InSGeP

Investigations of Slags from Next Generation Steel Making Processes

Deliverable 3.1

Analysis of slag samples from current industrial practice

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Abstract

Deliverable 3.1 characterizes various types of slags currently generated around the world from next generation steelmaking processes. Focusing mainly on their chemical composition, leaching behavior and physical properties. This deliverable focuses on the comprehensive gathering and analysis of slag samples from various next-generation steel production methods, including utilizing direct reduced iron, hot briquetted iron, and scrap. The primary objective is to characterize the diverse types of slags produced, which will serve as a foundation for subsequent work packages aimed at valorizing these materials. By assessing the chemical, mineralogical, leaching behavior, and physical properties of the collected slags, the project seeks to explore their potential applications in industries such as construction and cement, thereby contributing to a circular economy and aligning with the EU Green Deal's zero-pollution ambition.

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AMMR	ArcelorMittal Maizières Research
COD	Chemical oxygen demand
DRI	Direct reduced iron
EC	Electrical conductivity
EAF	Electric Arc Furnace
HBI	Hot briquetted iron
HPSR	Hydrogen Plasma Smelting Reduction
ICP-OES	Inductively coupled plasma optical emission spectroscopy
TIC	Total inorganic carbon
XRF	X-ray fluorescence

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1 Introduction

Next generation iron and steelmaking process to decrease CO_2 by using direct reduced iron (DRI) with varying reduction degrees, hot briquetted iron (HBI), hydrogen plasma smelting reduction (HPSR) or by operating electrical smelting furnaces (smelters) for medium- and low-grade ores will result in increase of electric arc furnace (EAF) slag and other slags with different properties. This requires the understanding of the possibility to valorize future slags in the present value chain and define innovative applications to assure smooth transition process without disruption to the steel industry as well as other sectors (such as road construction or cement) who currently rely on slag as raw material for their processes. To understand and move forward the transition of the steel industry, InSGeP project is investigating slags resulting from next generation steelmaking in Europe. The project relies on the limited amount of currently produced slags from next generation steel production in Europe and abroad as well as on laboratory, pilot scale and industrial scale tests that will be performed based on the needs of the involved partners.

Deliverable 3.1 aims to provide a systematic compilation and detailed analysis of slags generated from advanced steelmaking processes from around the world (Germany, Middle East, Canada, and Mexico). It serves as a resource for researchers, engineers, and industry stakeholders, facilitating a deeper understanding of the characteristics and potential applications of these materials. Key objectives of this deliverable include the collection and the characterization of the slag samples, including analysis of their chemical and mineral composition, leaching behavior and physical properties.

In this deliverable, a thorough review of current slag samples obtained from various sources from around the world within the steelmaking industry is presented. Each sample is subjected to rigorous analysis, which will help the steelworks understand what differences can be expected in slag quality after their transformation. This comprehensive collection not only enhances our understanding of these materials but also supports the development of more sustainable and efficient steel production practices.

2 Collected slag samples

Fifteen (15) EAF slag samples were collected from current industrial production in different regions (America's, Europe and Middle East). Table 1 shows an overview of all the slags that were collected and investigated. The samples originate from industrial scale EAFs collected after cooling in the slag yards. The EAF was operated with different percentages of DRI input ranging from 100 down to 9.5 %.

Table 1: Collected slag samples

Sample	Beneficiary	Percent of input material (DRI/Scrap)	Location
K1-I	FEhS	90 / 10 %	Middle East
K2-I	FEhS	90 / 10 %	Middle East
K3-I	FEhS	90 / 10 %	Middle East
G1-I	AMMR	70 / 30 %	Canada
G2-I	AMMR	50 / 50 %	Canada
G3-I	AMMR	10 / 90 %	Germany
G4-I	AMMR	9.5 / 90.5 %	Germany
G5-I	AMMR	61 / 39 %	Germany
G6-I	AMMR	68 / 32 %	Germany
N1-I	Primetals	100 / 0 %	Middle East
N2-I	Primetals	100 / 0 %	Middle East
Y1-I	Tenova	100 / 0 %	Mexico
Y2-I	Tenova	65 / 35 %	Mexico
Y3-I	Tenova	64 / 36 %	Mexico
Y4-I	Tenova	60 / 40 %	Mexico

2.1 Materials and Methods

2.1.1 Chemical composition

The samples were analyzed for chemical composition using XRF (X-Ray fluorescence) and ICP-OES (Inductively coupled plasma optical emission spectroscopy).

The chemical composition was determined in different ways which conform to:

XRF analysis EN ISO 12677

Infrared (IR) (TIC) EN 15936

IR (H_2O) based on DIN 19539

Aqua regia digestion EN 13346

ICP (solids) EN ISO 11885

BM Extraction Handbuch Eisenhüttenlabor, Bd. 1A (only available in German)

In the report, when XRF or ICP-OES are referred to, the following procedures were used:

1) XRF (analysis of fused sample with $Li_2B_4O_7$ after grinding < 90 µm)

2) Aqua regia composition (content excluding spinel phases): 250 mg of sample was digested for 20 min in a microwave using aqua regia (HNO3 + 3 HCl). The eluates were analyzed with ICP-OES, with analytical error 3%.
3) Chemical composition metals (metal content): 500 mg samples were digested for 1 hour in a microwave with bromine-methanol. The extracts were analyzed with ICP-OES, analytical error 3 %.

2.1.2 Mineral composition

Quantitative XRD
The mineral composition described in the report is based on quantitative XRD, unless otherwise stated. Analysis is carried out by using a powder diffractometer (PANalytical, type X'Pert pro) with Cu k-alpha1 radiation. The sample comminution was conducted in ethanol suspension for 45 min in a XRD mill (Retsch). Rutil was added as internal standard prior comminution at a mass fraction of 10 wt. %. Diffraction patterns were recorded between 5 to 92 ° 2-theta. Interpretation and quantification by Rietveld refinement was done by using Profex 5.3 software suite. Individual errors are calculated on a 3-sigma confidence level.

2.1.3 Leaching test

Two types of batch leaching tests (with different slag to water ratios) have been conducted for each sample, type 1 with slag to water ratio of 1:2 (DIN 19529), type and 2 with slag to water ratio of 1:10 (EN 12457-2). The procedure of EN 12457-2 was followed for both slag to water ratios as it is the same.

ICP (leachates) EN ISO 17294-2

The grain size in Austrian, French, Italian and Spanish regulation is < 10 mm, while only Belgium regulation has < 4 mm. The German regulation has the grain size of < 22.4 mm (with ≥ 45 wt.-% < 4 mm) or a testing of each grainsize that should go to the market. To simplify the number of tests for each slag sample, the grain size < 10 mm was used for all leaching tests.

To homogenize the tests, same distribution of the grain size < 10 mm was used. The distribution of grain size in the tests used are based on the percentage shown in Table 2 and Figure 1. The distribution is based on paving bedding material in Germany and ensure comparability between slag samples. Table 3 shows an example of the quantity of slag that should be used at each grain size when preparing for leaching tests based on 190 g of slag amount.

Table 2: Grain size distribution to be used in leaching tests

Sieves [mm]	Sieve passage	Lower limit	Upper limit
2.0	37.5 %	15 %	60 %
4.0	52.5 %	3 0%	75 %
5.6	70.0 %	50 %	90 %
10.0	100.0 %	100 %	100 %

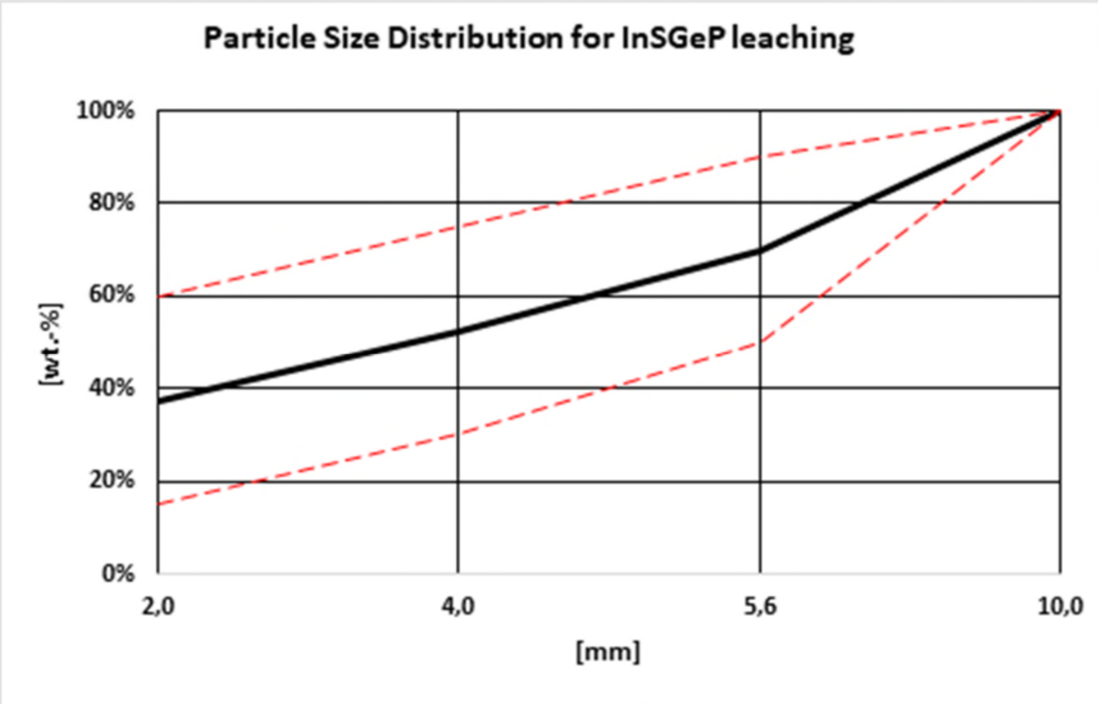

Figure 1: Grain size distribution with lower and upper range for slag sample < 10 mm

Table 3: Example of 190 g of slag sample to be prepared for leaching tests

Sieves [mm]	Sieve residue	Example
		190.0 g
0.0	37.5 %	71.3 g
2.0	15.0 %	28.5 g
4.0	17.5 %	33.3 g
5.6	30.0 %	57.0 g
10.0	0.0 %	0.0 g

Samples K1, K2 and K3 were analyzed at the beginning of the project before common parameters were decided. Due to this some parameters are missing from the analysis. In addition, it took much longer to obtain Austrian leaching values and parameters such as NH_4^+ and TOC, which are not included in the analysis as they are not common parameters that are required in any other country taken into consideration in this project.

2.1.4 Physical parameters

Bulk density was determined according to DIN EN 1015-10[1] by using a pycnometer. By determining the masses of the pycnometer, the added sample, and the added water to a marker at the pycnometer, the volume can be calculated with the known volume of the pycnometer.

Volume stability was determined according to DIN EN 1744-1 (2009) Chapter 19 – (24 h and 168 h) by the steam test. To perform this test, the sample must be screened to a defined grain size distribution of 0-22 mm according to Fuller and compacted into the test form. In the steam test device, hot steam passes the material to accelerate the hydration of free lime and periclase and the volume expansion is

[1] DIN EN 1015-10: Prüfverfahren für Mörtel für Mauerwerk - Teil 10: Bestimmung der Trockenrohdichte von Festmörtel; Deutsche Fassung EN 1015-10:1999+A1:2006

measured by a displacement sensor at the top. The characteristic volume expansions after 24 h and 168 h can be compared with the respective regulations.

2.2 Results of chemical and mineral composition, leaching and physical parameters

The following subsections present the results of chemical and mineral composition, leaching and physical parameters of each of the 15 slag samples.

2.2.1 K1-I

K1-I sample results are shown in Table 4 and Table 5 for chemical composition with XRF and ICP-OES, respectively.

Table 4: K1-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	5.19	MgO	wt.-%	11.30	SrO	wt.-%	< 0.020
BaO	wt.-%	0.07	MnO	wt.-%	2.09	TiO_2	wt.-%	1.03
CaO	wt.-%	23.50	Na_2O	wt.-%	0.11	V_2O_5	wt.-%	0.51
Cr_2O_3	wt.-%	0.29	NiO	wt.-%	< 0.007	ZnO	wt.-%	< 0.007
CuO	wt.-%	< 0.007	P_2O_5	wt.-%	0.48	ZrO	wt.-%	< 0.020
FeO	wt.-%	35.40	PbO	wt.-%	< 0.007	CO_2	wt.-%	0.09
HfO	wt.-%	< 0.007	S	wt.-%	0.03	H_2O	wt.-%	< 0.03
K_2O	wt.-%	0.02	SiO_2	wt.-%	15.20			

Table 5: K1-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	1.3	K	mg/kg	518	Sn	mg/kg	0.78
Ba	mg/kg	570	Mg	mg/kg	67,920	Sr	mg/kg	196
Be	mg/kg	3.8	Mn	mg/kg	12,870	Ti	mg/kg	5,686
Cd	mg/kg	0.06	Mo	mg/kg	5.05	V	mg/kg	2,619
Co	mg/kg	20.96	Na	mg/kg	996	W	mg/kg	156
Cr	mg/kg	1,956	Pb	mg/kg	2.79	Zn	mg/kg	20.71
Cu	mg/kg	19.13	Sb	mg/kg	0.36			
Fe	mg/kg	288,500	Se	mg/kg	0.57			

Table 6 shows mineral composition results of sample K1-I.

Table 6: K1-I Mineral composition

Mineral	Formula	Unit	Value
Larnite	Ca_2SiO_4	wt.-%	20
Bredigite	$Ca_{1.7}Mg_{0.3}SiO_4$	wt.-%	15
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	30
Gehlenite	$Ca_2Al_2SiO_7$	wt.-%	15
Wuestite	FeO	wt.-%	20
Spinel (Magnetite)	Fe_3O_4	wt.-%	< 5

Table 7 shows volume stability and bulk density results of sample K1-I.

Table 7: K1-I Physical properties

Parameter	Test	Unit	Value
Volume stability	Steam test	Vol.-%	0.0 (24 h) | 0.4 (168 h)
Bulk density	Pycnometer	kg/m³	3.85

Table 8 shows leaching results of sample K1-I.

Table 8: K1-I Leaching

		Slag:water ratio		
Parameter	Unit	1:10 8/11 mm batch shaking	1:2 8/11 mm batch shaking	1:2 0/22 mm percolation upflow
pH		10.9	11.2	10.5
EC	µS/cm	244	554	198
Al	mg/l	0.759	1.169	0.494
As	mg/l	< 0.0001	0.0001	0.0006
Ba	mg/l	0.12	0.166	0.048
Be	mg/l	< 0.0001	< 0.0001	0.0002
Bo	mg/l	0.0669	0.237	0.163
Ca	mg/l	22.101	46.029	15.085
Cd	mg/l	< 0.0001	< 0.0001	< 0.0001
Cl^-	mg/l	1.3	5.9	6.7
Co	mg/l	< 0.0005	< 0.0005	< 0.0005
Cr_{total}	mg/l	< 0.0005	< 0.0005	< 0.0005
Cu	mg/l	0.0015	0.0017	0.0019
F^- (IC)	mg/l	0.3	1.1	0.7
F^- (Pot)	mg/l	< 0.4	0.7	0.9
Fe	mg/l	0.0049	0.004	0.0075
Hg	mg/l	0.0001	0.0002	0.0005
K	mg/l	1.869	8.569	8.389
Li	mg/l	< 0.0001	0.0001	< 0.0001
Mg	mg/l	0.895	0.308	0.184
Mn	mg/l	< 0.001	< 0.001	0.001
Mo	mg/l	0.0044	0.0205	0.0171
Na	mg/l	2.747	12.574	11.865
Nb	mg/l	< 0.00004	< 0.00004	< 0.00004
Ni	mg/l	0.0002	0.0002	0.0005
P	mg/l	0.0599	0.0437	0.0795
Pb	mg/l	< 0.0001	< 0.0001	< 0.0001
Pl	mg/l	< 0.00004	< 0.00004	< 0.00004
Sb	mg/l	< 0.0001	0.0001	< 0.0001
Se	mg/l	0.0003	0.0007	0.0013
Si	mg/l	8.97	13.99	7.04

Parameter	Unit	Slag:water ratio		
		1:10 8/11 mm batch shaking	1:2 8/11 mm batch shaking	1:2 0/22 mm percolation upflow
Sn	mg/l	< 0.001	< 0.001	< 0.001
SO_4^{-2}	mg/l	2.2	9.3	9.1
Sr	mg/l	0.0348	0.0796	0.0287
Ti	mg/l	< 0.001	< 0.001	< 0.001
Tl	mg/l	< 0.0001	< 0.0001	< 0.0001
V	mg/l	0.161	0.405	0.222
W	mg/l	0.0214	0.0886	0.0745
Zn	mg/l	< 0.005	< 0.005	0.0146

2.2.2 K2-I

K2-I sample results are shown in Table 9 and Table 10 for chemical composition with XRF and ICP-OES, respectively.

Table 9: K2-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	3.92	MgO	wt.-%	10.70	SrO	wt.-%	< 0.020
BaO	wt.-%	0.06	MnO	wt.-%	1.60	TiO_2	wt.-%	0.86
CaO	wt.-%	25.20	Na_2O	wt.-%	0.10	V_2O_5	wt.-%	0.63
Cr_2O_3	wt.-%	0.20	NiO	wt.-%	< 0.007	ZnO	wt.-%	0.06
CuO	wt.-%	< 0.007	P_2O_5	wt.-%	0.44	ZrO	wt.-%	< 0.020
FeO	wt.-%	34.10	PbO	wt.-%	< 0.007	CO_2	wt.-%	2.40
HfO	wt.-%	< 0.007	S	wt.-%	0.06	H_2O	wt.-%	0.72
K_2O	wt.-%	0.05	SiO_2	wt.-%	14.40			

Table 10: K2-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	1.45	K	mg/kg	645	Sn	mg/kg	1.69
Ba	mg/kg	498	Mg	mg/kg	64,330	Sr	mg/kg	235
Be	mg/kg	3.91	Mn	mg/kg	10,729	Ti	mg/kg	5,410
Cd	mg/kg	0.5	Mo	mg/kg	4.35	V	mg/kg	3,797
Co	mg/kg	14.44	Na	mg/kg	1,180	W	mg/kg	170
Cr	mg/kg	1,202	Pb	mg/kg	16.69	Zn	mg/kg	502
Cu	mg/kg	28.9	Sb	mg/kg	0.49			
Fe	mg/kg	264,349	Se	mg/kg	0.63			

Table 11 shows mineral composition results of sample K2-I.

Table 11: K2-I Mineral composition

Mineral	Formula	Unit	Value
Larnite	Ca_2SiO_4	wt.-%	20
Bredigite	$Ca_{1.7}Mg_{0.3}SiO_4$	wt.-%	20
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	20
Gehlenite	$Ca_2Al_2SiO_7$	wt.-%	15
Wuestite	FeO	wt.-%	20
Spinel (Magnetite)	Fe_3O_4	wt.-%	5

Table 12 shows volume stability and bulk density results of sample K2-I.

Table 12: K2-I Physical properties

Parameter	Test	Unit	Value
Volume stability	Steam test	Vol.-%	0.0 (24 h) | 0.4 (168 h)
Bulk density	Pycnometer	kg/m³	3.85

Table 13 shows leaching results of sample K2-I.

Table 13: K2-I Leaching

		Slag:water ratio		
Parameter	**Unit**	**1:10 8/11 mm batch shaking**	**1:2 8/11 mm batch shaking**	**1:2 0/22 mm percolation upflow**
pH		11.1	11.2	10.4
EC	µS/cm	420	656	332
Al	mg/l	0.487	0.268	0.171
As	mg/l	0.0002	0.0001	0.0006
Ba	mg/l	0.0602	0.0746	0.0135
Be	mg/l	< 0.0001	< 0.0001	< 0.0001
Bo	mg/l	0.0482	0.141	0.113
Ca	mg/l	46.887	73.039	25.673
Cd	mg/l	< 0.0001	< 0.0001	< 0.0001
Cl^-	mg/l	2.7	13	25
Co	mg/l	< 0.0005	< 0.0005	< 0.0005
Cr	mg/l	0.0062	0.0055	0.0065
Cu	mg/l	0.0013	0.0019	0.0023
F^- (IC)	mg/l	0.6	1.9	1.3
F^- (Pot)	mg/l	< 0.4	1.31	1.89
Fe	mg/l	0.003	0.0022	0.0032
Hg	mg/l	< 0.0001	< 0.0001	0.0001
K	mg/l	0.770	2.577	5.369
Li	mg/l	0.0002	0.0005	0.0004
Mg	mg/l	0.440	0.259	0.436
Mn	mg/l	< 0.001	< 0.001	0.0021

Parameter	Unit	Slag:water ratio		
		1:10 8/11 mm batch shaking	1:2 8/11 mm batch shaking	1:2 0/22 mm percolation upflow
Mo	mg/l	< 0.001	0.0024	0.0017
Na	mg/l	2.483	9.463	34.358
Nb	mg/l	< 0.00004	< 0.00004	< 0.00004
Ni	mg/l	0.0002	0.0001	0.0013
P	mg/l	0.0574	0.081	0.090
Pb	mg/l	< 0.0001	< 0.0001	< 0.0001
Pl	mg/l	< 0.00004	< 0.00004	< 0.00004
Sb	mg/l	0.0001	0.0003	0.0005
Se	mg/l	0.0001	0.0004	0.0005
Si	mg/l	17.37	19.6	15.62
Sn	mg/l	< 0.001	< 0.001	< 0.001
SO_4^{-2}	mg/l	5.3	26	35
Sr	mg/l	0.0699	0.166	0.0744
Ti	mg/l	< 0.001	< 0.001	< 0.001
Tl	mg/l	< 0.0001	< 0.0001	0.0001
V	mg/l	0.540	1.240	1.150
W	mg/l	0.003	0.0088	0.006
Zn	mg/l	< 0.005	< 0.005	< 0.005

2.2.3 K3-I

K3-I sample results are shown in Table 14 and Table 15 for chemical composition with XRF and ICP-OES, respectively.

Table 14: K3-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	3.91	MgO	wt.-%	10.55	SrO	wt.-%	< 0.007
BaO	wt.-%	0.05	MnO	wt.-%	1.51	TiO_2	wt.-%	0.87
CaO	wt.-%	24.47	Na_2O	wt.-%	0.05	V_2O_5	wt.-%	0.63
Cr_2O_3	wt.-%	0.20	NiO	wt.-%	< 0.007	ZnO	wt.-%	0.06
CuO	wt.-%	< 0.007	P_2O_5	wt.-%	0.48	ZrO	wt.-%	< 0.020
FeO	wt.-%	37.40	PbO	wt.-%	< 0.007	CO_2	wt.-%	1.37
HfO	wt.-%	< 0.007	S	wt.-%	0.04	H_2O	wt.-%	0.40
K_2O	wt.-%	0.04	SiO_2	wt.-%	13.33			

Table 15: K3-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	1.29	K	mg/kg	675	Sn	mg/kg	1.47
Ba	mg/kg	499	Mg	mg/kg	62,700	Sr	mg/kg	208
Be	mg/kg	3.59	Mn	mg/kg	10,740	Ti	mg/kg	5,217
Cd	mg/kg	0.43	Mo	mg/kg	3.81	V	mg/kg	3,305
Co	mg/kg	15.82	Na	mg/kg	1,081	W	mg/kg	146
Cr	mg/kg	1,335	Pb	mg/kg	16.35	Zn	mg/kg	536
Cu	mg/kg	25.04	Sb	mg/kg	0.53			
Fe	mg/kg	256,400	Se	mg/kg	0.59			

Table 16 shows mineral composition results of sample K3-I.

Table 16: K3-I Mineral composition

Mineral	Formula	Unit	Value
Quartz	SiO_2	wt.-%	< 5
Larnite	Ca_2SiO_4	wt.-%	20
Bredigite	$Ca_{1.7}Mg_{0.3}SiO_4$	wt.-%	20
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	25
Gehlenite	$Ca_2Al_2SiO_7$	wt.-%	10
Wuestite	FeO	wt.-%	15
Spinel (Magnetite)	Fe_3O_4	wt.-%	5

Table 17 shows volume stability and bulk density results of sample K3-I.

Table 17: K3-I Physical properties

Parameter	Test	Unit	Value
Volume stability	Steam test	Vol.-%	0.0 (24 h) | 0.0 (168 h)
Bulk density	Pycnometer	kg/m³	3.91

Table 18 shows leaching results of sample K3-I.

Table 18: K3-I Leaching

		Slag:water ratio		
Parameter	Unit	1:10 8/11 mm batch shaking	1:2 8/11 mm batch shaking	1:2 0/22 mm percolation upflow
pH		11.1	11.1	10.5
EC	µS/cm	417	658	364
Al	mg/l	0.432	0.150	0.154
As	mg/l	0.0001	0.0002	0.0006
Ba	mg/l	0.045	0.0459	0.0135
Be	mg/l	< 0.0001	< 0.0001	< 0.0001
Bo	mg/l	0.0428	0.211	0.129
Ca	mg/l	43.630	66.461	30.239
Cd	mg/l	< 0.0001	< 0.0001	< 0.0001
Cl^-	mg/l	3.9	28	23

Parameter	Unit	Slag:water ratio		
		1:10 8/11 mm batch shaking	1:2 8/11 mm batch shaking	1:2 0/22 mm percolation upflow
Co	mg/l	< 0.0005	< 0.0005	< 0.0005
Cr	mg/l	0.0028	0.0156	0.0067
Cu	mg/l	0.0013	0.0018	0.0023
F^- (IC)	mg/l	0.4	2.1	1.4
F^- (Pot)	mg/l	0.5	2.53	1.66
Fe	mg/l	0.0021	0.0015	0.0029
Hg	mg/l	< 0.0001	< 0.0001	0.0001
K	mg/l	1.027	6.708	5.182
Li	mg/l	0.0001	0.0005	0.0005
Mg	mg/l	0.379	0.205	0.507
Mn	mg/l	< 0.001	< 0.001	0.0018
Mo	mg/l	< 0.001	0.004	0.0017
Na	mg/l	4.095	41.970	34.427
Nb	mg/l	< 0.00004	< 0.00004	< 0.00004
Ni	mg/l	< 0.0001	< 0.0001	0.0013
P	mg/l	0.0538	0.101	0.0891
Pb	mg/l	< 0.0001	< 0.0001	< 0.0001
Pl	mg/l	< 0.00004	< 0.00004	< 0.00004
Sb	mg/l	0.0001	0.0007	0.0005
Se	mg/l	0.0001	0.0004	0.0005
Si	mg/l	18.21	26.02	17.73
Sn	mg/l	< 0.0010	< 0.0010	< 0.0010
SO_4^{-2}	mg/l	6.9	47	32
Sr	mg/l	0.0687	0.243	0.0839
Ti	mg/l	< 0.001	< 0.001	< 0.001
Tl	mg/l	< 0.0001	< 0.0001	0.0001
V	mg/l	0.555	1.937	1.018
W	mg/l	0.0033	0.0139	0.0064
Zn	mg/l	< 0.005	< 0.005	< 0.005

2.2.4 G1-I

G1-I sample results are shown in Table 19 and Table 20 for chemical composition with XRF and ICP-OES, respectively.

Table 19: G1-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	4.08	MgO	wt.-%	12.90	SrO	wt.-%	< 0.01
BaO	wt.-%	0.04	MnO	wt.-%	1.27	TiO_2	wt.-%	1.85
CaO	wt.-%	25.90	Na_2O	wt.-%	0.04	V_2O_5	wt.-%	0.12
Cr_2O_3	wt.-%	0.59	NiO	wt.-%	< 0.01	ZnO	wt.-%	< 0.01
CuO	wt.-%	< 0.01	P_2O_5	wt.-%	0.15	ZrO	wt.-%	0.03
FeO	wt.-%	34.80	PbO	wt.-%	< 0.01			
HfO	wt.-%	< 0.007	S	wt.-%	0.02			
K_2O	wt.-%	< 0.01	SiO_2	wt.-%	12.50			

Table 20: G1-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	0.79	K	mg/kg	99.2	Sn	mg/kg	4.9
Ba	mg/kg	191	Mg	mg/kg	79,049	Sr	mg/kg	161
Be	mg/kg	2.95	Mn	mg/kg	10.287	Ti	mg/kg	10.935
Cd	mg/kg	<0.10	Mo	mg/kg	8.34	V	mg/kg	597
Co	mg/kg	10.83	Na	mg/kg	459	W	mg/kg	166
Cr	mg/kg	3.426	Pb	mg/kg	0.99	Zn	mg/kg	28.71
Cu	mg/kg	24.75	Sb	mg/kg	0.2			
Fe	mg/kg	267.471	Se	mg/kg	1.01			

Table 21 shows mineral composition results of sample G1-I.

Table 21: G1-I Mineral composition

Mineral	Formula	Unit	Value
Wuestite	FeO	wt.-%	27.8
Magnesioferrite	$MgFe_2O_4$	wt.-%	22.6
Gehlenite	$Ca_2Al_2SiO_7$	wt.-%	7.4
Tricalciumaluminate	$Al_2Ca_3O_6$	wt.-%	6.1
Bredigite	$Ca_{1.7}Mg_{0.3}SiO_4$	wt.-%	16.1
Larnite	β-Ca_2SiO_4	wt.-%	11.5
Periclase	MgO	wt.-%	4.9
Calcite	$CaCO_3$	wt.-%	2.6
Akermanite	$Ca_2MgSi_2O_7$	wt.-%	0.4
Quartz	SiO_2	wt.-%	0.6

Table 22shows volume stability and bulk density results of sample G1-I.

Table 22: G1-I Physical properties

Parameter	Test	Unit	Value
Volume stability	Steam test	Vol.-%	n.a. (24 h) | n.a. (168 h)
Bulk density	Pycnometer	kg/m³	3.83

Table 23 shows leaching results of sample G1-I.

Table 23: G1-I Leaching

		Slag:water ratio	
Parameter	**Unit**	**1:10 < 2 mm batch shaking**	**1:2 < 2 mm batch shaking**
pH		11.5	11.6
EC	µS/cm	747	1,049
COD	mg/l	11	5
Al	mg/l	1.585	2.260
As	mg/l	<0.001	<0.001
Ba	mg/l	0.038	0.056
Be	mg/l	<0.001	<0.001
Cd	mg/l	<0.001	<0.001
Cl^-	mg/l	<1.00	0.800
CN^-	mg/l	<0.010	<0.010
Co	mg/l	<0.001	<0.001
Cr^{6+}	mg/l	<0.010	<0.010
Cr_{total}	mg/l	0.013	0.052
Cu	mg/l	0.002	<0.001
F^-	mg/l	0.400	0.800
Hg	mg/l	<0.001	<0.001
Mo	mg/l	0.003	0.011
Ni	mg/l	<0.001	<0.001
NO_3^-	mg/l	<1.00	<1.00
Pb	mg/l	<0.001	<0.001
Sb	mg/l	<0.001	<0.001
Se	mg/l	0.001	0.006
SO_4^{-2}	mg/l	5.800	25.000
Ti	mg/l	0.001	0.001
V	mg/l	0.201	0.208
Zn	mg/l	0.011	<0.001

2.2.5 G2-I

G2-I sample results are shown in Table 24 and Table 25 for chemical composition with XRF and ICP-OES, respectively.

Table 24: G2-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	5.38	MgO	wt.-%	12.50	SrO	wt.-%	0.01
BaO	wt.-%	0.04	MnO	wt.-%	2.00	TiO_2	wt.-%	1.96
CaO	wt.-%	28.40	Na_2O	wt.-%	0.08	V_2O_5	wt.-%	0.18
Cr_2O_3	wt.-%	0.99	NiO	wt.-%	< 0.01	ZnO	wt.-%	< 0.01
CuO	wt.-%	< 0.01	P_2O_5	wt.-%	0.17	ZrO	wt.-%	0.04
FeO	wt.-%	28.20	PbO	wt.-%	< 0.01			
HfO	wt.-%	< 0.007	S	wt.-%	0.04			
K_2O	wt.-%	0.01	SiO_2	wt.-%	14.90			

Table 25: G2-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	1.05	K	mg/kg	146	Sn	mg/kg	4.4
Ba	mg/kg	251	Mg	mg/kg	76,036	Sr	mg/kg	179
Be	mg/kg	2.83	Mn	mg/kg	16,403	Ti	mg/kg	11,540
Cd	mg/kg	0.12	Mo	mg/kg	13.52	V	mg/kg	840
Co	mg/kg	16.55	Na	mg/kg	336	W	mg/kg	287
Cr	mg/kg	4,622	Pb	mg/kg	42.44	Zn	mg/kg	49.29
Cu	mg/kg	47.96	Sb	mg/kg	0.65			
Fe	mg/kg	216,074	Se	mg/kg	0.91			

Table 26 shows mineral composition results of sample G2-I.

Table 26: G2-I Mineral composition

Mineral	Formula	Unit	Value
Wuestite	FeO	wt.-%	16.6
Magnesioferrite	$MgFe_2O_4$	wt.-%	23.3
Gehlenite	$Ca_2Al_2SiO_7$	wt.-%	6.9
Tricalciumaluminate	$Al_2Ca_3O_6$	wt.-%	8.1
Bredigite	$Ca_{1.7}Mg_{0.3}SiO_4$	wt.-%	24.2
Larnite	β-Ca_2SiO_4	wt.-%	11.6
Periclase	MgO	wt.-%	2.8
Calcite	$CaCO_3$	wt.-%	3.6
Akermanite	$Ca_2MgSi_2O_7$	wt.-%	2.2
Quartz	SiO_2	wt.-%	0.7

Table 27 shows volume stability and bulk density results of sample G2-I.

Table 27: G2-I Physical properties

Parameter	Test	Unit	Value
Volume stability	Steam test	Vol.-%	n.a. (24 h) | n.a. (168 h)
Bulk density	Pycnometer	kg/m³	3.69

Table 28 shows leaching results of sample G3-I.

Table 28: G2-I Leaching

		Slag:water ratio	
Parameter	**Unit**	**1:10 < 2 mm batch shaking**	**1:2 < 2 mm batch shaking**
pH		11.5	11.8
EC	µS/cm	726	1.594
COD	mg/l	1	4
Al	mg/l	3.421	6.720
As	mg/l	<0.001	<0.001
Ba	mg/l	0.040	0.125
Be	mg/l	<0.001	<0.001
Cd	mg/l	<0.001	<0.001
Cl^-	mg/l	<1.0	2.3
CN^-	mg/l	<0.010	<0.010
Co	mg/l	<0.001	<0.001
Cr^{6+}	mg/l	<0.01	<0.01
Cr_{total}	mg/l	0.020	0.079
Cu	mg/l	<0.001	0.001
F^-	mg/l	0.4	0.9
Hg	mg/l	<0.001	<0.001
Mo	mg/l	0.006	0.025
Ni	mg/l	<0.001	<0.001
NO_3^-	mg/l	<1.0	<1.0
Pb	mg/l	<0.001	0.006
Sb	mg/l	0.001	0.002
Se	mg/l	0.002	0.004
SO_4^{-2}	mg/l	12	45
Ti	mg/l	<0.001	<0.001
V	mg/l	0.168	0.070
Zn	mg/l	0.001	0.017

2.2.6 G3-I

G3-I sample results are shown in Table 29 and Table 30 for chemical composition with XRF and ICP-OES, respectively.

Table 29: G3-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	7.29	MgO	wt.-%	7.63	SrO	wt.-%	0.02
BaO	wt.-%	0.14	MnO	wt.-%	4.34	TiO_2	wt.-%	0.64
CaO	wt.-%	24.97	Na_2O	wt.-%	0.04	V_2O_5	wt.-%	0.13
Cr_2O_3	wt.-%	2.61	NiO	wt.-%	< 0.01	ZnO	wt.-%	< 0.01
CuO	wt.-%	< 0.01	P_2O_5	wt.-%	0.33	ZrO	wt.-%	< 0.01
FeO	wt.-%	35.73	PbO	wt.-%	< 0.01	CO_2	wt.-%	
HfO	wt.-%	< 0.007	S	wt.-%	0.06	H_2O	wt.-%	
K_2O	wt.-%	< 0.01	SiO_2	wt.-%	10.50			

Table 30: G3-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	1.02	K	mg/kg	56.57	Sn	mg/kg	14.94
Ba	mg/kg	987	Mg	mg/kg	44,501	Sr	mg/kg	273
Be	mg/kg	0.77	Mn	mg/kg	33,343	Ti	mg/kg	3,699
Cd	mg/kg	0.12	Mo	mg/kg	33.99	V	mg/kg	550
Co	mg/kg	16.20	Na	mg/kg	292	W	mg/kg	407
Cr	mg/kg	5,477	Pb	mg/kg	4.16	Zn	mg/kg	165
Cu	mg/kg	116	Sb	mg/kg	0.31			
Fe	mg/kg	273,963	Se	mg/kg	1.12			

Table 31 shows mineral composition results of sample G3-I.

Table 31: G3-I Mineral composition

Mineral	Formula	Unit	Value
Wuestite	FeO	wt.-%	38.5
Gehlenite	$Ca_2Al_2SiO_7$	wt.-%	11.3
Larnite	Ca_2SiO_4	wt.-%	30.2
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	6.7
Spinel (Magnetite)	Fe_3O_4	wt.-%	2.7
Titanomagnetite	$Fe(Fe_{0.75}Ti_{0.25})_2O_4$	wt.-%	9.1
Hematite	Fe_2O_3	wt.-%	1.7

Table 32 shows volume stability and bulk density results of sample G3-I.

Table 32: G3-I Physical properties

Parameter	Test	Unit	Value
Volume stability	Steam test	Vol.-%	0.0 (24 h) | 0.1 (168 h)
Bulk density	Pycnometer	kg/m^3	3.92

Table 33 shows leaching results of sample G3-I.

Table 33: G3-I Leaching

		Slag:water ratio			
Parameter	**Unit**	**1:10 < 2 mm batch shaking**	**1:2 < 2 mm batch shaking**	**1:10 < 8 mm batch shaking**	**1:2 < 8 mm batch shaking**
pH		11.6	11.8	11.4	11.7
EC	µS/cm	829	1,714	642	1,328
COD	mg/l	1	8	<1	<1
Al	mg/l	5.478	0.005	6.902	31.738
As	mg/l	<0.001	<0.001	<0.001	<0.001
Ba	mg/l	0.298	0.000	0.222	1.079
Be	mg/l	<0.001	<0.001	<0.001	<0.001
Cd	mg/l	<0.001	<0.001	<0.001	<0.001
Cl^-	mg/l	2.8	13.0	1.7	7.7
CN^-	mg/l	<0.010	<0.010	<0.010	<0.010
Co	mg/l	<0.001	<0.001	<0.001	<0.001
Cr^{6+}	mg/l	<0.01	0.010	<0.01	0.010
Cr_{total}	mg/l	0.074	0.000	0.045	0.141
Cu	mg/l	0.001	0.000	<0.001	0.001
F^-	mg/l	<0.4	<0.4	<0.4	0.8
Hg	mg/l	0.001	<0.001	<0.001	<0.001
Mo	mg/l	0.013	0.000	0.013	0.054
Ni	mg/l	<0.001	<0.001	<0.001	<0.001
NO_3^-	mg/l	<1.0	<1.0	<1.0	<1.0
Pb	mg/l	<0.001	<0.001	<0.001	<0.001
Sb	mg/l	<0.001	<0.001	<0.001	<0.001
Se	mg/l	0.001	0.000	0.001	0.001
SO_4^{-2}	mg/l	2.3	6.3	1.8	6.7
Ti	mg/l	0.003	<0.001	<0.001	<0.001
V	mg/l	0.068	0.000	0.067	0.012
Zn	mg/l	0.015	0.000	0.008	0.004

2.2.7 G4-I

G4-I sample results are shown in Table 34 and Table 35 for chemical composition with XRF and ICP-OES, respectively.

Table 34: G4-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	5.38	MgO	wt.-%	4.23	TiO_2	wt.-%	0.515
BaO	wt.-%	0.085	MnO	wt.-%	4.21	V_2O_5	wt.-%	0.083
CaO	wt.-%	21.3	Na_2O	wt.-%	0.02	ZnO	wt.-%	<0.01
Cr_2O_3	wt.-%	0.99	P_2O_5	wt.-%	0.28	ZrO_2	wt.-%	<0.01
CuO	wt.-%	<0.01	PbO	wt.-%	<0.01	H_2O	wt.-%	0.00
FeO	wt.-%	47.68	SiO_2	wt.-%	9.50	TIC	wt.-%	0.04
K_2O	wt.-%	< 0.01	SO_4	wt.-%	0.093			

Table 35: G4-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	< 1.0	K	mg/kg	13.0	Sn	mg/kg	1.0
Ba	mg/kg	58.5	Mg	mg/kg	2,257	Sr	mg/kg	28.5
Be	mg/kg	< 1.0	Mn	mg/kg	3,080	Ti	mg/kg	254
Cd	mg/kg	1.0	Mo	mg/kg	3.25	V	mg/kg	41.25
Co	mg/kg	< 1.0	Na	mg/kg	36.5	W	mg/kg	10.25
Cr	mg/kg	352	Pb	mg/kg	1.0	Zn	mg/kg	9.25
Cu	mg/kg	8.5	Sb	mg/kg	1.0			
Fe	mg/kg	35,000	Se	mg/kg	1.75			

Table 36 shows mineral composition results of sample G4-I.

Table 36: G4-I Mineral composition

Mineral	Formula	Unit	Value
Wuestite	FeO	wt.-%	48.4
Larnite	β-Ca_2SiO_4	wt.-%	24.5
Spinel (Magnetite)	Fe_3O_4	wt.-%	3.8
Gehlenite	$Ca_2Al_2SiO_7$	wt.-%	14.6
Periclase	MgO	wt.-%	4.0
C3A cub		wt.-%	1.4
Hercynite	$FeAl_2O_4$	wt.-%	0.7
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	1.0
C3A cub		wt.-%	1.2

Table 37 shows volume stability and bulk density results of sample G4-I.

Table 37: G4-I Physical properties

Parameter	Test	Unit	Value
Volume stability	Steam test	Vol.-%	0.0 (24 h) | 2.9 (168 h)
Bulk density	Pycnometer	kg/m^3	4.17

Table 38 shows leaching results of sample G4-I.

Table 38: G4-I Leaching

		Slag:water ratio	
Parameter	**Unit**	**1:10 < 10 mm batch shaking**	**1:2 < 10 mm batch shaking**
pH		11.3	12.0
EC	µS/cm	508	1,160
COD	mg/l	7	12
Al	mg/l	5.287	82.723
As	mg/l	<0.001	<0.001
Ba	mg/l	0.265	1.536
Be	mg/l	<0.001	<0.001
Cd	mg/l	<0.001	<0.001
Cl^-	mg/l	0.8	3.6
CN^-	mg/l	<0.010	<0.010
Co	mg/l	<0.001	<0.001
Cr^{6+}	mg/l	<0.01	<0.01
Cr_{total}	mg/l	<0.001	0.001
Cu	mg/l	<0.001	0.001
F^-	mg/l	0.7	6.5
Hg	mg/l	<0.001	0.001
Mo	mg/l	0.004	0.015
Ni	mg/l	<0.001	<0.001
NO_3^-	mg/l	<1.0	<1.0
Pb	mg/l	0.002	<0.001
Sb	mg/l	<0.001	<0.001
Se	mg/l	<0.001	0.003
SO_4^{2-}	mg/l	1.4	4.4
Ti	mg/l	<0.001	<0.001
V	mg/l	0.133	0.127
Zn	mg/l	0.009	0.011

2.2.8 G5-I

A5-I sample results are shown in Table 39 and Table 40 for chemical composition with XRF and ICP-OES, respectively.

Table 39: G5-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	4.00	MgO	wt.-%	4.24	TiO_2	wt.-%	0.51
BaO	wt.-%	0.08	MnO	wt.-%	1.47	V_2O_5	wt.-%	0.16
CaO	wt.-%	28.9	Na_2O	wt.-%	0.03	ZnO	wt.-%	< 0.01
Cr_2O_3	wt.-%	0.29	P_2O_5	wt.-%	0.28	ZrO_2	wt.-%	< 0.01
CuO	wt.-%	< 0.01	PbO	wt.-%	< 0.01	H_2O	wt.-%	< 0.01
FeO	wt.-%	33.7	SiO_2	wt.-%	13.4	TIC	wt.-%	0.09
K_2O	wt.-%	< 0.01	SO_4	wt.-%	0.09			

Table 40: G5-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	< 1.0	K	mg/kg	18.25	Sn	mg/kg	< 1.0
Ba	mg/kg	53	Mg	mg/kg	2,603	Sr	mg/kg	22.5
Be	mg/kg	< 1.0	Mn	mg/kg	1,111	Ti	mg/kg	237
Cd	mg/kg	1.0	Mo	mg/kg	1.25	V	mg/kg	82
Co	mg/kg	< 1.0	Na	mg/kg	62.5	W	mg/kg	8.75
Cr	mg/kg	162.5	Pb	mg/kg	1.0	Zn	mg/kg	1.75
Cu	mg/kg	1.25	Sb	mg/kg	< 1.0			
Fe	mg/kg	31.961	Se	mg/kg	1.0			

Table 41 shows mineral composition results of sample G5-I.

Table 41: G5-I Mineral composition

Mineral	Formula	Unit	Value
Wuestite	FeO	wt.-%	39.4
Larnite	β-Ca_2SiO_4	wt.-%	39.5
Spinel (Magnetite)	Fe_3O_4	wt.-%	5.4
Gehlenite	$Ca_2Al_2SiO_7$	wt.-%	6.7
Periclase	MgO	wt.-%	4.4
Dicalciumdiiron(III)oxide		wt.-%	0.1
C3A cub		wt.-%	2.0
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	1.6
Hercynite	$FeAl_2O_4$	wt.-%	0.6

Table 42 shows volume stability and bulk density results of sample G5-I.

Table 42: G5-I Physical properties

Parameter	Test	Unit	Value
Volume stability	Steam test	Vol.-%	0.1 (24 h) | 3.2 (168 h)
Bulk density	Pycnometer	kg/m³	3.93

Table 43 shows leaching results of sample G5-I.

Table 43: G5-I Leaching

		Slag:water ratio	
Parameter	**Unit**	**1:10 < 10 mm batch shaking**	**1:2 < 10 mm batch shaking**
pH		11.5	12.0
EC	µS/cm	778	1,688
COD	mg/l	6	9
Al	mg/l	35.892	197.770
As	mg/l	<0.001	<0.001
Ba	mg/l	0.370	3.918
Be	mg/l	<0.001	<0.001
Cd	mg/l	<0.001	<0.001
Cl^-	mg/l	1.3	3.0
CN^-	mg/l	<0.010	<0.010
Co	mg/l	<0.001	<0.001
Cr^{6+}	mg/l	<0.010	<0.010
Cr_{total}	mg/l	<0.001	<0.001
Cu	mg/l	<0.001	<0.001
F^-	mg/l	3.8	6.3
Hg	mg/l	<0.001	<0.001
Mo	mg/l	0.002	0.004
Ni	mg/l	<0.001	<0.001
NO_3^-	mg/l	<1.0	<1.0
Pb	mg/l	<0.001	<0.001
Sb	mg/l	<0.001	<0.001
Se	mg/l	<0.001	<0.001
SO_4^{2-}	mg/l	1.3	2.8
Ti	mg/l	<0.001	<0.001
V	mg/l	0.218	0.103
Zn	mg/l	0.011	0.014

2.2.9 G6-I

G6-I sample results are shown in Table 44 and Table 45 for chemical composition with XRF and ICP-OES, respectively.

Table 44: G6-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	4.42	MgO	wt.-%	9.7	SrO	wt.-%	< 0.01
BaO	wt.-%	0.05	MnO	wt.-%	3.28	TiO_2	wt.-%	1.06
CaO	wt.-%	27.4	Na_2O	wt.-%	0.02	V_2O_5	wt.-%	0.1
Cr_2O_3	wt.-%	1.08	NiO	wt.-%	< 0.01	ZnO	wt.-%	0.03
CuO	wt.-%	< 0.01	P_2O_5	wt.-%	0.2	ZrO	wt.-%	0.02
FeO	wt.-%	28.78	PbO	wt.-%	0.06	CO_2	wt.-%	1.71
HfO	wt.-%	< 0.007	S	wt.-%	0.07	H_2O	wt.-%	1.13
K_2O	wt.-%	0.02	SiO_2	wt.-%	11.7			

Table 45: G6-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	1.00	K	mg/kg	381	Sn	mg/kg	5.44
Ba	mg/kg	482	Mg	mg/kg	62,506	Sr	mg/kg	213
Be	mg/kg		Mn	mg/kg	19,967	Ti	mg/kg	6,170
Cd	mg/kg	< 0.10	Mo	mg/kg	15.8	V	mg/kg	560
Co	mg/kg	19.1	Na	mg/kg	478	W	mg/kg	< 0.04
Cr	mg/kg	5.178	Pb	mg/kg	0.2	Zn	mg/kg	96.8
Cu	mg/kg	44.6	Sb	mg/kg	0.2			
Fe	mg/kg	258,367	Se	mg/kg	0.5			

Table 46 shows mineral composition results of sample G6-I.

Table 46: G6-I Mineral composition

Mineral	Formula	Unit	Value
Wuestite	FeO	wt.-%	33.8
Larnite	Ca_2SiO_4	wt.-%	30.2
Akermanite	$Ca_2MgSi_2O_7$	wt.-%	15.2
Calcite	$CaCO_3$	wt.-%	8.0
Spinel (Magnetite)	Fe_3O_4	wt.-%	2.5
Quartz	SiO_2	wt.-%	1.9
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	8.4

Table 47 shows volume stability and bulk density results of sample G6-I.

Table 47: G6-I Physical properties

Parameter	Test	Unit	Value
Volume stability	Steam test	Vol.-%	0.0 (24 h) | 0.1 (168 h)
Bulk density	Pycnometer	kg/m^3	3.89

Table 48 shows leaching results of sample G6-I.

Table 48: G6-I Leaching

		Slag:water ratio	
Parameter	**Unit**	**1:10 < 10 mm batch shaking**	**1:2 < 10 mm batch shaking**
pH		11.6	10.7
EC	µS/cm	872	682
COD	mg/l	7	6
Al	mg/l	90.717	89.195
As	mg/l	<0.001	<0.001
Ba	mg/l	0.473	0.110
Be	mg/l	<0.001	<0.001
Cd	mg/l	<0.001	<0.001
Cl^-	mg/l	<0.1	<0.1
CN^-	mg/l	<0.01	<0.01
Co	mg/l	<0.001	<0.001
Cr^{6+}	mg/l	<0.01	<0.01
Cr_{total}	mg/l	0.001	0.002
Cu	mg/l	<0.001	0.002
F^-	mg/l	3.7	5.0
Hg	mg/l	<0.001	<0.001
Mo	mg/l	0.010	0.038
Ni	mg/l	<0.001	0.001
NO_3^-	mg/l	<1.0	<1.0
Pb	mg/l	0.0001	< 0.00004
Sb	mg/l	<0.001	<0.001
Se	mg/l	<0.001	0.002
SO_4^{2-}	mg/l	5.4	120.0
Ti	mg/l	<0.001	< 0.00004
V	mg/l	0.023	0.028
Zn	mg/l	0.009	0.001

2.2.10 N1-I

N1-I sample results are shown in Table 49 and Table 50 for chemical composition with XRF and ICP-OES, respectively.

Table 49: N1-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	4.77	MgO	wt.-%	10.4	SrO	wt.-%	< 0.01
BaO	wt.-%	0.07	MnO	wt.-%	1.01	TiO_2	wt.-%	1.65
CaO	wt.-%	27.2	Na_2O	wt.-%	0.12	V_2O_5	wt.-%	0.94
Cr_2O_3	wt.-%	0.39	NiO	wt.-%	< 0.01	ZnO	wt.-%	< 0.01
CuO	wt.-%	< 0.01	P_2O_5	wt.-%	0.44	ZrO	wt.-%	0.02
FeO	wt.-%	30.6	PbO	wt.-%	< 0.01			
HfO	wt.-%	< 0.007	S	wt.-%	0.04			
K_2O	wt.-%	0.03	SiO_2	wt.-%	16.0			

Table 50: N1-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	0.73	K	mg/kg	307	Sn	mg/kg	< 0.10
Ba	mg/kg	450	Mg	mg/kg	66,129	Sr	mg/kg	169
Be	mg/kg	3.24	Mn	mg/kg	8,533	Ti	mg/kg	10,022
Cd	mg/kg	0.47	Mo	mg/kg	2.97	V	mg/kg	4,840
Co	mg/kg	31.61	Na	mg/kg	986	W	mg/kg	238
Cr	mg/kg	2158	Pb	mg/kg	20.15	Zn	mg/kg	206
Cu	mg/kg	11.53	Sb	mg/kg	0.54			
Fe	mg/kg	234,688	Se	mg/kg	0.52			

Table 51shows mineral composition results of sample N1-I.

Table 51: N1-I Mineral composition

Mineral	Formula	Unit	Value
Wuestite	FeO	wt.-%	17.5
Periclase	MgO	wt.-%	6.2
Quartz	SiO_2	wt.-%	1.3
Iron	Fe	wt.-%	0.2
Spinel (Magnetite)	Fe_3O_4	wt.-%	8.7
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	26.7
Calcite	$CaCO_3$	wt.-%	10.1
Akermanite/Gehlenite		wt.-%	9.1
Calcio-Olivine	Ca_2SiO_4	wt.-%	2.6
Bredigite	$Ca_7Mg (SiO_4)_4$	wt.-%	16.3
Larnite	β-Ca_2SiO_4	wt.-%	1.2

Table 52 shows volume stability and bulk density results of sample N1-I.

Table 52: N1-I Physical properties

Parameter	Test	Unit	Value
Volume stability	Steam test	Vol.-%	0.0 (24 h) | 0.0 (168 h)
Bulk density	Pycnometer	kg/m³	3.79

Table 53 shows leaching results of sample N1-I.

Table 53: N1-I Leaching

		Slag:water ratio		
Parameter	**Unit**	**1:10 < 10 mm batch shaking**	**1:2 < 10 mm batch shaking**	**1:2 < 22 mm percolation upflow**
pH		11.8	12.4	12.3
EC	µS/cm	1,354	6,380	5,450
COD	mg/l	5	10	-
Al	mg/l	6.677	0.302	1.192
As	mg/l	< 0.001	< 0.001	< 0.001
Ba	mg/l	0.172	1.059	1.224
Be	mg/l	< 0.001	< 0.001	< 0.001
Cd	mg/l	< 0.001	< 0.001	< 0.001
Cl^-	mg/l	1.7	7.9	9.1
CN^-	mg/l	<0.010	< 0.010	-
Co	mg/l	< 0.001	< 0.001	< 0.001
Cr^{6+}	mg/l	< 0.010	< 0.010	< 0.010
Cr_{total}	mg/l	0.013	0.008	0.261
Cu	mg/l	< 0.001	0.001	< 0.001
F^-	mg/l	1.2	4.9	6.1
Hg	mg/l	< 0.001	< 0.001	< 0.001
Mo	mg/l	0.007	0.014	0.009
Ni	mg/l	0.001	0.001	0.001
NO_3^-	mg/l	< 1.000	< 1.000	< 1.000
Pb	mg/l	0.002	0.075	0.222
Sb	mg/l	0.004	0.002	0.002
Se	mg/l	< 0.001	< 0.001	< 0.001
SO_4^{2-}	mg/l	14.0	2.6	2.8
Ti	mg/l	0.001	0.001	0.002
V	mg/l	0.068	0.005	0.008
Zn	mg/l	0.016	0.222	0.063

2.2.11 N2-I

N2-I sample results are shown in Table 54 and Table 55 for chemical composition with XRF and ICP-OES, respectively.

Table 54: N2-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	4.69	MgO	wt.-%	9.92	SrO	wt.-%	< 0.01
BaO	wt.-%	0.09	MnO	wt.-%	1.17	TiO_2	wt.-%	1.76
CaO	wt.-%	26.3	Na_2O	wt.-%	0.11	V_2O_5	wt.-%	0.99
Cr_2O_3	wt.-%	0.36	NiO	wt.-%	< 0.01	ZnO	wt.-%	< 0.01
CuO	wt.-%	< 0.01	P_2O_5	wt.-%	0.41	ZrO	wt.-%	0.01
FeO	wt.-%	34.0	PbO	wt.-%	< 0.01			
HfO	wt.-%	< 0.007	S	wt.-%	0.02			
K_2O	wt.-%	0.02	SiO_2	wt.-%	15.9			

Table 55: N2-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	0.65	K	mg/kg	233	Sn	mg/kg	< 0.10
Ba	mg/kg	519	Mg	mg/kg	62,643	Sr	mg/kg	156
Be	mg/kg	4.23	Mn	mg/kg	9,711	Ti	mg/kg	10,654
Cd	mg/kg	< 0.10	Mo	mg/kg	2.54	V	mg/kg	5,082
Co	mg/kg	41.56	Na	mg/kg	813	W	mg/kg	320
Cr	mg/kg	2,119	Pb	mg/kg	1.7	Zn	mg/kg	89.67
Cu	mg/kg	19.6	Sb	mg/kg	0.21			
Fe	mg/kg	258,327	Se	mg/kg	0.51			

Table 56 shows mineral composition results of sample N2-I.

Table 56: N2-I Mineral composition

Mineral	Formula	Unit	Value
Wuestite	FeO	wt.-%	16.3
Periclase	MgO	wt.-%	2.5
Quartz	SiO_2	wt.-%	2.0
Iron	Fe	wt.-%	0.0
Spinel (Magnetite)	Fe_3O_4	wt.-%	10.7
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	22.5
Calcite	$CaCO_3$	wt.-%	7.9
Akermanite/Gehlenite		wt.-%	6.6
Calcio-Olivine	Ca_2SiO_4	wt.-%	1.9
Bredigite	$Ca_7Mg(SiO_4)_4$	wt.-%	14.5
Larnite	β-Ca_2SiO_4	wt.-%	2.6

Table 57 shows volume stability and bulk density results of sample N2-I.

Table 57: N2-I Physical properties

Parameter	Test	Unit	Value
Volume stability	Steam test	Vol.-%	0.0 (24 h) | 0.0 (168 h)
Bulk density	Pycnometer	Mg/m^3	3.96

Table 58 shows leaching results of sample N2-I.

Table 58: N2-I Leaching

		Slag:water ratio		
Parameter	**Unit**	**1:10 < 10 mm batch shaking**	**1:2 < 10 mm batch shaking**	**1:2 < 22 mm percolation upflow**
pH		11.3	11.6	12.4
EC	µS/cm	473	900	5,760
COD	mg/l	6.0	9.0	-
Al	mg/l	1.187	2.865	0.525
As	mg/l	0.001	0.001	0.000
Ba	mg/l	0.175	0.336	0.956
Be	mg/l	< 0.001	< 0.001	< 0.001
Cd	mg/l	< 0.001	< 0.001	< 0.001
Cl^-	mg/l	< 1.00	< 1.0	6.6
CN^-	mg/l	< 0.010	< 0.010	-
Co	mg/l	< 0.001	< 0.001	< 0.001
Cr^{6+}	mg/l	< 0.010	< 0.010	0.000
Cr_{total}	mg/l	0.004	0.003	0.008
Cu	mg/l	< 0.001	< 0.001	0.001
F^-	mg/l	< 0.40	< 0.4	4.3
Hg	mg/l	< 0.001	< 0.001	< 0.001
Mo	mg/l	0.003	0.010	0.014
Ni	mg/l	0.001	0.000	0.000
NO_3^-	mg/l	< 1.00	< 1.0	< 1.0
Pb	mg/l	< 0.001	< 0.001	0.051
Sb	mg/l	0.001	0.002	0.002
Se	mg/l	< 0.001	0.002	0.001
SO_4^{2-}	mg/l	1.600	6.2	2.5
Ti	mg/l	0.001	0.002	0.001
V	mg/l	0.955	0.831	0.007
Zn	mg/l	< 0.001	< 0.001	0.132

2.2.12 Y1 -I

Y1-I sample results are shown in Table 59 and Table 60 for chemical composition with XRF and ICP-OES, respectively.

Table 59: Y1-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	9.23	MgO	wt.-%	6.79	SrO	wt.-%	< 0.01
BaO	wt.-%	0.09	MnO	wt.-%	1.62	TiO_2	wt.-%	1.28
CaO	wt.-%	36.34	Na_2O	wt.-%	0.11	V_2O_5	wt.-%	< 0.01
Cr_2O_3	wt.-%	0.37	NiO	wt.-%	< 0.01	ZnO	wt.-%	< 0.01
CuO	wt.-%	< 0.01	P_2O_5	wt.-%	0.29	ZrO	wt.-%	0.01
FeO	wt.-%	23.59	PbO	wt.-%	< 0.01			
HfO	wt.-%	< 0.007	S	wt.-%	0.01			
K_2O	wt.-%	0.15	SiO_2	wt.-%	18.37			

Table 60: Y1-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	2.5	K	mg/kg	2000	Sn	mg/kg	<1
Ba	mg/kg	400	Mg	mg/kg	35000	Sr	mg/kg	200
Be	mg/kg	<1	Mn	mg/kg	8000	Ti	mg/kg	5000
Cd	mg/kg	<1	Mo	mg/kg	6.4	V	mg/kg	6.4
Co	mg/kg	16.6	Na	mg/kg	11000	W	mg/kg	1.8
Cr	mg/kg	2000	Pb	mg/kg	2.4	Zn	mg/kg	2000
Cu	mg/kg	10	Sb	mg/kg	<1			
Fe	mg/kg	320000	Se	mg/kg	<1			

Table 61 shows mineral composition results of sample Y1-I.

Table 61: Y1-I Mineral composition

Mineral	Formula	Unit	Value
Wuestite	FeO	wt.-%	4.1
Periclase	MgO	wt.-%	3.3
Spinel (Magnetite)	Fe_3O_4	wt.-%	19.5
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	30.7
Larnite	β-Ca_2SiO_4	wt.-%	30.1
Spinel/Hercynite	$FeAl_2O_4$	wt.-%	12.3

Table 62 shows bulk density results of sample Y1-I.

Table 62: Y1-I Physical properties

Parameter	Test	Unit	Value
Bulk density	Pycnometer	kg/m^3	3.96

Table 63 shows leaching results of sample Y1-I.

Table 63: Y1-I Leaching

		Slag:water ratio		
Parameter	**Unit**	**1:10 < 10 mm batch shaking**	**1:2 < 10 mm batch shaking**	**1:2 < 22 mm percolation upflow**
pH	mg/l	11.49	11.50	11.7
EC	µS/cm	650	700	620
COD	mg/l	6.2	7.3	4.0
Al	mg/l	2.3	4.5	1.7
As	mg/l	0.00033	0.00033	0.00033
Ba	mg/l	0.0848	0.11	0.062
Be	mg/l	<0.0001	<0.0001	<0.0001
Cd	mg/l	0.00023	0.00026	0.00023
Cl^-	mg/l	1.4	2.3	3.1
CN^-	mg/l	0.018	0.018	0.018
Co	mg/l	0.00011	0.00011	0.00014
Cr^{6+}	mg/l	<0.001	<0.001	<0.001
Cr_{total}	mg/l	0.0045	0.0063	0.0041
Cu	mg/l	0.00242	0.0046	0.00240
F^-	mg/l	<0.5	<0.5	<0.5
Hg	mg/l	0.00026	0.00035	0.00035
Mo	mg/l	0.22	0.18	0.14
Ni	mg/l	0.0005	0.0005	0.0005
NO_3^-	mg/l	<0.5	<0.5	<0.5
Pb	mg/l	0.0001	0.0001	0.0001
Sb	mg/l	<0.0001	<0.0001	<0.0001
Se	mg/l	0.00274	0.00385	0.00180
SO_4^{2-}	mg/l	15	24	11
Ti	mg/l	0.0061	0.0075	0.0043
V	mg/l	0.38	0.75	0.22
Zn	mg/l	0.00324	0.0054	0.0029

2.2.13 Y2-I

Y2-I sample results are shown in Table 64 and Table 65 for chemical composition with XRF and ICP-OES, respectively.

Table 64: Y2-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	9.59	MgO	wt.-%	6.02	SrO	wt.-%	< 0.01
BaO	wt.-%	0.09	MnO	wt.-%	1.10	TiO_2	wt.-%	0.70
CaO	wt.-%	29.50	Na_2O	wt.-%	2.82	V_2O_5	wt.-%	0.50
Cr_2O_3	wt.-%	0.20	NiO	wt.-%	0.05	ZnO	wt.-%	0.02
CuO	wt.-%	0.02	P_2O_5	wt.-%	0.29	ZrO	wt.-%	<0.01
FeO	wt.-%	34.83	PbO	wt.-%	<0.01			
HfO	wt.-%	< 0.007	S	wt.-%	0.02			
K_2O	wt.-%	0.5	SiO_2	wt.-%	18.87			

Table 65: Y2-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	3.8	K	mg/kg	3000	Sn	mg/kg	15
Ba	mg/kg	290	Mg	mg/kg	26000	Sr	mg/kg	100
Be	mg/kg	<1	Mn	mg/kg	5000	Ti	mg/kg	3000
Cd	mg/kg	<1	Mo	mg/kg	15.2	V	mg/kg	2000
Co	mg/kg	23.5	Na	mg/kg	15000	W	mg/kg	1.8
Cr	mg/kg	20.5	Pb	mg/kg	1.8	Zn	mg/kg	2000
Cu	mg/kg	100	Sb	mg/kg	<1			
Fe	mg/kg	387000	Se	mg/kg	<1			

Table 66 shows mineral composition results of sample Y2-I.

Table 66: Y2-I Mineral composition

Mineral	Formula	Unit	Value
Periclase	MgO	wt.-%	4.74
Spinel (Magnetite)	Fe_3O_4	wt.-%	31.08
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	13.60
Larnite	β-Ca2SiO4	wt.-%	33.19
Spinel/Hercynite	FeAl2O4	wt.-%	14.54
Spinel/Galaxyte	MnAl2O4	wt.-%	2.85

Table 67 shows bulk density results of sample Y2-I.

Table 67: Y2-I Physical properties

Parameter	Test	Unit	Value
Bulk density	Pycnometer	kg/m^3	4.05

Table 68 shows leaching results of sample Y2-I.

Table 68: Y2-I Leaching

		Slag:water ratio		
Parameter	**Unit**	**1:10 < 10 mm batch shaking**	**1:2 < 10 mm batch shaking**	**1:2 < 22 mm percolation upflow**
pH		12.5	12.3	12.3
EC	µS/cm	690	870	710
COD	mg/l	7.3	7.2	5.1
Al	mg/l	1.6	2.2	0.9
As	mg/l	0.00022	0.00045	0.00018
Ba	mg/l	0.00013	0.00013	0.00013
Be	mg/l	<0.0001	<0.0001	<0.0001
Cd	mg/l	<0.0001	<0.0001	<0.0001
Cl^-	mg/l	7.8	7.9	7.5
CN^-	mg/l	0.02	0.02	0.02
Co	mg/l	<0.0001	<0.0001	<0.0001
Cr^{6+}	mg/l	<0.001	<0.001	<0.001
Cr_{total}	mg/l	0.0081	0.01	0.0055
Cu	mg/l	<0.0001	0.0003	<0.0001
F^-	mg/l	0.7	0.8	0.7
Hg	mg/l	0.00012	0.00021	0.00012
Mo	mg/l	0.013	0.013	0.015
Ni	mg/l	<0.0005	<0.0005	<0.0005
NO_3^-	mg/l	<0.5	<0.5	<0.5
Pb	mg/l	<0.0001	<0.0001	<0.0001
Sb	mg/l	<0.0001	<0.0001	<0.0001
Se	mg/l	0.0026	0.0026	0.0026
SO_4^{2-}	mg/l	27	38	32
V	mg/l	0.0816	0.12	0.065
Zn	mg/l	0.00972	0.0085	0.0063

2.2.14 Y3-I

Y3-I sample results are shown in Table 69 and Table 70 for chemical composition with XRF and ICP-OES, respectively.

Table 69: Y3-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	8.59	K_2O	wt.-%	0.33	S	wt.-%	0.02
BaO	wt.-%	0.09	MgO	wt.-%	8.06	SiO_2	wt.-%	15.48
CaO	wt.-%	32.46	MnO	wt.-%	1.76	SrO	wt.-%	<0.01
Cr_2O_3	wt.-%	0.41	Na_2O	wt.-%	2.06	TiO_2	wt.-%	1.16
CuO	wt.-%	0.02	NiO	wt.-%	0.11	V_2O_5	wt.-%	0.74
FeO	wt.-%	28.65	P_2O_5	wt.-%	0.19	ZnO	wt.-%	<0.01
HfO	wt.-%	<0.007	PbO	wt.-%	<0.01	ZrO	wt.-%	0.01

Table 70: Y3-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	5.1	K	mg/kg	1000	Sn	mg/kg	23
Ba	mg/kg	300	Mg	mg/kg	32000	Sr	mg/kg	150
Be	mg/kg	<1	Mn	mg/kg	80000	Ti	mg/kg	6000
Cd	mg/kg	<1	Mo	mg/kg	15.2	V	mg/kg	15
Co	mg/kg	15.6	Na	mg/kg	3000	W	mg/kg	2.3
Cr	mg/kg	12.0	Pb	mg/kg	1.2	Zn	mg/kg	210
Cu	mg/kg	10	Sb	mg/kg	<1			
Fe	mg/kg	286000	Se	mg/kg	<1			

Table 71 shows mineral composition results of sample Y3-I.

Table 71: Y3-I Mineral composition

Mineral	Formula	Unit	Value
Periclase	MgO	wt.-%	5.74
Spinel (Magnetite)	Fe_3O_4	wt.-%	25.66
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	22.38
Larnite	β-Ca2SiO4	wt.-%	30.82
Spinel/Hercynite	FeAl2O4	wt.-%	10.87
Spinel/Galaxyte	MnAl2O4	wt.-%	4.52

Table 72 shows bulk density results of sample Y3-I.

Table 72: Y3-I Physical properties

Parameter	Test	Unit	Value
Bulk density	Pycnometer	kg/m^3	3.8

Table 73 shows leaching results of sample Y3-I.

Table 73: Y3-I Leaching

		Slag:water ratio		
Parameter	**Unit**	**1:10<10mm batch shaking**	**1:2<10mm batch shaking**	**1:2<22mm percolation up flow**
pH		12.25	11.9	12.1
EC	µS/cm	480	670	590
COD	mg/l	4.8	6.5	6.2
Al	mg/l	1.3	1.9	1.5
As	mg/l	0.0001	0.0001	0.0001
Ba	mg/l	0.0011	0.0015	0.0011
Be	mg/l	0.0001	0.0001	0.0001
Cd	mg/l	0.0001	0.0001	0.0001
Cl^-	mg/l	1.6	1.8	1.3
CN^-	mg/l	0.047	0.061	0.035
Co	mg/l	0.0001	0.0001	0.0001
Cr^{6+}	mg/l	<0.0001	<0.0001	<0.0001
Cr_{total}	mg/l	0.0003	0.0004	0.0003
Cu	mg/l	0.0005	0.0005	0.0005
F^-	mg/l	<0.5	<0.5	<0.5
Hg	mg/l	0.0001	0.0001	0.0001
Mo	mg/l	0.0191	0.020	0.0180
Ni	mg/l	0.0005	0.0005	0.0004
NO_3^-	mg/l	<0.5	<0.5	<0.5
Pb	mg/l	0.0003	0.0002	0.0002
Sb	mg/l	<0.0001	<0.0001	<0.0001
Se	mg/l	0.00233	0.0035	0.0018
SO_4^{2-}	mg/l	<0.5	<0.5	<0.5
Ti	mg/l	1.2	0.8	0.6
V	mg/l	0.0031	0.0038	0.0032
Zn	mg/l	0.00925	0.012	0.0073

2.2.15 Y4-I

Y4-I sample results are shown in Table 74 and Table 75 for chemical composition with XRF and ICP-OES, respectively.

Table 74: Y4-I Chemical composition (XRF)

Parameter	Unit	Value	Parameter	Unit	Value	Parameter	Unit	Value
Al_2O_3	wt.-%	13.42	MgO	wt.-%	6.78	SrO	wt.-%	<0.01
BaO	wt.-%	0.09	MnO	wt.-%	1.57	TiO_2	wt.-%	1.03
CaO	wt.-%	40.78	Na_2O	wt.-%	0.67	V_2O_5	wt.-%	0.44
Cr_2O_3	wt.-%	0.36	NiO	wt.-%	0.08	ZnO	wt.-%	<0.01
CuO	wt.-%	0.01	P_2O_5	wt.-%	0.14	ZrO	wt.-%	0.01
FeO	wt.-%	18.14	PbO	wt.-%	<0.01			
HfO	wt.-%	<0.007	S	wt.-%	0.02			
K_2O	wt.-%	0.15	SiO_2	wt.-%	15.15			

Table 75: Y4-I Chemical composition (ICP-OES)

Element	Unit	Value	Element	Unit	Value	Element	Unit	Value
As	mg/kg	5.1	K	mg/kg	1000	Sn	mg/kg	23
Ba	mg/kg	400	Mg	mg/kg	33000	Sr	mg/kg	100
Be	mg/kg	<1	Mn	mg/kg	8000	Ti	mg/kg	4900
Cd	mg/kg	<1	Mo	mg/kg	15.2	V	mg/kg	2000
Co	mg/kg	15.6	Na	mg/kg	4030	W	mg/kg	<1
Cr	mg/kg	2000	Pb	mg/kg	1.8	Zn	mg/kg	200
Cu	mg/kg	100	Sb	mg/kg	<1			
Fe	mg/kg	227000	Se	mg/kg	<1			

Table 76 shows mineral composition results of sample Y4-I.

Table 76: Y4-I Mineral composition

Mineral	Formula	Unit	Value
Periclase	MgO	wt.-%	6.70
Spinel (Magnetite)	Fe_3O_4	wt.-%	10.30
Merwinite	$Ca_3MgSi_2O_8$	wt.-%	3.3
Larnite	β-Ca_2SiO_4	wt.-%	55.4
Spinel/Hercynite	$FeAl_2O_4$	wt.-%	19.8
Spinel/Galaxyte	$MnAl_2O_4$	wt.-%	3.83

Table 77 shows bulk density results of sample Y4-I.

Table 77: Y4-I Physical properties

Parameter	Test	Unit	Value
Bulk density	Pycnometer	kg/m^3	3.80

Table 78 shows leaching results of sample Y4-I.

Table 78: Y4-I Leaching

Parameter	Unit	Slag:water ratio 1:10<10mm batch shaking	1:2<10mm batch shaking	1:2<22mm percolation up flow
pH		12.36	12.20	12.20
EC	µS/cm	620	790	590
COD	mg/l	3.8	4.2	3.1
Al	mg/l	1.2	1.8	1.2
As	mg/l	0.0012	0.0016	0.0012
Ba	mg/l	0.145	0.220	0.132
Be	mg/l	0.0004	0.0006	0.0003
Cd	mg/l	0.0001	0.0001	0.0001
Cl^-	mg/l	1.0	1.3	0.85
CN^-	mg/l	0.15	0.15	0.15
Co	mg/l	0.00022	0.00015	0.00010
Cr_{total}	mg/l	0.0246	0.035	0.021
Cr^{6+}	mg/l	<0.0001	<0.0001	<0.0001
Cu	mg/l	0.045	0.030	0.025
F^-	mg/l	0.8	0.8	0.6
Hg	mg/l	<0.0001	<0.0001	<0.0001
Mo	mg/l	0.00289	0.00350	0.00277
Ni	mg/l	0.00155	0.00155	0.00155
NO_3^-	mg/l	<0.5	<0.5	<0.5
Pb	mg/l	0.0115	0.031	0.0110
Sb	mg/l	<0.0001	<0.0001	<0.0001
Se	mg/l	0.0023	0.0020	0.0020
SO_4^{2-}	mg/l	<0.5	<0.5	<0.5
V	mg/l	0.033	0.041	0.033
Zn	mg/l	0.0713	0.0651	0.0664

2.3 Chemical composition of EAF slag samples with reference

The chemical composition of the 15 DRI EAF slag samples are compared to minimum and maximum values of typical EAF slag samples with 100% scrap (information provided by FEhS from internal investigations). Figure 2 shows simple basicity (CaO/SiO_2), MgO, FeO, Cr_2O_3 and V_2O_5. In samples originating from an EAF fed with DRI, simple basicity is within the lower end compared to EAF slag from 100% scrap charging, close to or below 2. MgO and FeO in samples from EAFs operated with DRI are within the minimum and maximum values seen compared to EAF slag from 100% scrap operation. Cr_2O_3 from an EAF operated with DRI is much lower than what is usually seen in EAF slag samples. However, with respect to V_2O_5, the values might be much higher, depending on the input DRI material.

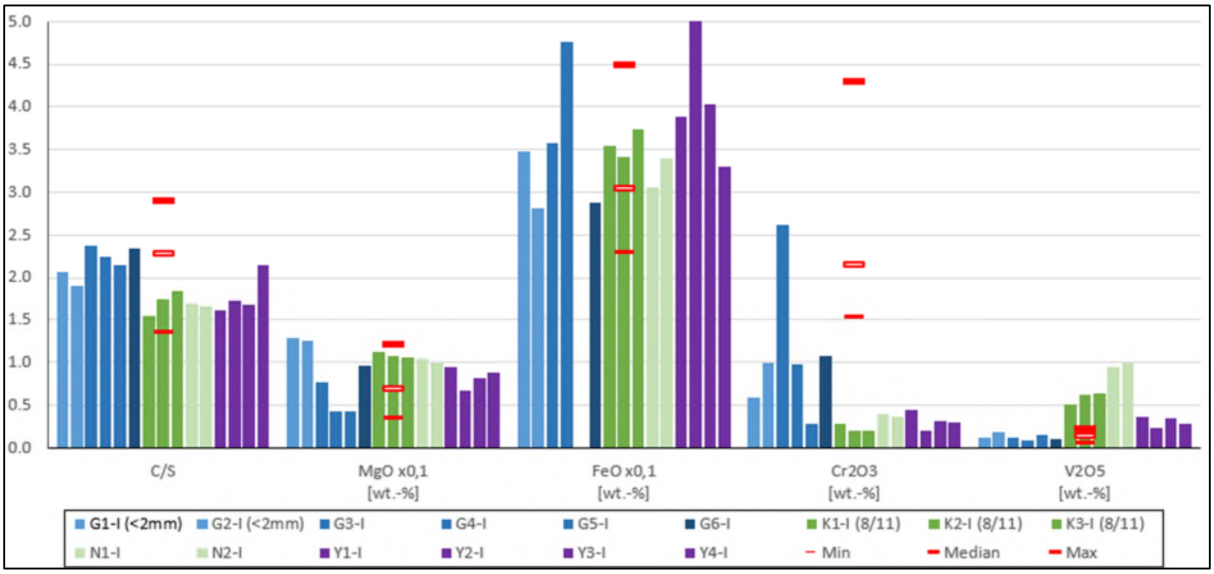

Figure 2: Comparison of simple basicity (CaO/SiO_2), MgO, FeO, Cr_2O_3 and V_2O_5 between average values of investigated slag samples and EAF slag currently produced based on FEhS internal data

2.4 Leaching results

The leaching values were compared with regulations from Austria, Belgium, France, Germany, Italy, and Spain. The parameters that exceed limit leaching values are shown in Table 79.

The following parameters exceeded the leaching limits:

- Austria: none
- Belgium: pH or Mo
- France: F- or Mo
- Germany: Cr_{total}, F^-, Mo or V
- Italy: Cr_{total}, V
- Spain: none

Table 79: Parameters that exceed leaching limiting values in different countries

Sample	Austria	Belgium	France	Germany	Italy	Spain
F1-I	none1)2)3)4)	none1)5)6)	none5)	F^-, V	none1)6)7)	none5)
F2-I	none1)2)3)4)	none1)5)6)	none5)	F^-, V	V1)6)7)	none5)
F3-I	none1)2)3)4)	none1)5)6)	none5)	F^-, V	V1)6)7)	none5)
A1-I	none2)3)4)	none	none	V	none	none
A2-I	none2)3)4)	none	none	none	none	none
A3-I	none2)3)4)	none	none	Cr_{total}	Cr_{total}, Hg	none
A4-I	none2)3)4)	none	none	F^-	none	none
A5-I	none2)3)4)	none	F^-	F^-	F^-	none
A6-I	none2)3)4)	none	F^-	F^-	F^-	none
P1-I	none2)3)4)	none	none	F^-	F^-	none
P2-I	none2)3)4)	none	none	V	V	none
T1-I	none2)3)4)	Mo	Mo	Mo, V	Mo, V	none
T2-I	none2)3)4)	pH8)	none	none	pH	none
T3-I	none2)3)4)	pH	none	none	pH	none
T4-I	none2)3)4)	pH8)	none	none	pH	none

1) NO_3^- was not analyzed in this sample
2) NO_2^- was not analyzed in this sample
3) NH_4^+ was not analyzed in this sample
4) TOC was not analyzed in this sample
5) Cr^{6+} was not analyzed in this sample
6) CN^- was not analyzed in this sample
7) COD was not analyzed in this sample
8) Ti was not analyzed in this sample

3 Conclusion

This deliverable 3.1 has successfully established a detailed repository of slag samples, marking a significant milestone in the pursuit of sustainable steel production. The documentation and analysis of slag characteristics have not only provided a clearer understanding of the by-products from steelmaking technologies but also opened avenues for innovative reuse in various sectors. The potential applications identified for these slags reflect a promising synergy between industrial advancement and ecological stewardship, resonating with global sustainability goals.

In conclusion, this deliverable has not only provided a solid foundation for the valorization of slag from next-generation steelmaking processes but has also set a precedent for the integration of sustainable practices in the industry. The detailed insights gained from this work will serve as a cornerstone for future research and development efforts aimed at closing the loop in steel production and establishing a truly circular economy.

InSGeP

Investigations of Slag from Next Generation Steel Making Processes

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