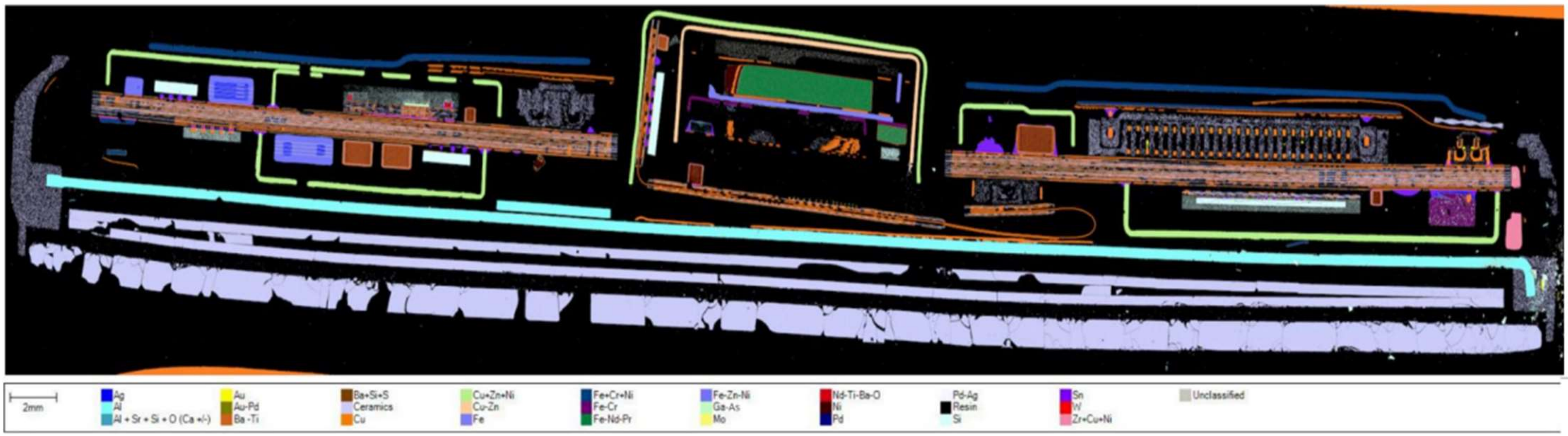
Extractive metallurgy of man-made minerals: opportunities for short-loop processes.

Ir David Bastin



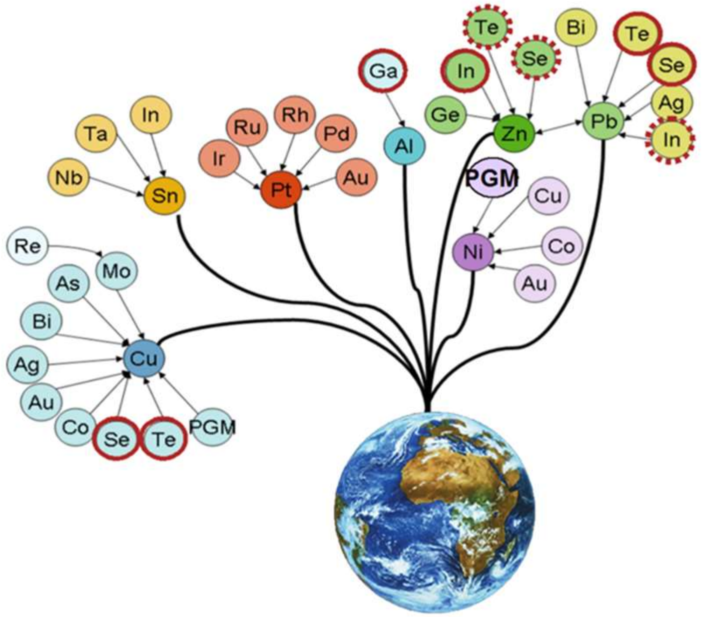
Cross section EDS mapping of a Nokia Lumina 925

Giaro & Al at Hi-Tech Metals'18, Cape Town.

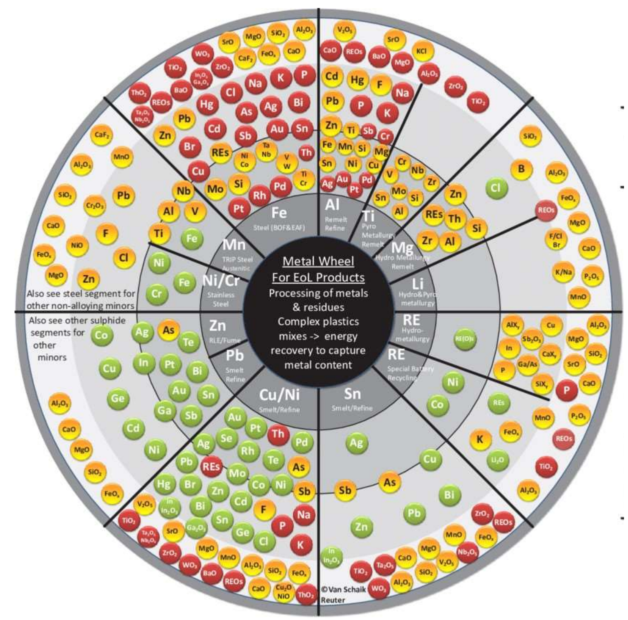
Journées scientifiques du GDR Prométhée

23/05/2024, IFPEN Rueil-Malmaison

GeMMe
Géoressources, Minéralurgie & Métallurgie Extractive



Source: modified from Hagelüken, Meskers in Linkages of sustainability, 2010.



The Metal Wheel, Reuter & al., 2013.

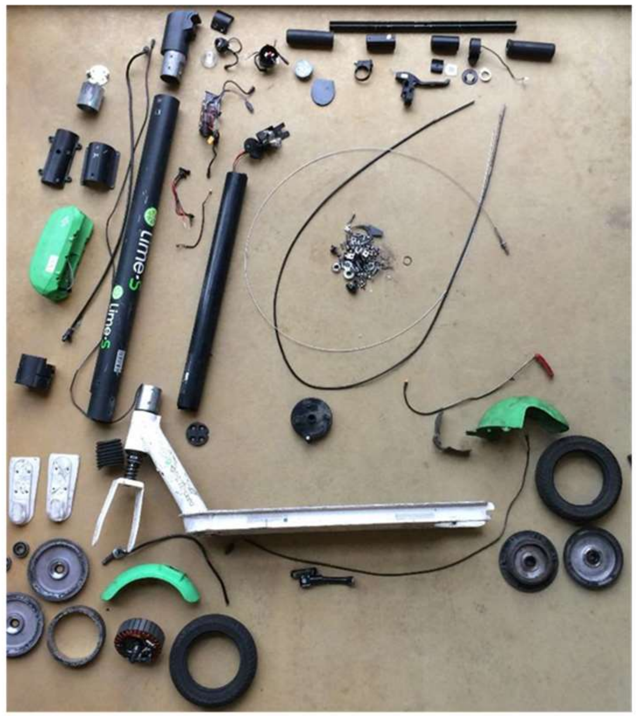
Extractive metallurgy originally developed for natural metals paragenesis .

End Of Life Equipements and opportunities for specific short-loop urban extractive metallurgies

Spent Automotive Catalytic Coverters

KIC RM Upscaling **CEBRA**
MSCA-RISE **ChemPGM**

EOL Permanent Magnets



EOL Li-ion Batteries

Regional Innovation Partnership **REVERSE METALLURGY**
Next Generation EU **CISTEMEEC**
HE **MAGELLAN**

Reverse Metallurgy

Spent Automotive Catalytic Converters

Application	ACC Type	PGMs Associations
Gasoline & HEV cars	TWC	Pt/Pd/Rh
	cGPF	Pt/Pd/Rh
Diesel Light and Heavy Duty Vehicles	DOC	Pt/Pd
	cDPF	Pt/Pd

Monolith		Pt (ppm)	Pd (ppm)	Rh (ppm)	PGMs (ppm)
DOC		4480	2380	-	6860
DPF		1460	-	31	1491
CTWC		839	-	620	1459
MTWC	*Washcoat-rich*	-	12600	1010	13610
	Steel-rich	-	324	125	449
	Overall	-	2436	277	2713

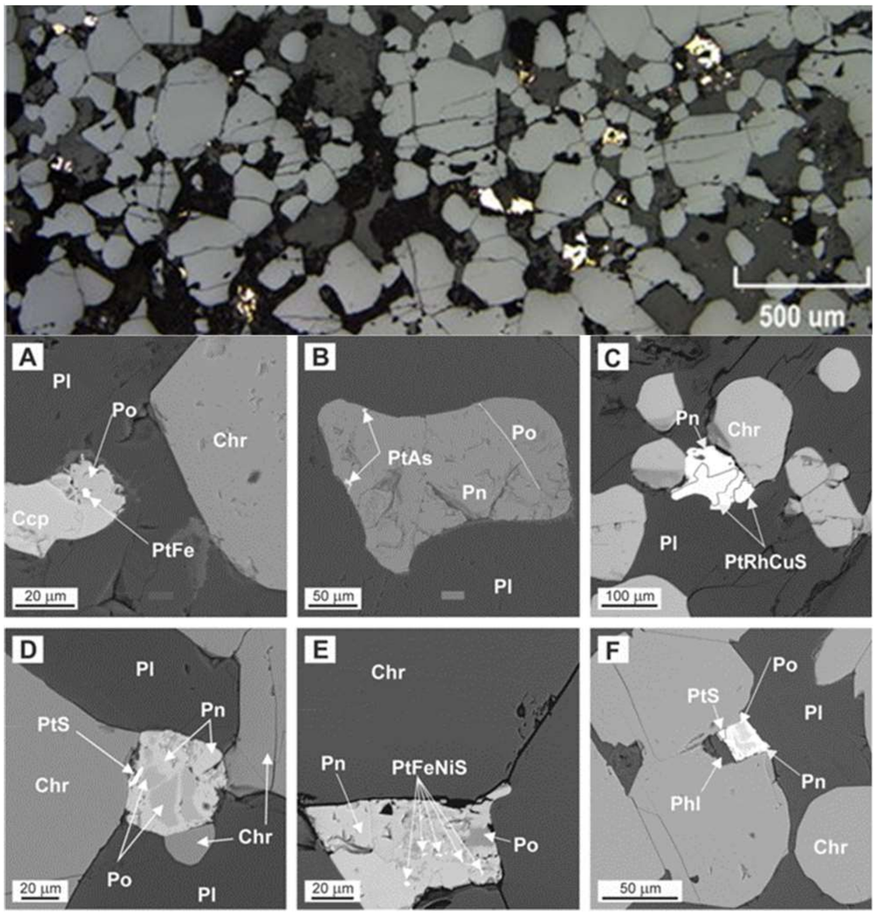
Table 6-2: Composition of washcoat & poisoning components used for Characterization A (XRF analysis)

Monolith	Washcoat Components						Poisoning Components				
	Zr (%)	*Ce* (%)	*La* (ppm)	*Nd* (ppm)	*Pr* (ppm)	*Sm* (ppm)	*Ca* (ppm)	*P* (ppm)	*Zn* (ppm)	*S* (ppm)	*Pb* (ppm)
DOC	0.85	0.53	-	-	-	-	609	1160	3070	612	-
DPF	1.18	0.60	-	626	6410	-	5850	4590	13200	7430	775
CTWC	8.99	4.92	3810	5720	2880	2790	674	177	489	798	-
MTWC	0.85	3.77	264	107	34	-	4199	11773	6346	333	133

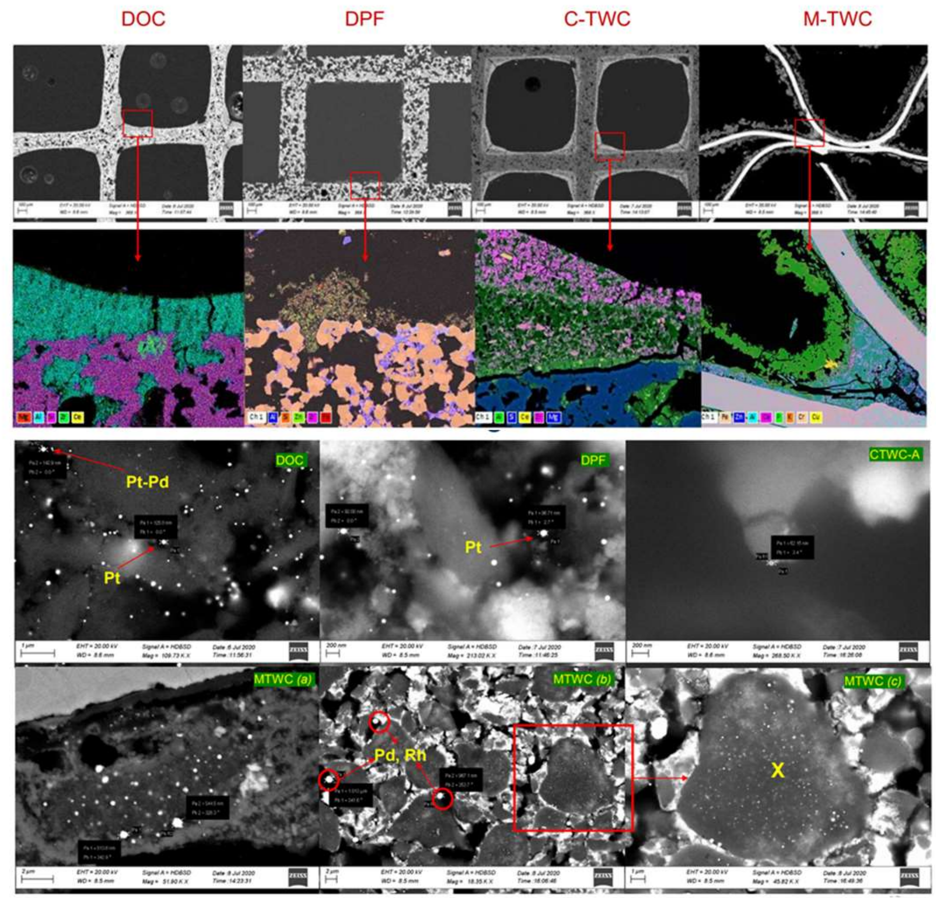
Al, C_{org}, Mn, Ti

Ceramic (Cordierite), Metallic and SiC supports

UG 2 Ore, Bushveld, South Africa



Man-made minerals



Ali Hassan, Master Thesis, Emerald 2020

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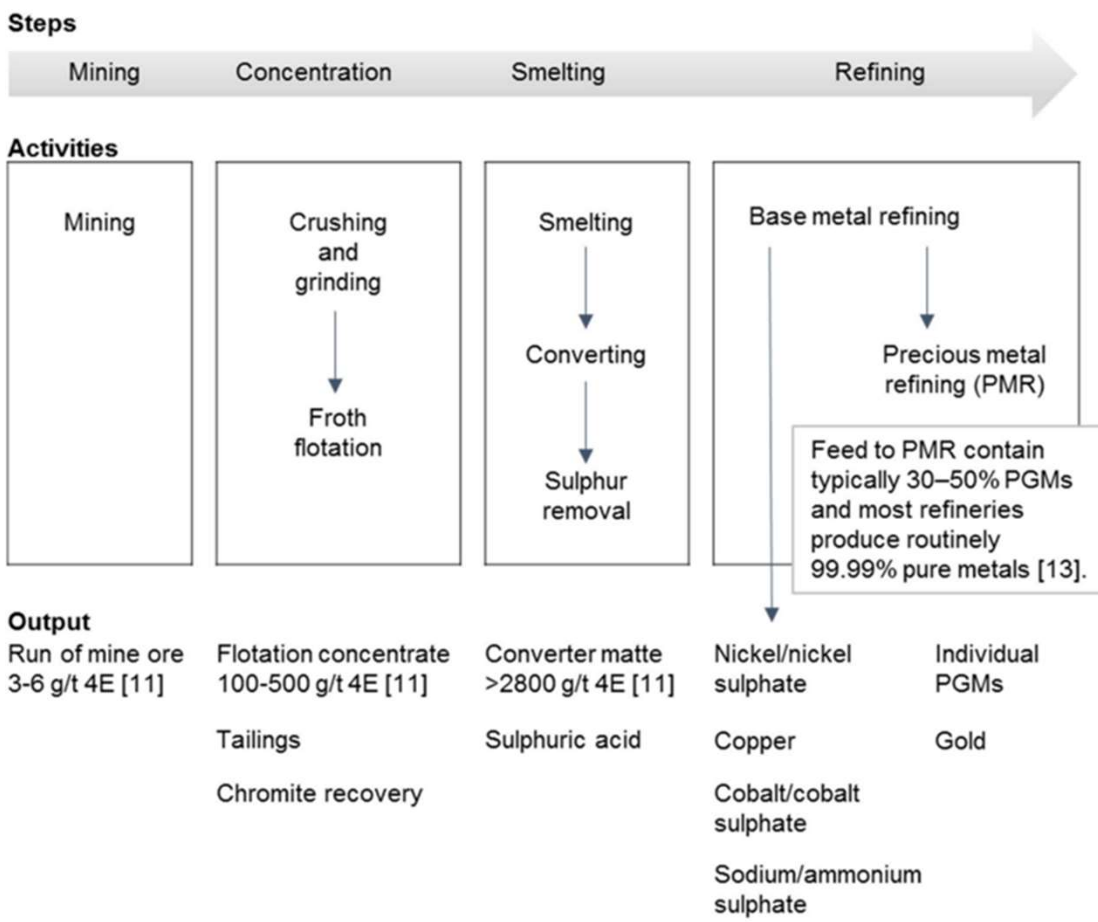
PGEs Primary Ores and Metallurgy

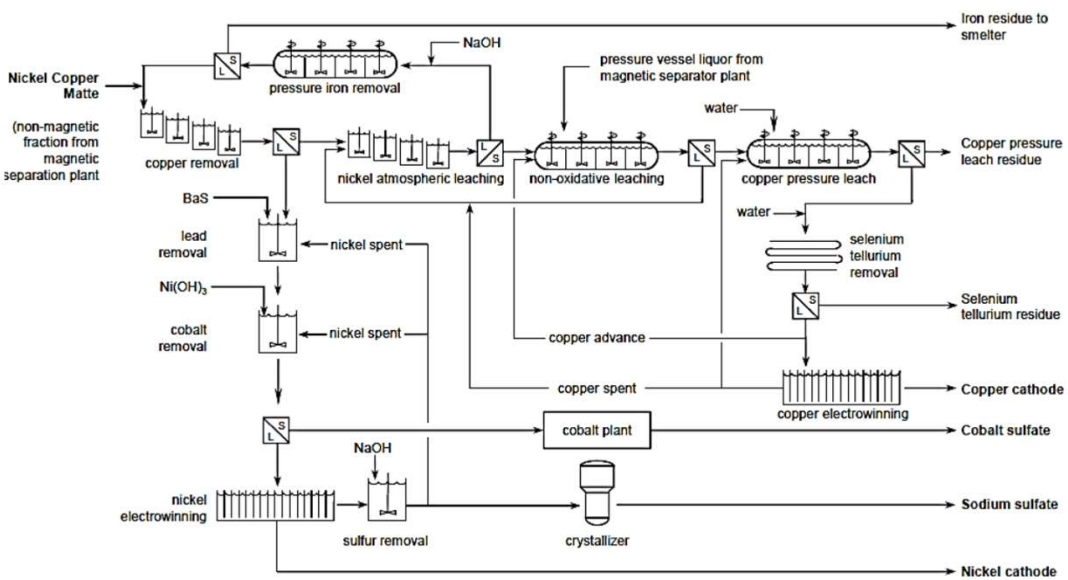
	Pt	Pd	Rh	Ru	Ir	Os	Au	PGM total	Cu	Ni
	[g/t]								[%]	
South Africa										
Merensky Reef	2,7	1,4	0,16	0,33	0,05	0,04	0,24	4-10	0,08	0,13
UG 2	2,0	1,3	0,34	0,45	0,13	0,05	0,05	4-10	0,02	0,07
Platreef	1,9	1,9	0,12	0,14	0,04	0,03	0,21	4-5	0,18	0,36
Zimbabwe (Hartley)	2,6	1,8	0,21	k.A.	k.A.	k.A.	0,47	4-5	0,14	0,17
USA (Stillwater)	3,3	11	0,6	0,36	0,21	-	0,21	10-15	0,04	0,1
Canada										
Sudbury	0,3	0,4	0,03	0,04	0,01	0,01	0,09	1-2	1,2	1,5
Lac des Iles Mines	0,2	2,3	k.A.	k.A.	k.A.	k.A.	0,1	2-3	0,07	0,06
Russia (Norilsk)	2,5	7	0,24	k.A.	k.A.	k.A.	0,25	>10	3	1,8

Impurities: Si, S, Mg, As, Pb, Sb, Bi, Fe, Sn – Cr, Se, Te

PGEs ores, from Mine to Metals



PGM – Base metal refining



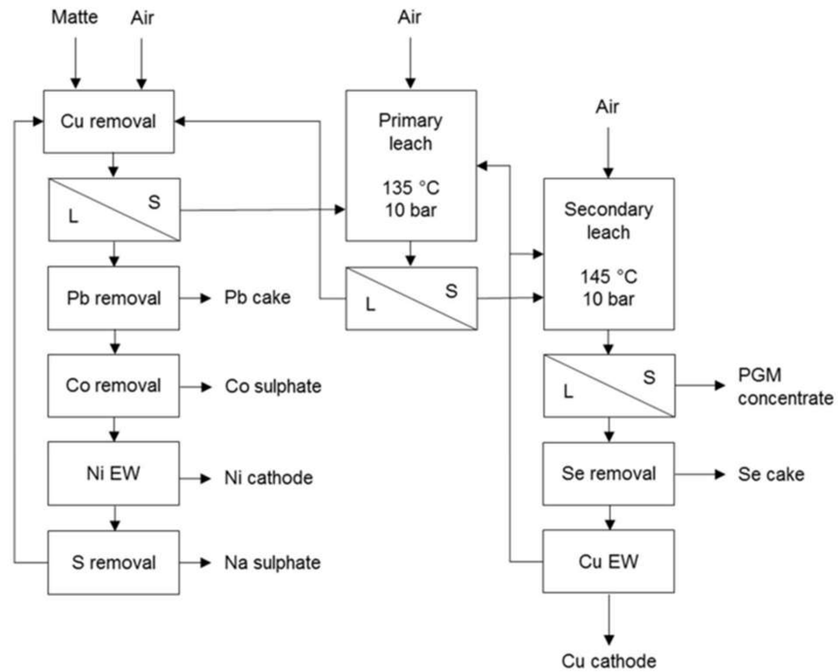
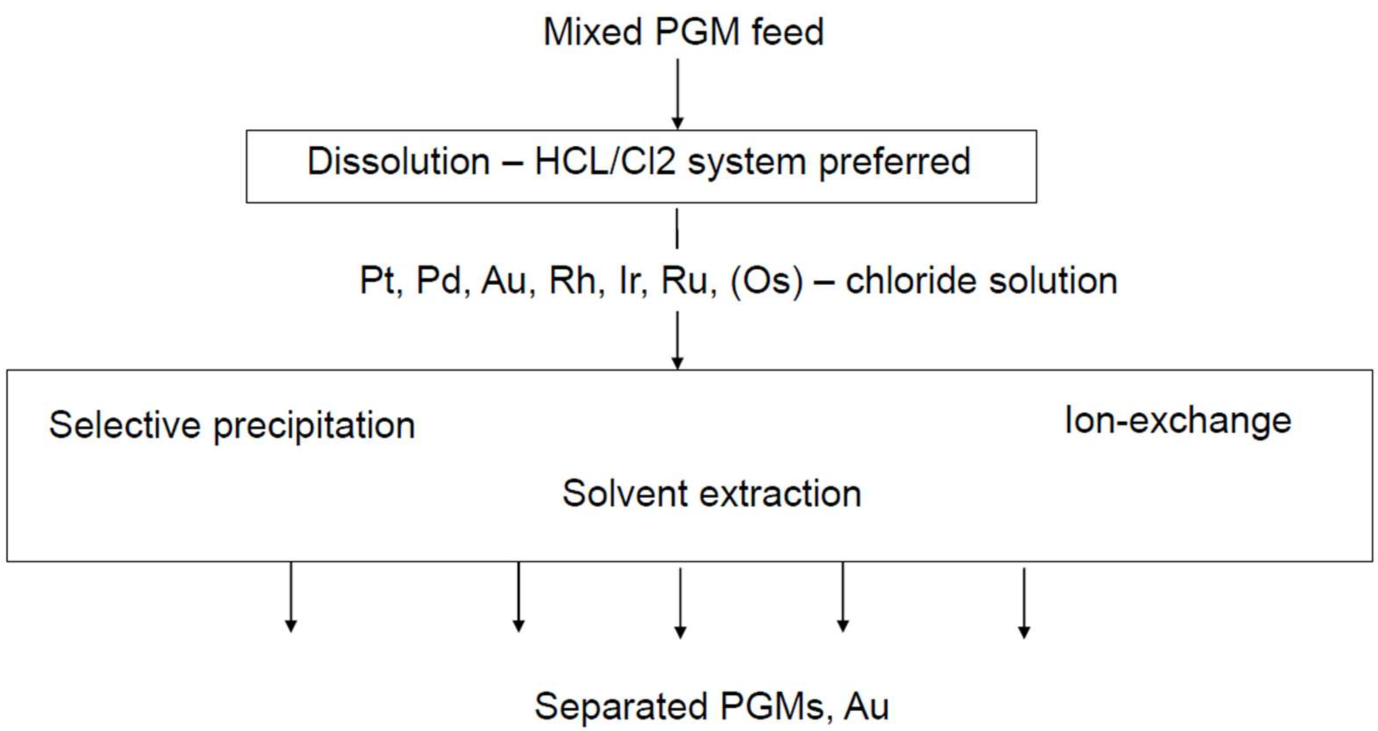


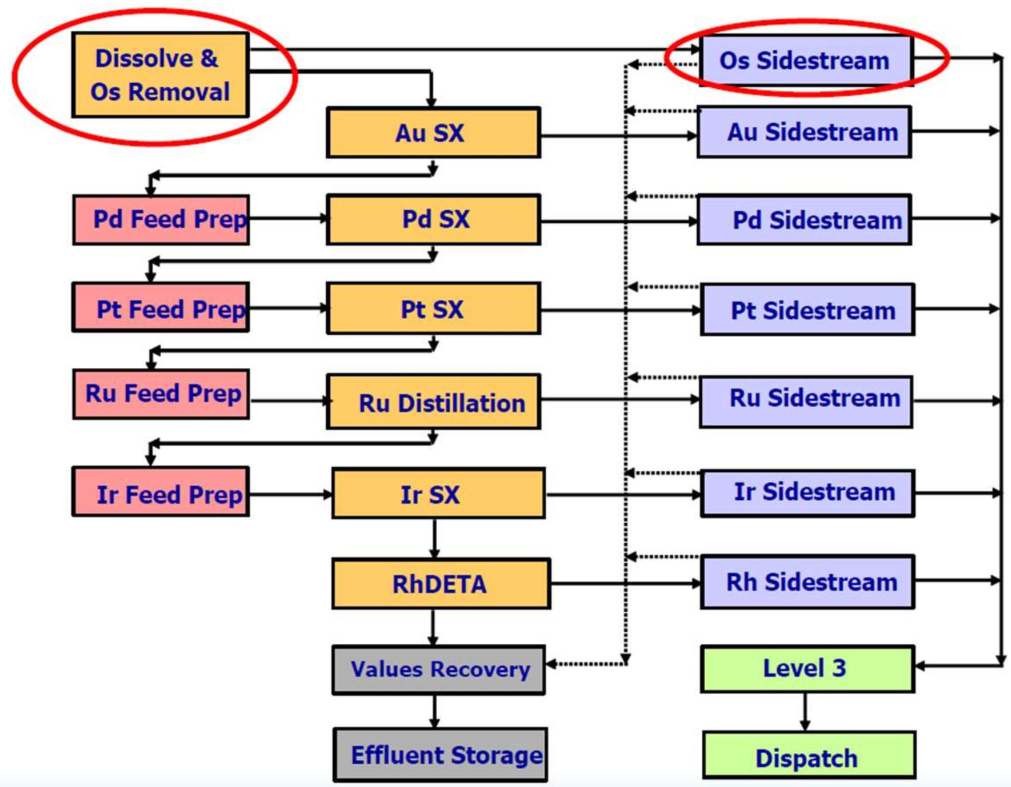
Figure 2. Simplified flow sheet of Rustenburg Base Metals Refinery (adapted from Hofirek & Halton [20]).

PGM – precious metal refining



Rustenburg Precious Metals Refinery

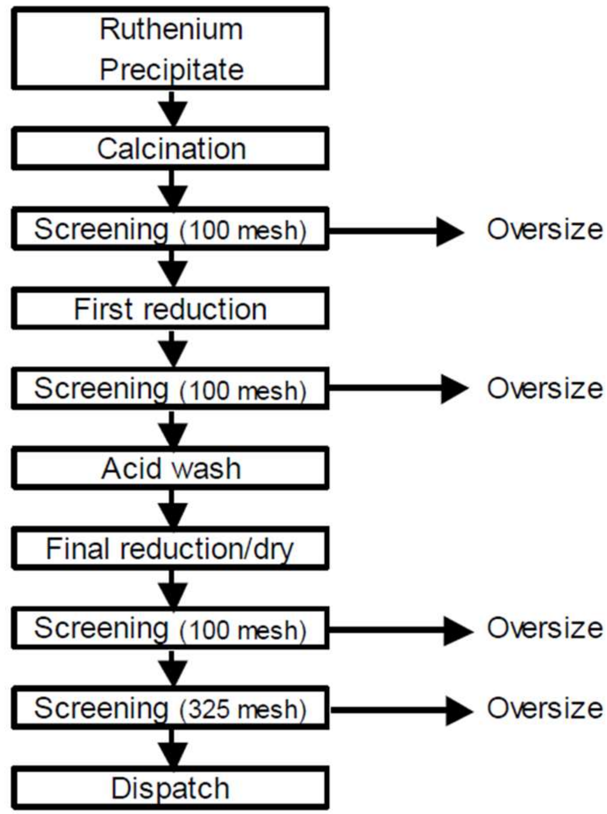
PMR Flowsheet



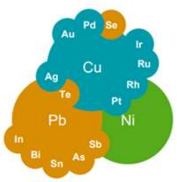
Prof. Jochen Petersen, University of Cape Town, short course on PGM Metallurgy

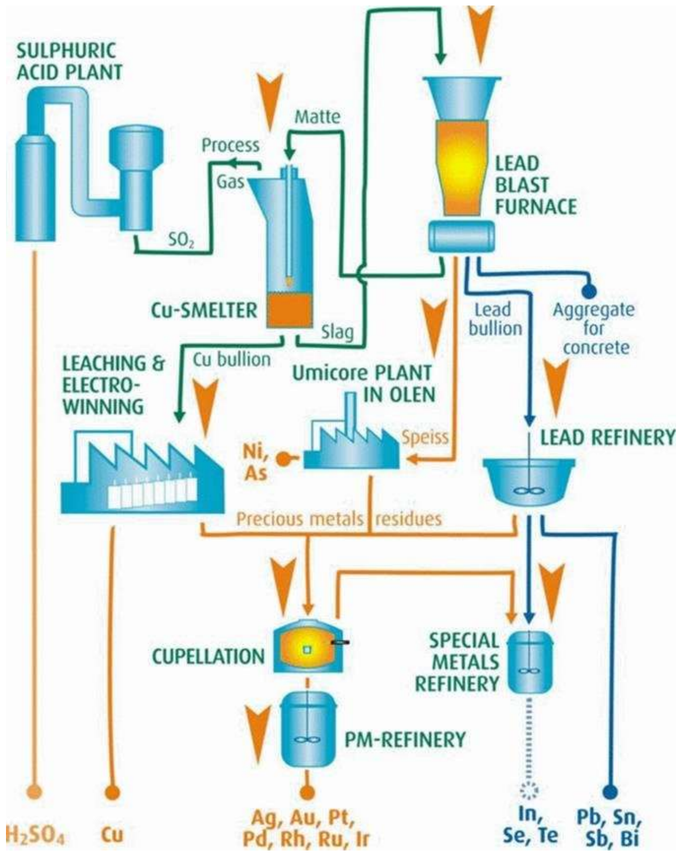
Pure Metals Handling (Level 3)

- Calcination of salts and sponges.
- Reduction of metal oxides (cracked ammonia).
- Acid (HF + HCl) washing to remove base metals and silica.
- Screening and milling.



Co-processing of e-scraps, catalysts and multiple feedstocks





Principal flowsheet of Umicore's smelter and refinery at Hoboken, Belgium.

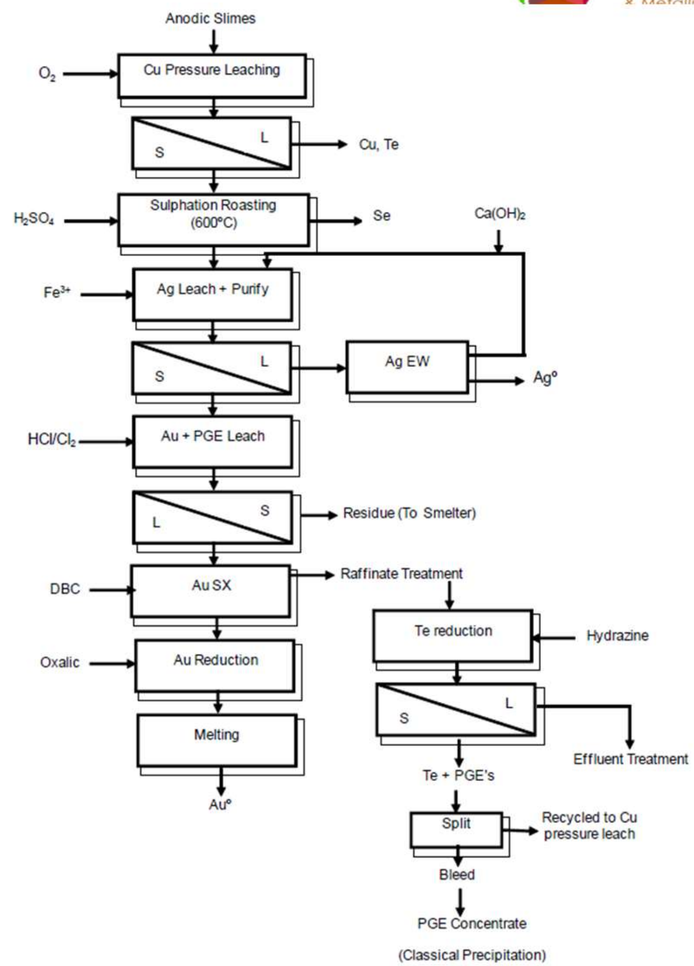


Figure 18. Degussa dmC² Process to Recover PGE's from Autocatalysts

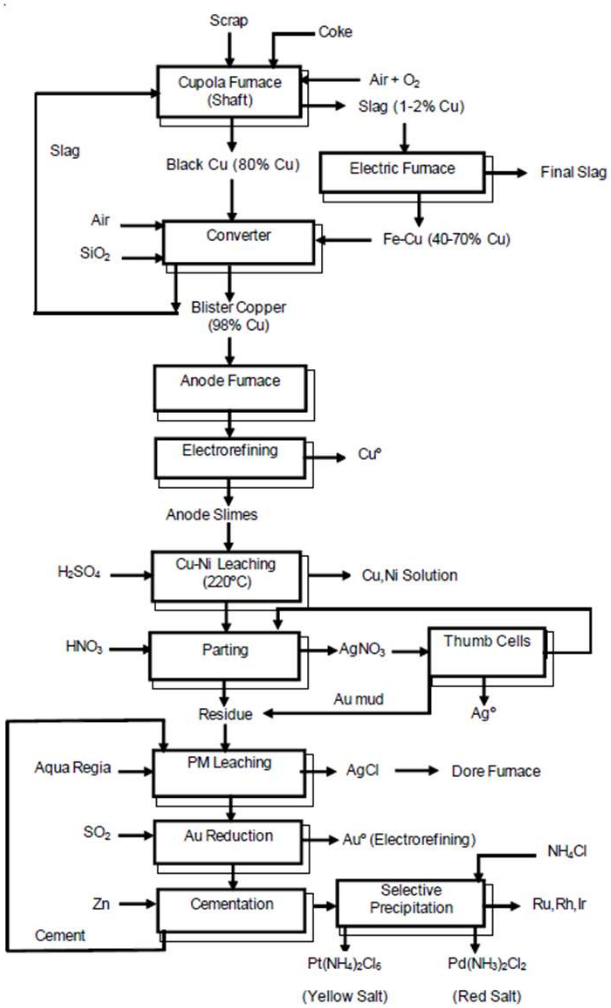


Figure 21. Classical Refining Process for Au, Pt, Pd - Inco Acton Refinery

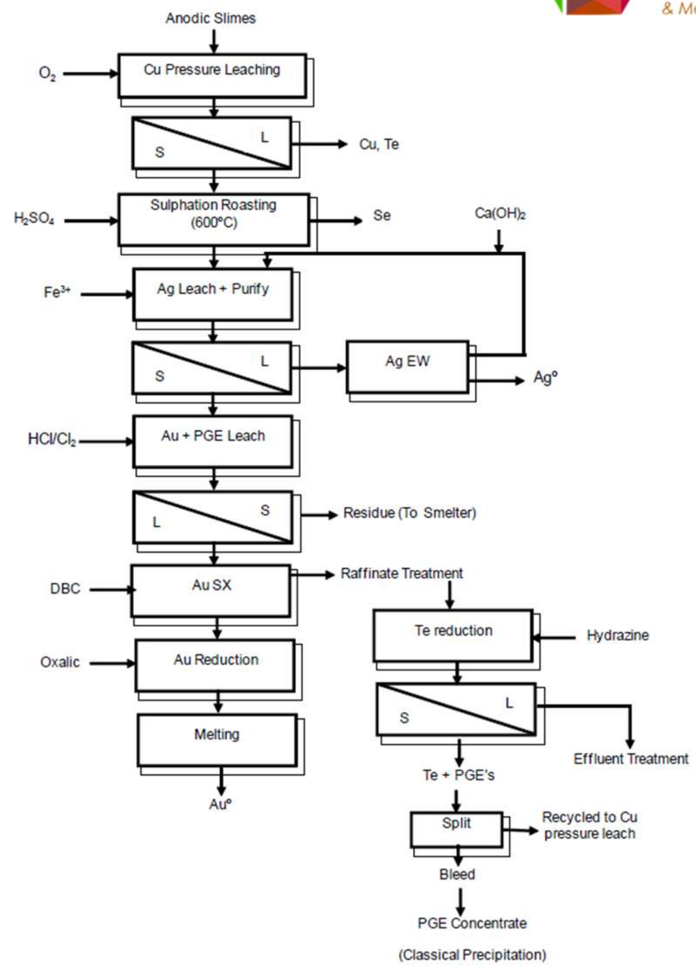


Figure 18. Degussa dmC² Process to Recover PGE's from Autocatalysts

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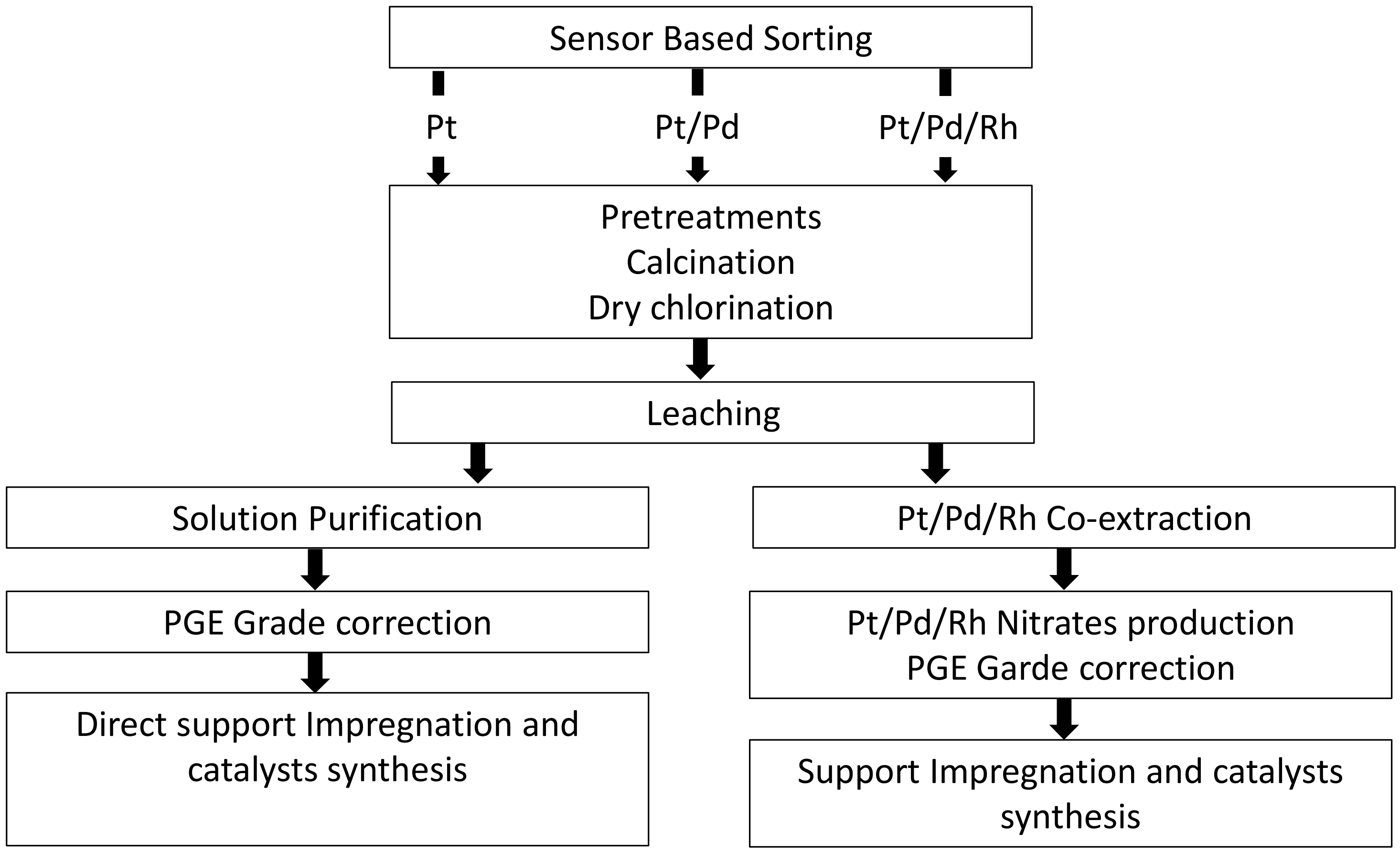
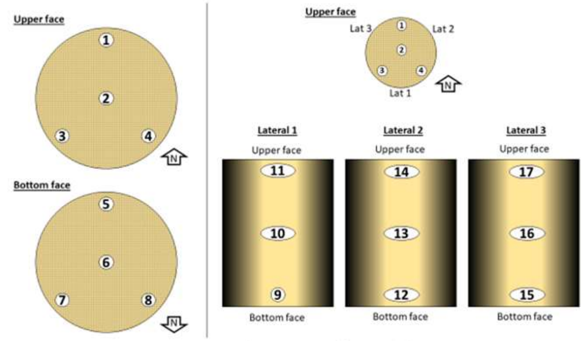
Spent Automotive Catalysts
Is there a room for dedicated flowsheets shortening the recycling process loop from EOL equipments to new catalysts?



Close the gap between Recyclers/Metallurgits and Material Scientists.

Smart sorting to unlock short-loop recycling.

Handheld XRF (SciAps)



Shooting pattern of the monoliths

COM - B3 - 29B

	Location	Ref.	Pt [ppm]	Pd [ppm]	Rh [ppm]
Upper face	1	627	543	73	110
	2	628	550	82	108
	3	629	598	65	106
	4	630	578	51	115
Bottom face	5	631	643	11	78
	6	632	942	11	106
	7	633	1085	0	116
	8	634	1026	0	128
Lateral 1	9	635	1539	0	131
	10	636	709	7	183
	11	637	834	10	164
Lateral 2	12	638	1172	0	135
	13	639	791	0	162
	14	640	846	0	135
Lateral 3	15	641	1139	0	134
	16	642	570	0	149
	17	643	1174	0	141
Inside	1	895	711	0	141
	2	896	894	0	113
	3	897	732	0	126

Beam shot times : 10 sec/each

After grinding

		Pt	Pd	Rh
Stationary calibrated XRF	AEP 2202 001	**1720**	**22**	**243**
Handheld XRF on powder	959	832	13	130
	960	885	16	141
	961	947	12	140
Mean		**888**	**14**	**137**

TWC

COM - B3 - 031

	Location	Ref.	Pt [ppm]	Pd [ppm]	Rh [ppm]
Upper face	1	648	1518	8	261
	2	649	1665	8	264
	3	650	1770	0	272
	4	651	1620	7	246
Bottom face	5	644	984	7	180
	6	645	775	9	149
	7	646	928	8	166
	8	647	1263	7	183
Lateral 1	9	652	2578	10	274
	10	653	3542	11	319
	11	654	3507	10	310
Lateral 2	12	655	2562	7	311
	13	656	2652	0	287
	14	657	2916	8	278
Lateral 3	15	658	2946	13	350
	16	659	4061	10	338
	17	660	4172	22	363
Inside	1	886	1236	0	228
	2	887	1017	0	172
	3	888	1051	7	194

Beam shot times : 10 sec/each

After grinding

		Pt	Pd	Rh
Stationary calibrated XRF	AEP 2202 004	**1448**	**0**	**290**
Handheld XRF on powder	969	1319	0	263
	970	1372	0	266
	971	1306	9	270
Mean		**1332**	**3**	**266**

MON - B4 - 010

	Location	Ref.	Pt [ppm]	Pd [ppm]	Rh [ppm]
Upper face (brighter)	1	609	6966	0	0
	2	610	7050	0	0
	3	611	6718	0	0
	4	612	6649	0	0
Bottom face (darker)	5	613	5632	0	0
	6	614	5537	0	0
	7	615	5528	0	0
	8	616	5659	0	0
Lateral 1 (dark to bright)	9	617	4600	0	0
	10	618	4196	0	0
	11	619	4625	0	0
Lateral 2 (dark to bright)	12	620	4513	0	0
	13	621	4475	0	0
	14	622	5468	0	0
Lateral 3 (dark to bright)	15	623	5865	0	0
	16	624	5682	0	0
	17	625	4728	0	0
Inside	1	904	4051	0	0
	2	905	8370	0	0
	3	906	9171	4	0

Beam shot times : 10 sec/each

After grinding

		Pt [ppm]	Pd [ppm]	Rh [ppm]
Stationary calibrated XRF	AEP 2202 008	**7475**	**57**	**1**
Handheld XRF on powder	981	8588	5	0
	982	8390	5	0
	983	9024	0	0
Mean		**8667**	**3**	**0**

MON - B4 - 008

	Location	Ref.	Pt [ppm]	Pd [ppm]	Rh [ppm]
Upper face (brighter)	1	575	3498	1497	9
	2	576	3854	1652	10
	3	577	3442	1499	9
	4	578	3470	1486	9
Bottom face (darker)	5	579	2201	1030	8
	6	580	2092	1009	8
	7	581	2252	1006	6
	8	582	2268	1019	6
Lateral 1 (dark to bright)	9	583	1761	1837	14
	10	584	1451	1693	10
	11	585	1695	1846	16
Lateral 2 (dark to bright)	12	586	1360	1706	14
	13	587	1306	1828	15
	14	588	1425	1865	13
Lateral 3 (dark to bright)	15	589	1859	1898	10
	16	590	1845	1878	16
	17	591	2267	2224	18
Inside	1	913	2526	1217	8
	2	914	3420	1544	9
	3	915	3019	1395	8

Beam shot times : 10 sec/each

After grinding

		Pt [ppm]	Pd [ppm]	Rh [ppm]
Stationary calibrated XRF	AEP 2202 006	**4000**	**3008**	**41**
Handheld XRF on powder	975	4097	2438	19
	976	4314	2615	20
	977	4173	2502	19
Mean		**4195**	**2518**	**19**

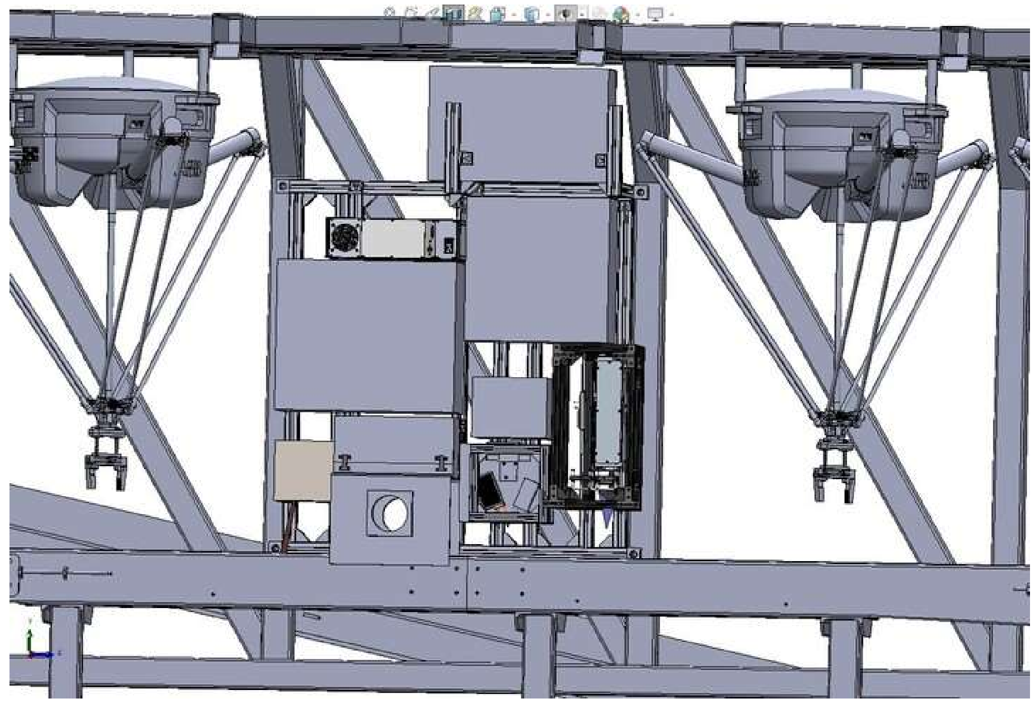
DOC

DPF

MON - B5 - 001

	Location	Ref.	Pt [ppm]	Pd [ppm]	Rh [ppm]
Upper face (brighter)	1	541	301	116	0
	2	542	275	96	0
	3	543	366	164	0
	4	544	365	154	0
Bottom face (darker)	5	545	2048	710	0
	6	546	1969	678	0
	7	547	2124	701	0
	8	548	2145	705	0
Lateral 1 (dark to bright)	9	549	707	562	0
	10	550	0	62	0
	11	551	127	126	17
Lateral 2 (dark to bright)	12	552	549	346	0
	13	553	0	0	0
	14	554	0	0	0
Lateral 3 (dark to bright)	15	555	1082	604	0
	16	556	0	28	0
	17	557	98	31	0
Inside	1	898	977	369	0
	2	899	142	30	0
	3	900	684	361	0
After grinding					
Stationary calibrated XRF		AEP 2202 009	**390**	**200**	**0**
Handheld XRF on powder		984	715	331	0
		985	696	302	0
		986	688	332	0
Mean			**700**	**322**	**0**

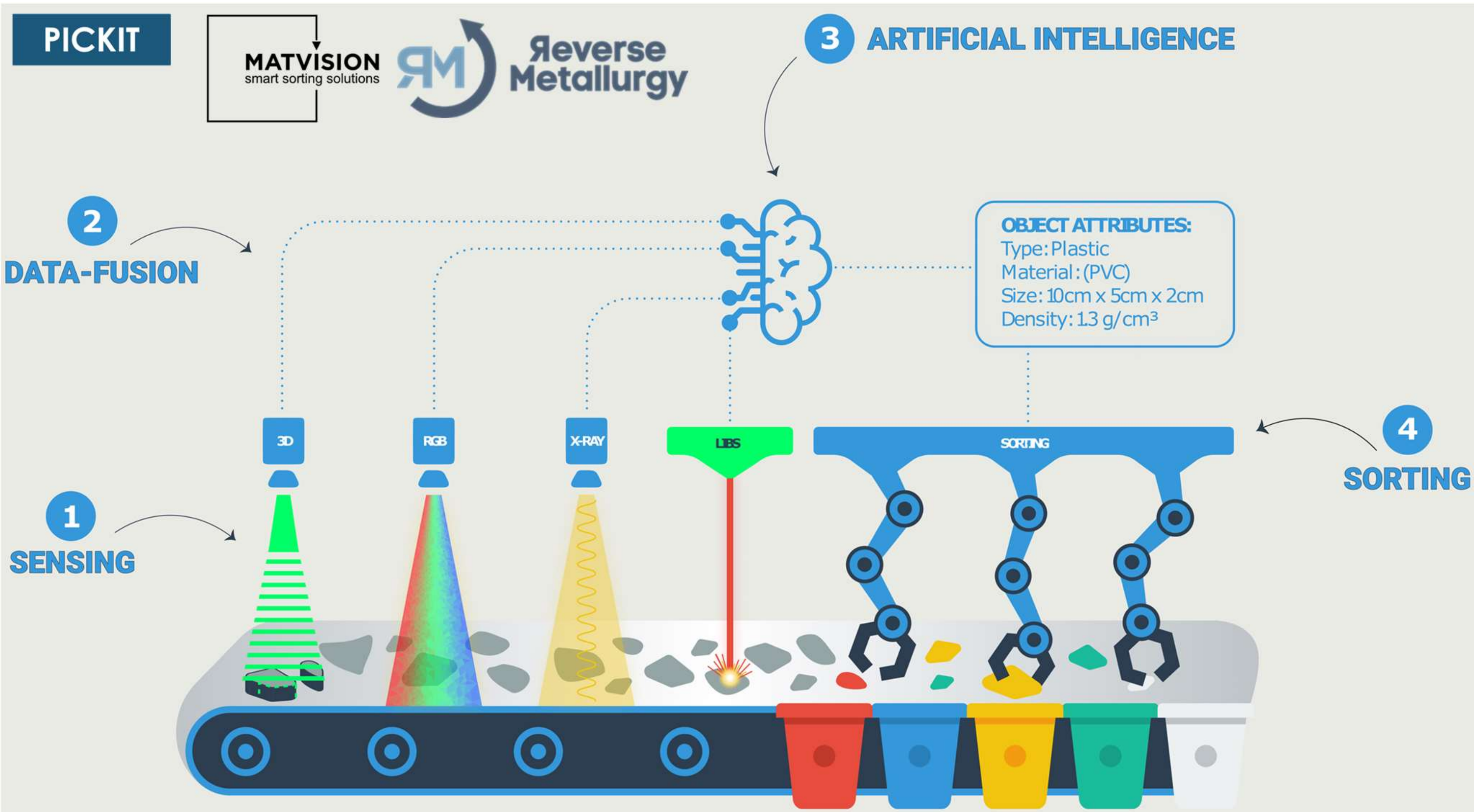
Beam shot times : 10 sec/each

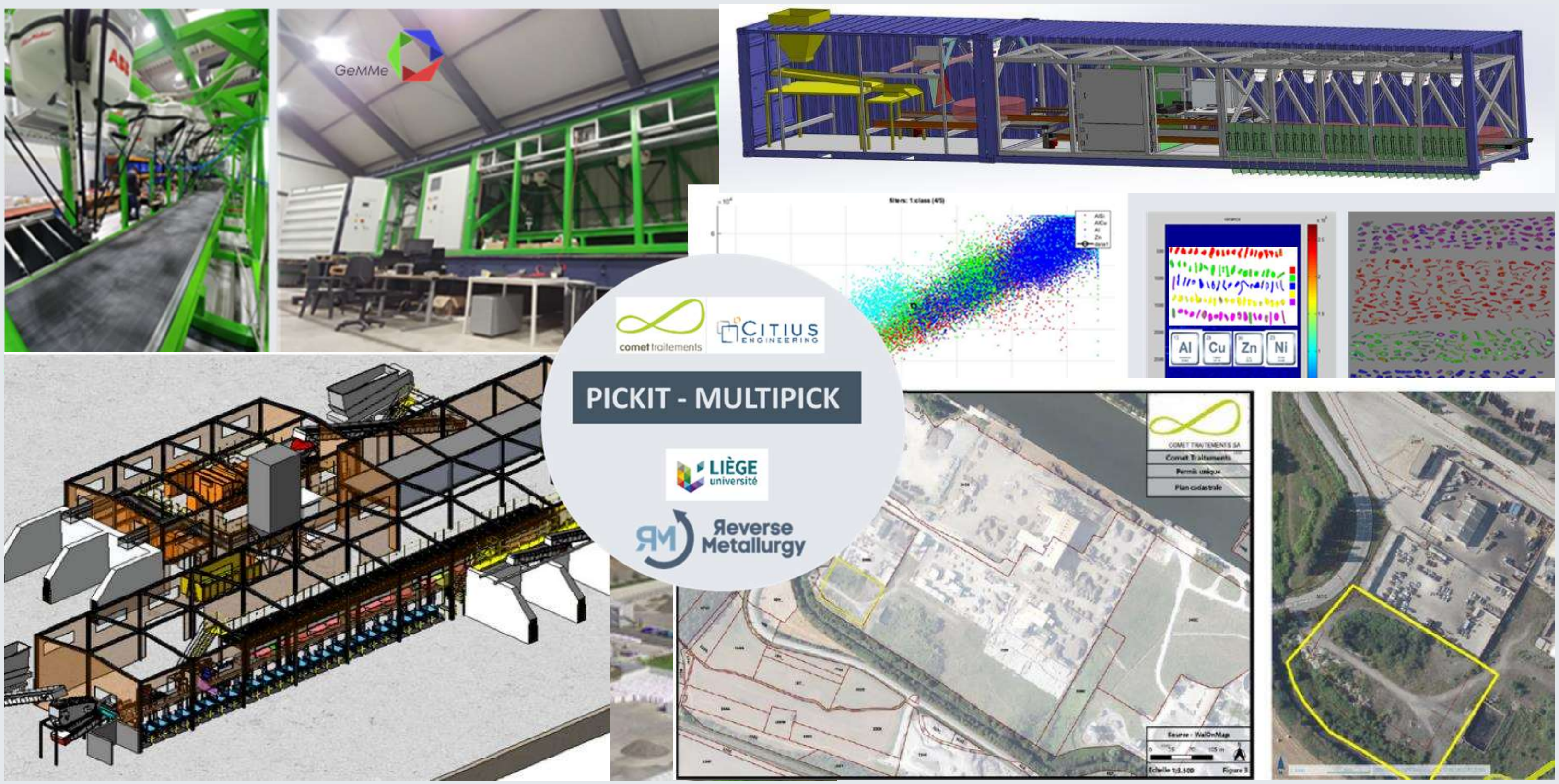


GeMMe’s on-line XRF analysis and robotic sorting prototype

The **PICKIT** concept and technology: **SINGLE PASS MULTI-CLASS SORTING**

https://matvision.eu





PICKIT – MULTIPICK: Investissement de 9.4 M€ sur le site industriel d'Obourg – Capacité de traitement de 20 000 t/an de Zorba (Valeur métal > 30M€/an) - Création de 15 emplois .

EOL Rare Earth Permanent Magnets from e-Mobility.

e-Scooters

e-Bikes

BEV – HEV - FCEV

LREEs		HREEs	
Nd Wt %	Pr Wt %	Dy Wt %	Gd Wt %
19	5	-	4

LREEs		HREEs	
Nd Wt %	Pr Wt %	Dy Wt %	Gd Wt %
24	-	6	-

Exploring short-loops for EOL Rare Earth Permanent Magnets.

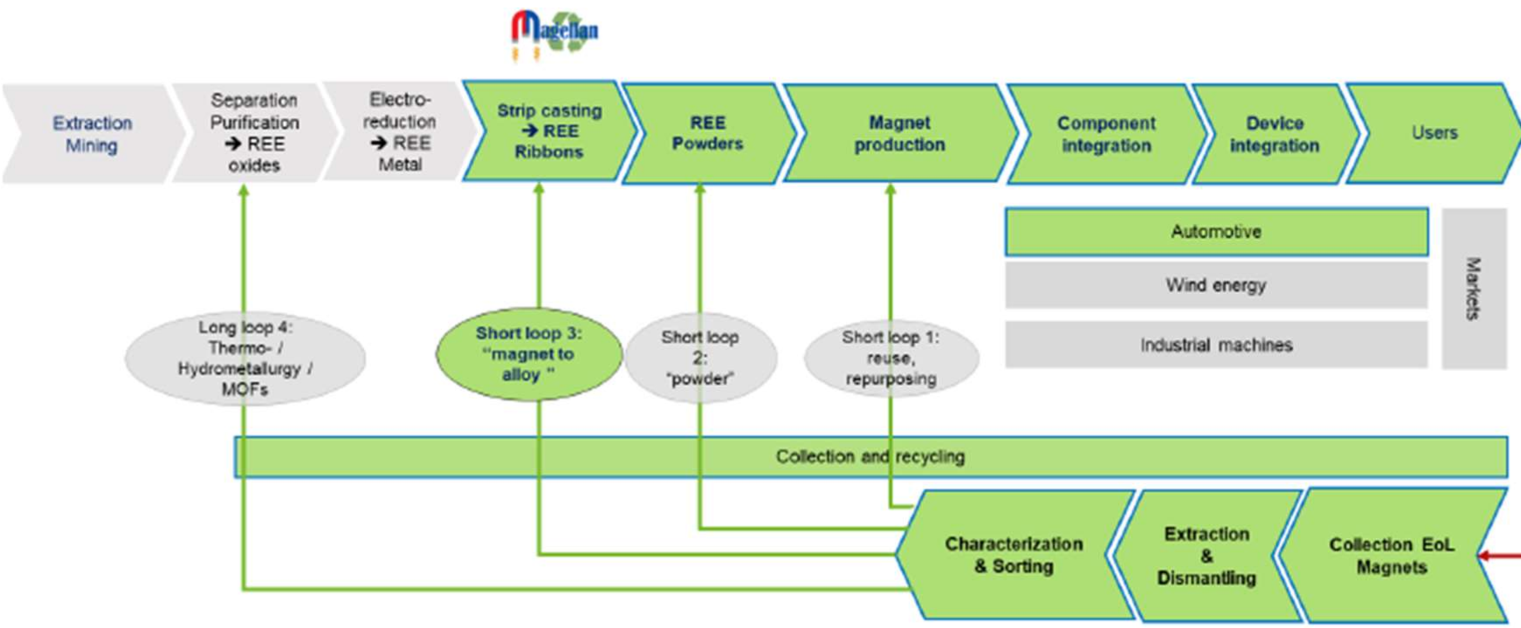


Figure 10 MAGELLAN choice of recycling process: "Magnet-to-alloy"

HORIZON-CL4-2023-RESILIENCE-01-09: Recyclability and resource efficiency of Rare Earth based magnets

Ref. Ares(2023)2904744 - 25/04/2023

The Li-ion batteries case study.

Blackmass from Spent Li – ion NMC Batteries

↓

Leaching

↓

PLS Purification

↓

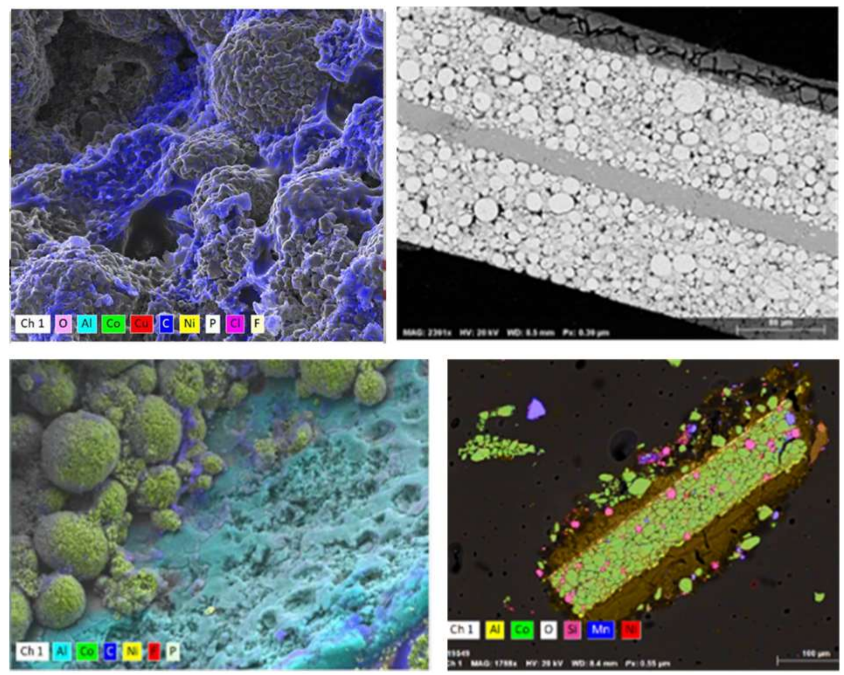
Ni-Mn-Co mixed salts Precipitation

↓

Ni-Mn-Co grades and Ratio Adjustment with pure salts

↓

New CAM Synthesis methods from mixed salts



Close the gap between Recyclers/Metallurgits and Material Science Actors.

Summary of today's sharing

- Close the gap between Recyclers, Metallurgists, Materials Scientists and Products Designers.
- Explore the Designed from Recycled options.
- Do we always have to go back to pure elements or do we have to keep the maximum of the energy embedded in man-made minerals and anthropic elemental associations.
- Develop Smart Sorting Solutions to chanel the EOL products to the shortest recycling loop.

- **No sustainable Circular Economy and Urban Mining without Primary Mining.**
- **Stop using slogans like Zero Waste, 100 % recycled, carbon neutral and climate neutral.**
- Mitigating and minimizing the environmntal impacts of our societies require to think in terms of systems.

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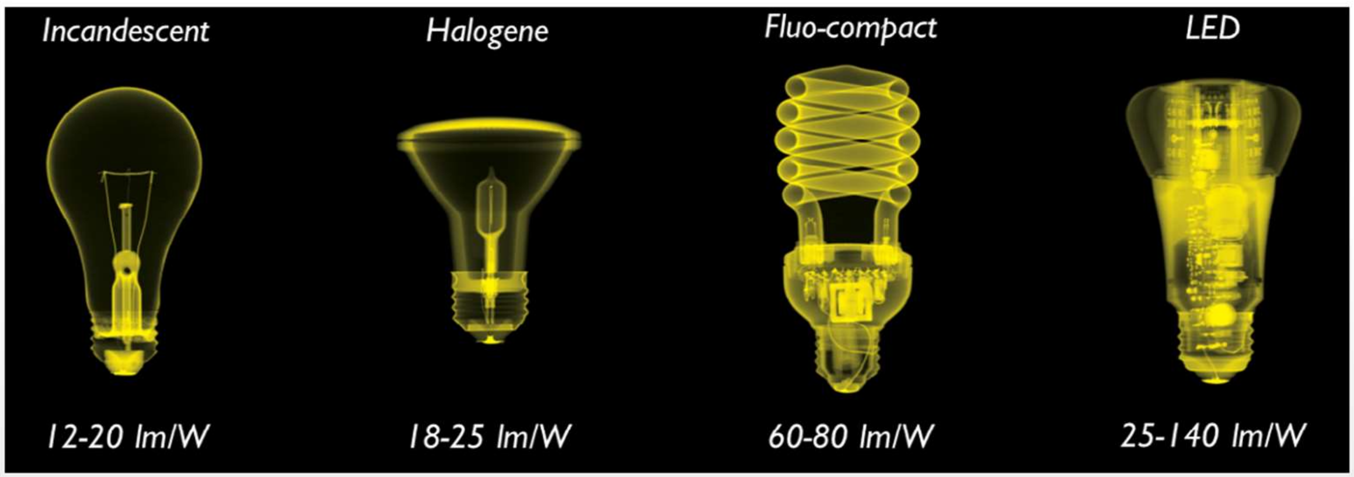

Tungsten	**Tungsten**	**Tungsten**	**Gallium**
Glass,…	Iodine, Bromine, … Glass,…	Mercury, Rare Earths,… Glass, Plastics,…	Indium, Cerium, Yttrium, Copper, Silver, Silicium, … Plastics, …

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Mini means 600kg in 1960

Mini SE means 1440 kg in 2021

Engineering the circular economy of minerals and metals

- 25⁺ Research Staff
- 3 M€ annual turnover

Université de Liège hosts the GeMMe, a Research Unit specialized in georesources, mineral engineering and extractive metallurgy.

The GeMMe contributes to the development of innovative processes for the efficient management of mineral and metallic resources while providing unparalleled upscaling experience in urban ore characterization and processing (with a focus on innovative sorting techniques and hydrometallurgy) derived from a long research tradition in primary ores mining and processing.