations between SM content in the Fe scrap and Al coarse fractions matrix ("core") the respective values for the SM mismatch Δ_x and relative mismatch δ_x are listed in the last two columns.

We defined the SM mass balance mismatch Δ between shredder output mass M_x^{out} and shredder input mass M_x^{in} as:

$$\Delta_x = M_x^{out} - M_x^{in}$$

the relative mismatch δ is defined as:

$$\delta_x = \frac{M_x^{out} - M_x^{in}}{M_x^{out}}$$

the assignment of the error is defined as:

$\Delta = 0$; i.e. output and input are balanced (or errors have been cancelled out)

$\Delta > 0$; i.e. output larger than input, we missed something in the input thus it's an input error

$\Delta < 0$; i.e. input larger than output, we missed something in the output thus it's an output error

The "shredder input" according to these definitions is NOT the 95.3 t total mass of the 100 cars which physically went into the shredder but the total mass of all 31 SM found in the analyzed EE-components and projected to 100 hypothetical mid-range passenger vehicles.

Table SI 10: Average mass $\overline{m}$ of EE components considered for the calculation of mass of SM in one passenger vehicle. The device to which the components belong is also presented.

EE component	EE device	Average EE component mass in grams	Number L of EE components used to determine the average mass
Populated Printed Circuit Boards	ABS pump	40	1
	Fuel pump	1.8	4
	GPS navigation system Radio	329.27	11
	Instruments (user interface)	160.30	11
	Multi-function control stalk	25.8	6
	Fuse box	379.40	4
	Air mass meter	41.2	1
	Airbag/crash sensor	10.28	7
	Airbag controller	75.78	5
	Motor controller	147.66	19
Connectors	ABS pump	169.03	3
	Fuel pump	10.40	4
	Power windows	16.92	4
	Wiper Motor	56.30	4
	Radiator fan motor	63.80	2
	GPS navigation system Radio / CD	5.5	8
	Instruments (User Interface)	10.00	1
	Multi-function control stalk	106.78	5
	Fuse box	9.50	5
	Air mass meter	17.50	1
	Airbag / crash sensor	11.60	1
	Motor controller	35.60	2
	Oxygen sensor	12.78	10
	ABS sensor	35.70	1
Magnets	ABS pump	234.00	2
	Fuel pump	137.40	4
	Starter motor	528.97	3
	Power windows	144.10	4
	Wiper Motor	157.00	4
	GPS navigation system Radio / CD	13.17	4
	Instruments (User Interface)	4.90	1
	Multi-function control stalk	4.80	1
Electric brushes	ABS pump Fuel pump Alternator	6.29	10

	Starter motor		
	Power windows		
	Wiper Motor		
	Radiator fan motor		
Commutators	ABS pump	24.70	20
	Fuel pump		
	Alternator		
	Starter motor		
	Power windows		
	Wiper Motor		
	Radiator fan motor		
	Instruments (User Interface)	2.00	1
LCD displays (foil)	GPS navigation system	13.6	11
	Radio / CD		
LCD displays (glass)	GPS navigation system	43.17	11
	Radio / CD		
Sensor element in lambda probe	Oxygen sensor	1.11	10
ABS sensor (plastic part)	ABS sensor	53.64	4
ABS sensor (metal part)	ABS sensor	22.47	4
Resistors from air mass meter	Air mass meter	0.10	2

The average mass of the components in the individual parts and devices was calculated as follows:

$$m_{ijk} = \overline{m} = \frac{1}{L}\sum_{l=1}^{L} m_l$$

With m_l being the mass of one particular component i contained in a certain part j of a specific device k; $\overline{m}$ is calculated from a set of L components i extracted from parts and devices of the same kind (means i, j and k = constant; L is given in the new Table SI 10). For example: the average mass $\overline{m}$ of the "Magnets" used in the "Electromotors" of a "Fuel pump" is 137.4 g, which was derived from weighing L=4 "Magnets" extracted from 4 different fuel pumps.
The average mass fraction w_{xi} of one particular component i (see Table SI 2) was obtained by mixing components (i=constant) found in selected j parts and k devices. The sample preparation procedure thus did the averaging, i.e. the average mass fraction was not calculated.