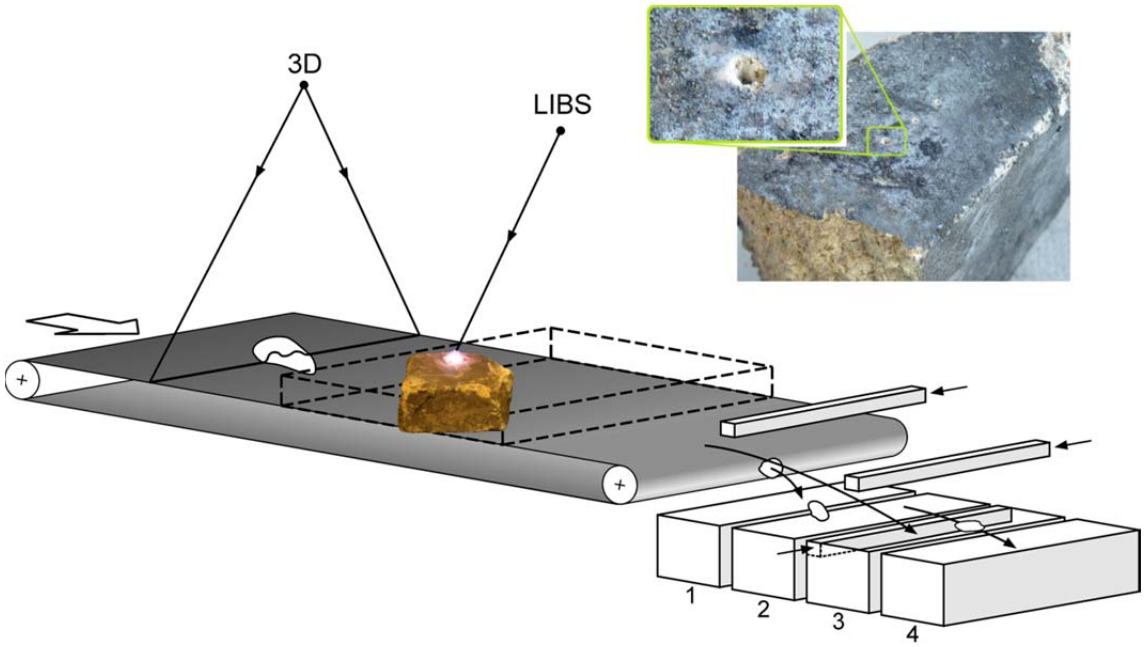

Figure 1: Basic principle of LIBS system in a sorting system (shown here with pneumatic separation). Inlay: photography of laser-penetration of surface contamination

Table 1: Properties of 8 types of refractories studied in REFRASORT

Group	Type	Composition
MgO-based	Fired MgO	High MgO, no C, low CaO
	MgO-C with antioxidant	High MgO, 5 – 15 wt-% C, low CaO, antioxidant ~3%
	MgO-C without antioxidant	High MgO, 5 – 15 wt-% C, low CaO, no antioxidant
Doloma-based	Fired doloma	High MgO, high CaO, no C
	Doloma carbon	High MgO, high CaO, 5-15 wt-% C
Alumina-based	Fired bauxite	High Al, Al/Si ~8/1, low CaO/MgO/C
	Fired andalusite	High Al, Al/Si ~2/1, low CaO/MgO/C
	Fired chamotte	High Al, Al/Si ~1/1, low CaO/MgO/C

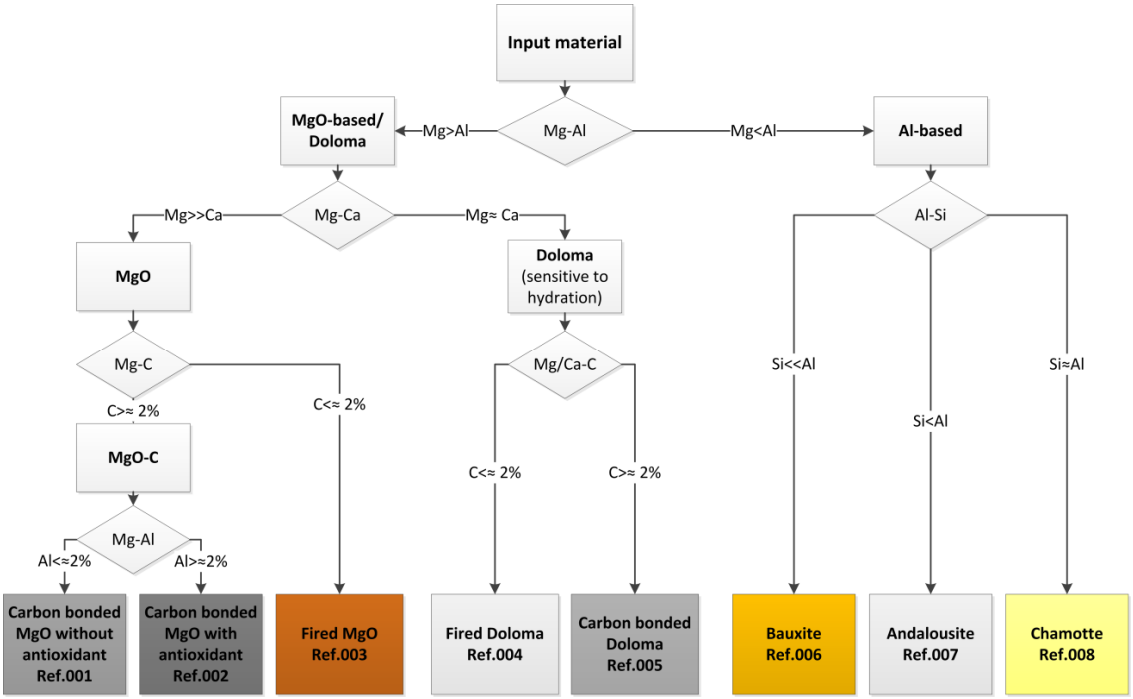

Figure 2: Concept for identification of eight classes

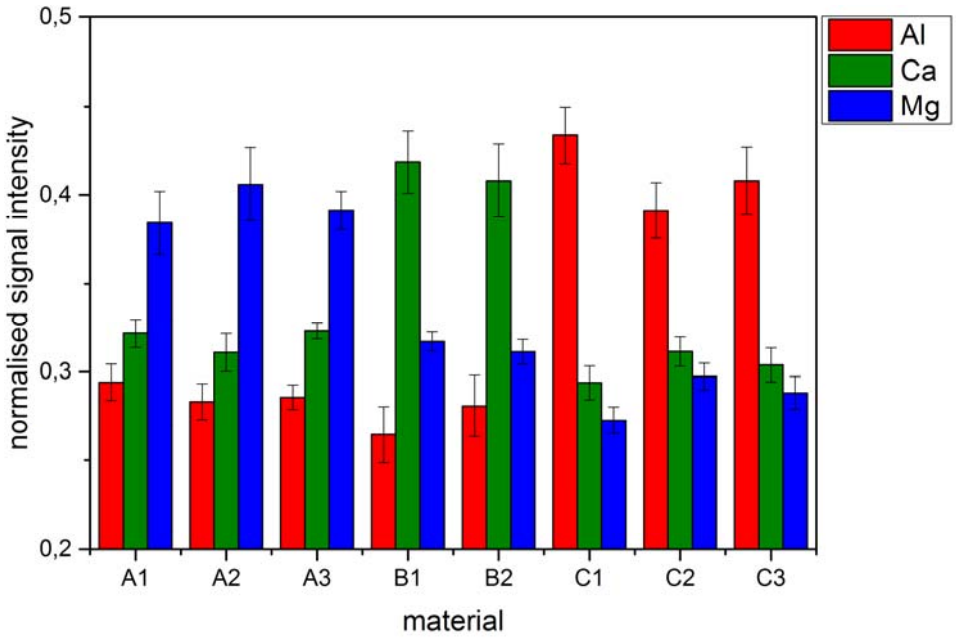

Figure 3: Results of laser spectroscopic signals.

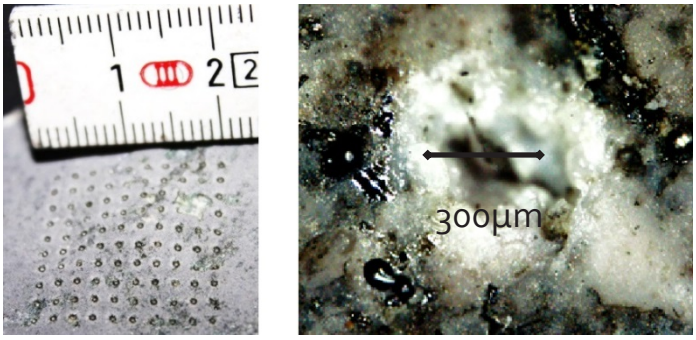

Figure 4: Left) Craters produced by tailored laser pulses in the cover layer of a used brick. Right) Microscopic photograph of one crater (width ~300 µm, depth ~100 µm)

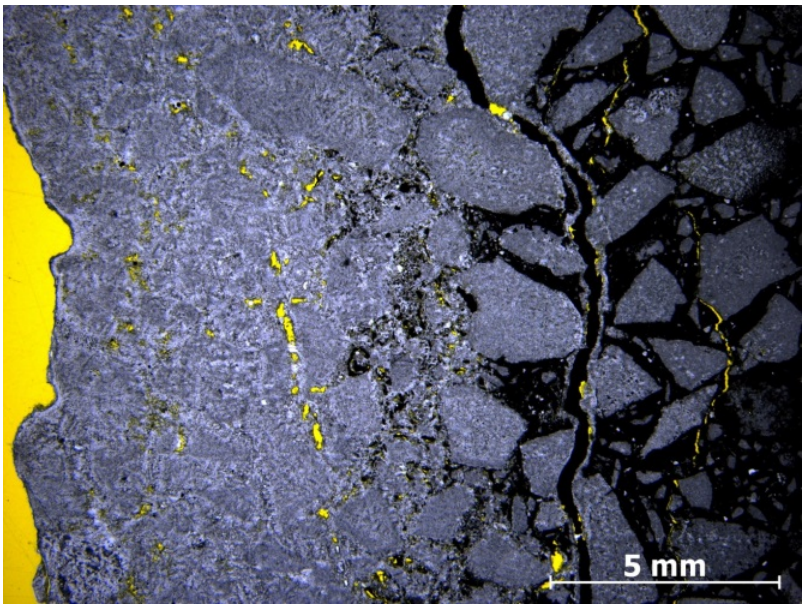

Figure 5: Doloma carbon brick with severe decarbonisation at outer surface

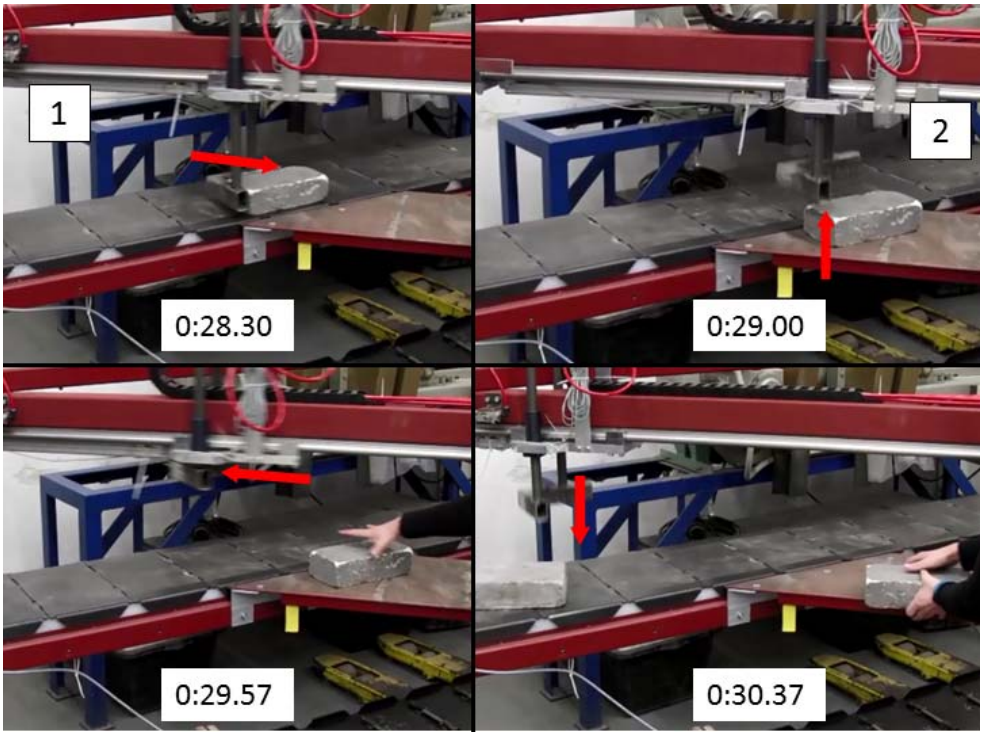

Figure 6 - Motion sequence of the pushing device

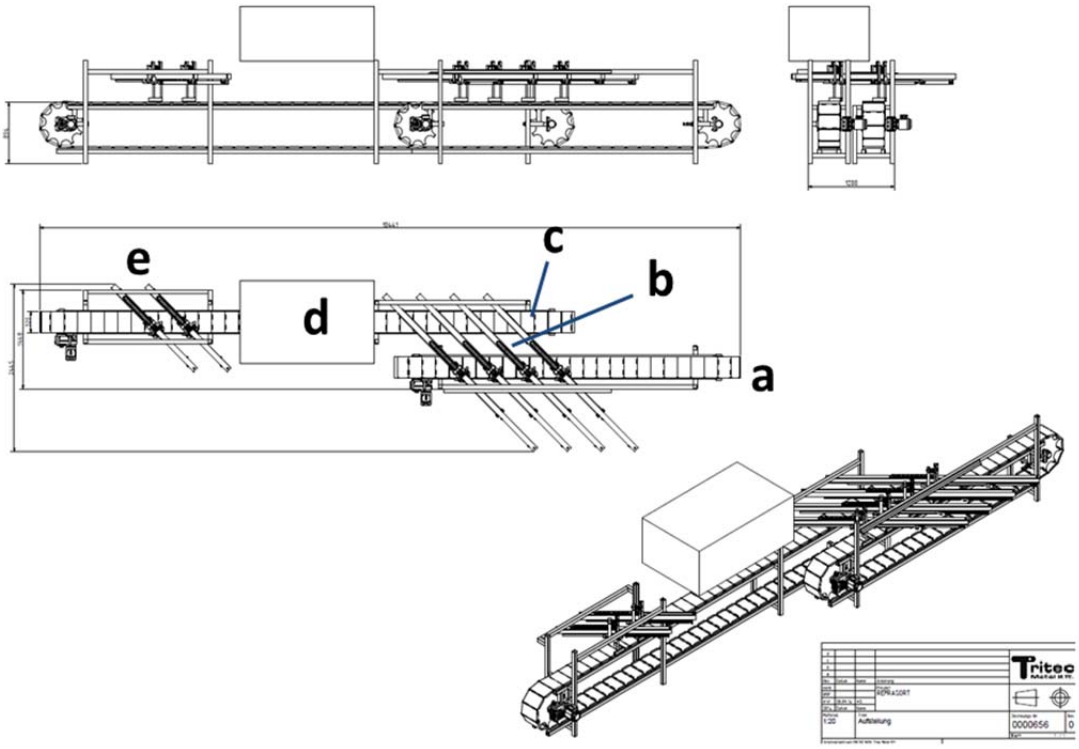

Figure 7: Drawing of the proposed set up for the demonstrator

a: first plate conveyor, b: buffer, c: second plate conveyor, d: LIBS station, e: sorting pushers

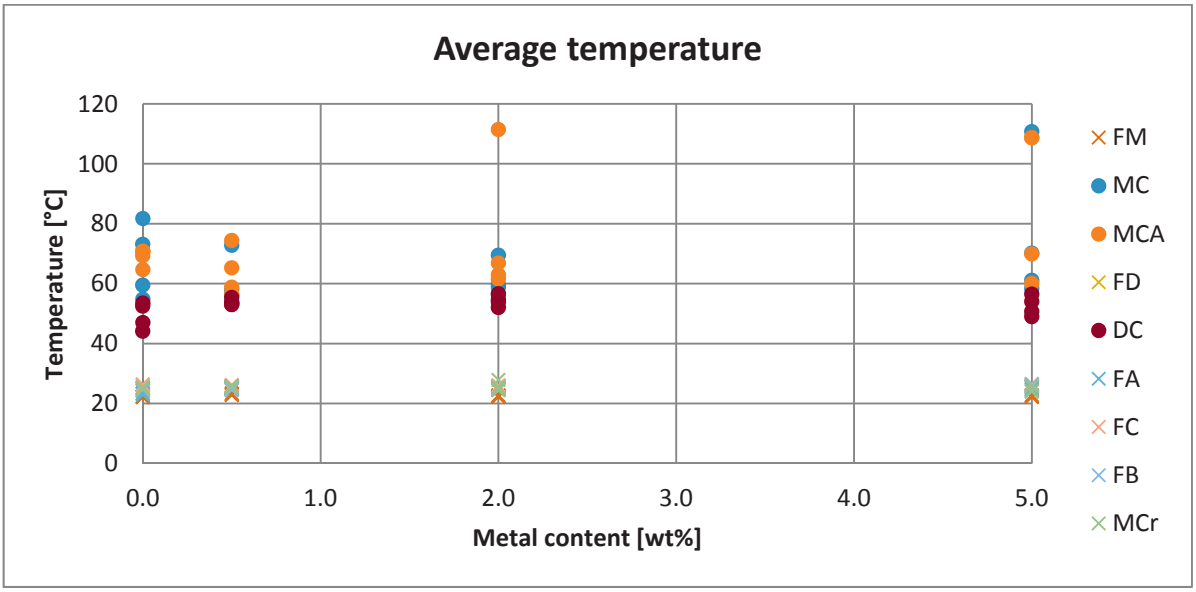

Figure 8: Temperature after microwave heating with different metal contents

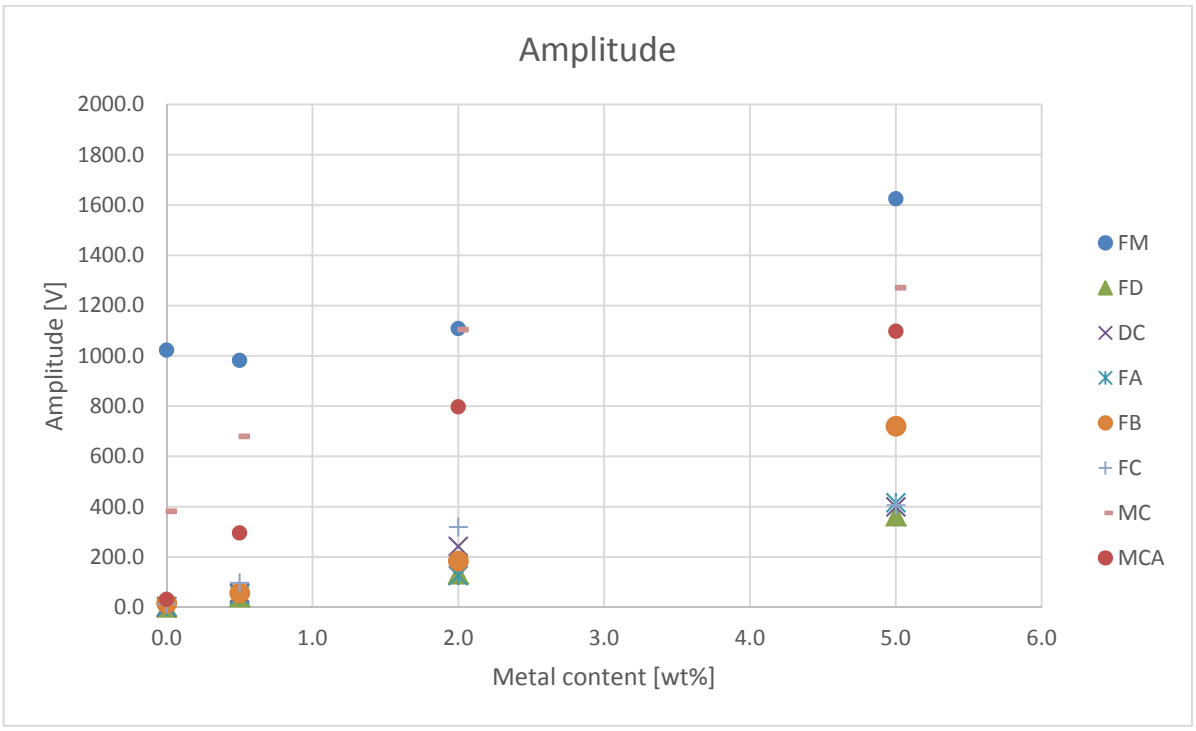

Figure 9: Metal detector results for artificial samples with metal

Table 2: Summary of the sensor tests (screening tests)

Sorting method	Analysed zone	Advantages	Weaknesses	Potential for REFRASORT project
Color	Surface	-	Dust sensitive	No
X-ray transmission (XRT)	Particles	Can detect doloma, maybe alumina	For particle size < 50 mm	No
Laser induced fluorescence (LIF)	Surface	-	Gives a weak signal, gives similar responses for all types of bricks	No
Near infrared (NIR) spectroscopy	Surface	Can detect doloma after hydration	Bricks need to be hydrated	No because LIBS can separate doloma
Fourier Transform Infrared spectroscopy (FTIR)	Surface	Industrial equipment available, can distinguish different types of refractories	Dedusting required; high cost	No
X-Ray Fluorescence (XRF) - handheld	Surface	Can detect pure metal	Needs a long time for light elements; practical limitation for metal detection	Can be used only for pure metal, not for metal containing bricks.

Table 3: Summary of the sensor tests focused on metal and carbon detection

Sorting method	**Analysed zone**	**Advantages**	**Weaknesses**	**Potential for Refrasort project**
Metal detection portal	Volume	Can detect metal and C	Gives a signal which depends on the size of the brick	Promising technique for metal and/or C detection, to be tested further to determine its limitations (metal concentration, metal amount, C concentration, C amount)
Magnetic susceptibility	Volume	Can detect MgCr and antioxidant	No available industrial sensor suited for Refrasort tests. Can be used only for bricks with same size and same weight.	No
Microwave heating	Heating of the whole brick; measurement of the surface temperature	Can detect C in fresh bricks with no influence of the metal content.	Gives different responses for same kind of bricks. No correlation observed between C content and heating behavior for magnesia based spent bricks.	To be tested further for C detection
Terahertz	Volume	Can detect conductive materials	Influenced by the thickness of the brick and the roughness of the surface	Cannot be applied at industrial scale because the size of the spent bricks vary a lot and their surface is rough.

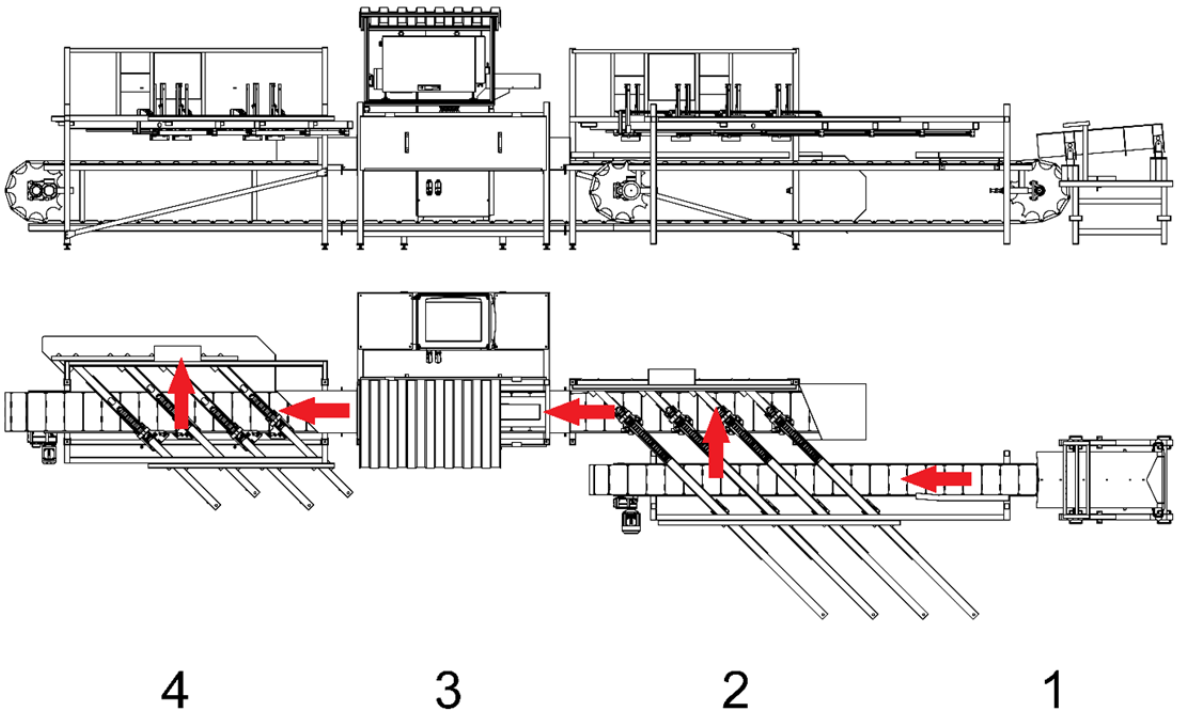

Figure 10: Concept of the sorting system. The conveying direction is indicated by red arrows, beginning on the right hand side. The numbers denote the sections of the system decribed in the text.

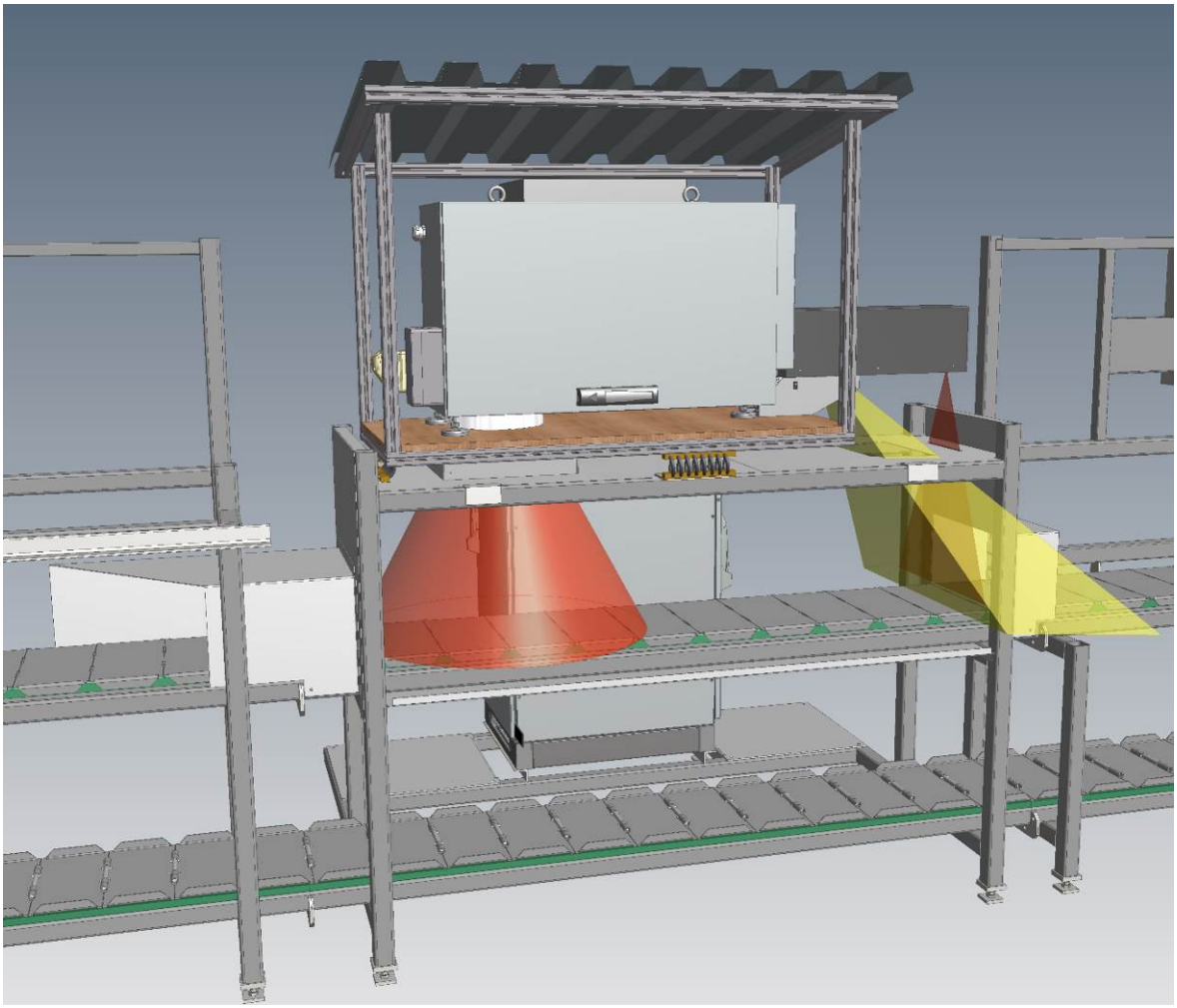

Figure 11: Schematic of the integration of the laser-based identification system with the conveyor (with opened service access). Measurement areas are shown in yellow (3D) and red (LIBS).

Figure 12: View of the sorting system

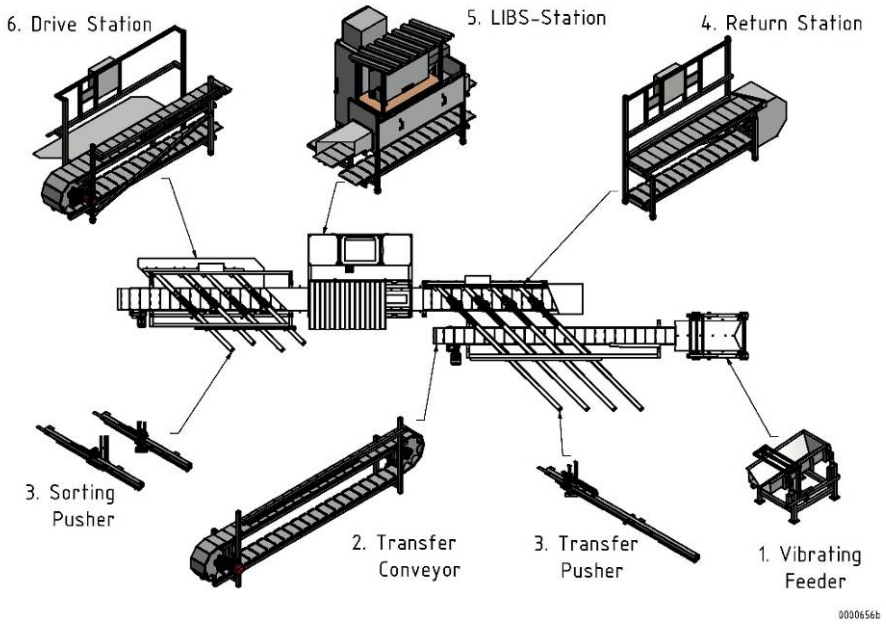

Figure 13: Modular design of the demonstrator

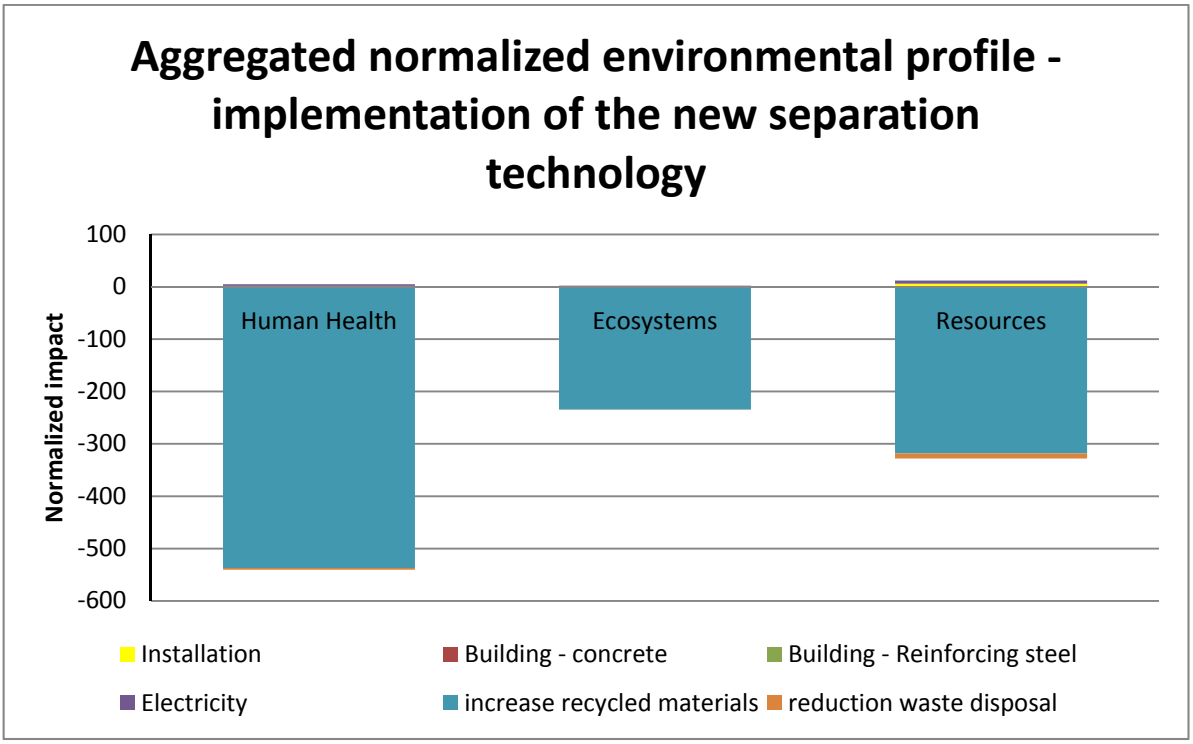

Figure 14: Aggregated normalized environmental profile of the implementation of the new separation technology, ReCiPe method (normalized against an average European in the year 2000)

Table 4: Potential for replication of REFRASORT system

Refractory market	Refractory use (ktpa)	Spent refractory generated (ktpa)	Spent refractories to sort (ktpa)	Number of installations (capacity 20 ktpa)
EU steel industry	1690	1014	372	18
EU all industries	4000	2400	880	44
World steel industry	16700	10020	3674	184
World all industries	35000	21000	7700	385

The assumptions on which these calculations are based, are described in detail in D8.1

List of partners

Partner	Country	Type
Vlaamse Instellling voor Technologisch onderzoek NV (VITO) – Coordinator	Belgium	Research institute
Orbix (Orbix)	Belgium	SME
Fraunhofer Society – Fraunhofer institute for laser technology (ILT)	Germany	Research institute
Department for Mineral Processing at RWTH Aachen University (AMR)	Germany	University
Laser Analytical Systems and Automation GmbH (LSA)	Germany	SME
Tritec - Metal Kft. (Tritec)	Hungary	SME
Magnesita Refractories Gmbh (Magnesita)	Germany	Large company

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