REVaMP Deliverable 3.3

Retrofitting Equipment for Efficient Use of Variable Feedstock in Metal Making Processes - REVaMP

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LIBS sensor tested with scrap samples at laboratory and ready for installation

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<u>Dissemination level</u>

PU	public	☒
CO	Confidential, only for members of the consortium (incl. the Commission Services)	☐

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1. About REVaMP

The main objective of the project "Retrofitting Equipment for Efficient Use of Variable Feedstock in Metal Making Processes" (REVaMP) is to develop, adapt and apply novel retrofitting technologies to cope with the increasing variability and to ensure an efficient use of the feedstock in terms of materials and energy.

For this purpose, existing metal production plants shall be retrofitted with appropriate sensors for scrap analysis and furnace operation. Furthermore, the selection of the optimal feedstock in terms of material and energy efficiency shall be improved by application of appropriate process control and decision support tools. Also, a solid scrap preheating system operated with waste derived fuel shall increase the energy efficiency of the melting processes. To monitor and control the process behaviour in an optimal way, model-based software tools will be developed and applied.

The retrofitting solutions will be exemplarily demonstrated within three different use cases from the metal making industry, namely electric and oxygen steelmaking, aluminium refining and lead recycling. The performance of the different technologies will be assessed, and the benefits will be evaluated in terms of economic and ecological effects, as well as cross-sectorial applicability in other process industries.

2. Introduction and Objectives (of Deliverable)

This deliverable D3.3, "LIBS sensor tested with scrap samples at laboratory and ready for installation", is included in the work package WP 3 "Sensor adaptation and equipment plug-in development" of the REVaMP project.

Within Task 3.3, a smart LIBS sensor system ready for installation in different use cases is engineered, set up and tested.

Based on existing LIBS industrial installation concepts of ILT and LSA, a universal sensor layout was developed, which allows the application in all use cases. The sensor includes high-speed 3D scanning optics to address flexibly a broad variation of feed material (steel scrap, Al chips, Pb shredder). Laser, spectrometer and other optical components have been selected to cover all analytical requirements of the different use cases. The LIBS sensor is combined with a 3D camera and software for fast evaluation of beam steering parameters. The camera will allow further to determine the material distribution and filling grade of the transport devices. Unified interfaces for mechanical installation, system control and data output are implemented. The sensor system is first set up at the premises of LSA, calibrated and validated on a belt conveyor installation with scrap samples provided by the partners.

<u>Note</u>: Since this deliverable is public, no numerical values of concern for the industrial partners have been included in this report.

3. Concept of retrofitting LIBS

For the analysis of scrap material in the recycling plants, a sensor based on the method of **laser-induced breakdown spectroscopy (LIBS)** was developed. The principle of the LIBS process is shown in Figure 1 (left).

A laser beam of high intensity is applied to the material under inspection and focused onto its surface. The laser beam source generates repeatedly short pulses, in the order of nanoseconds, with high power. The fluence on the surface is high enough to ablate and evaporate a small amount of material, which is then further excited by the laser light. The excited material plasma plume emits optical radiation during its de-excitation, which contains spectral line emissions originating from the atomic and ionic electronic state transitions. This light emission is collected and registered with sufficient spectral resolution to detect the individual emission lines. From the relative intensity of the lines the abundance of the emitting species can be calculated.

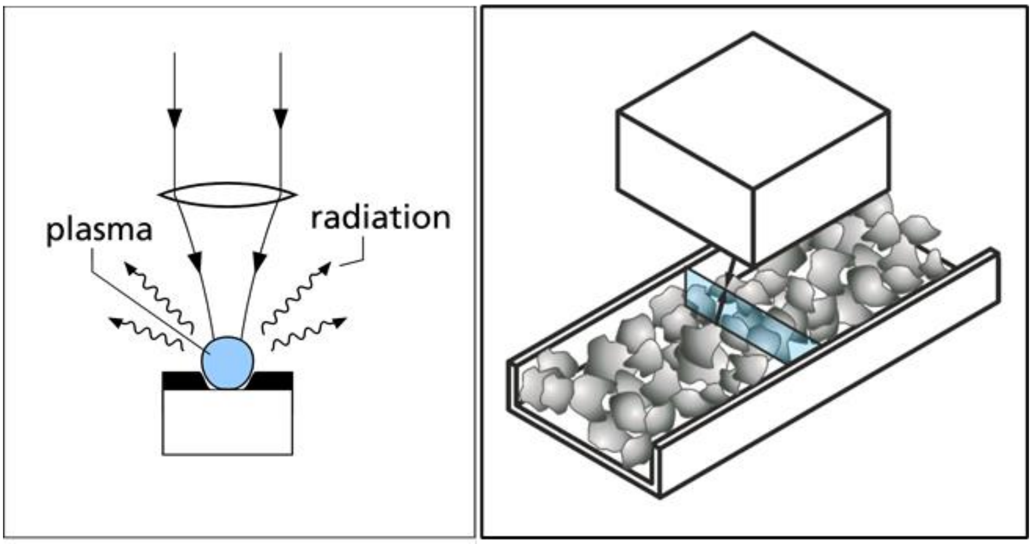

Figure 1 Scheme of LIBS measurement process (left) and LIBS scanning of a material layer (right)

A single LIBS measurement is a fast process and can be repeated hundreds of times per minute. This allows to obtain a good coverage and statistical averaging, when applied to inhomogeneous material. Scrap loads consist of a large number of individual pieces which can be of different composition. Due to the material preparation and pre-classification, similar pieces can be expected to occur in a larger batch of delivered feedstock. In classical processes, a limited amount of material is sampled from a batch and then send to an analytical laboratory. The procedure of taking the macroscopic sample is organized in such a way to achieve a good representativeness of the batch. In contrast, the LIBS measurements create a much higher number of individual microscopic samples from the material. The distribution of the sampling points, i.e., the measurement locations for LIBS are important to achieve a representative result.

In order to achieve a good distribution of the measurement locations, the presentation of the material to the LIBS sensor has to be considered. When the material is stored in a big heap, a representative sampling is hindered, since the optical measurement can access only the surface of the heap. However, when a shallow layer of material can be provided, the chance is high that all types of material pieces are accessible at the surface and that the mean composition can be derived by statistical means. The better the measurement locations can be distributed over the surface, the better the average will represent the whole batch.

In the LIBS system designed with REVaMP, the laser beam will be actively steered in order to reach different measurement locations, see Figure 1 (right). Using fast scanner mirrors, the laser beam can be directed for each single laser pulse onto a predefined position. The plasma emission is collected backwards along the same optical path. Using two mirrors, a 2-dimensional area can be accessed for LIBS measurements. Because the material cannot be expected to form a flat layer, the surface shape is additionally measurement using a 3D camera. From the height of the material, the measurement distance is calculated for each measurement location and the focal length of the system is adjusted by a focusing unit integrated in the optical scanner.

For retrofitting a LIBS sensor into different scrap processing plants, the present scrap handling procedures have to be considered. In principle, there are two ways of material handling which are to be treated differently. Usually, the material is delivered to the plants by individual batches, e.g., by truck, ship or train. In some installations this material is transported internally on a conveyor to an intermediate storage. This type of transport forms, to some degree, a continuous material flow with a large surface and can be a preferable measurement option. In other plants, the material is directly dumped to the storage place from the truck. In order to make good use of analytical information obtained for the individual batches, it is important to have the information available once the material is placed in the intermediate storage. Depending on the composition data, the scrap mixtures for processing can be optimized. Additionally, an individual storage might not be available for each batch delivered. This case, it would be beneficial to obtain the composition information even before unloading the trucks, so that the load can be directed to the best suited storage bunker, collecting similar deliveries.

In REVaMP, it was attempted to build a single universal LIBS sensor which can be applied to different material handling schemes at different plants. It was designed to be suitable for conveyor operation as well as for direct measurements of truck deliveries. In case of the conveyor installation, the sensor will be placed in a fixed location overhead the flow of material. The LIBS measurements are taken continuously from the flow, with the measurement locations being selected and distributed over the width of the belt by 3D measurements and the scanning capability. For the measurement of a bulk volume, as e.g. on a truck, the distribution of the measurement points over the surface has to be realized mainly by the sensor itself. For this purpose, it is beneficial to design and build a compact active sensor which can be mounted and moved mechanically across the material surface in addition to its capability to select individual measurement locations for each laser pulse.

In REVaMP, a layout concept was worked out for the LIBS sensor. In Figure 2 the concept of installation at a conveyor belt is shown. The belt in this case, as planned by GrupalArt, consists of a bunker (blue) attached to the belt (red cover) on a transportable platform. The LIBS sensor is displayed together with the 3D camera which will be mounted as one unit. Since the belt can divert from a horizontal transport, in this case upward, it is beneficial to mount the optical sensor in a flexible way to adjust it for the used angle of movement in the application.

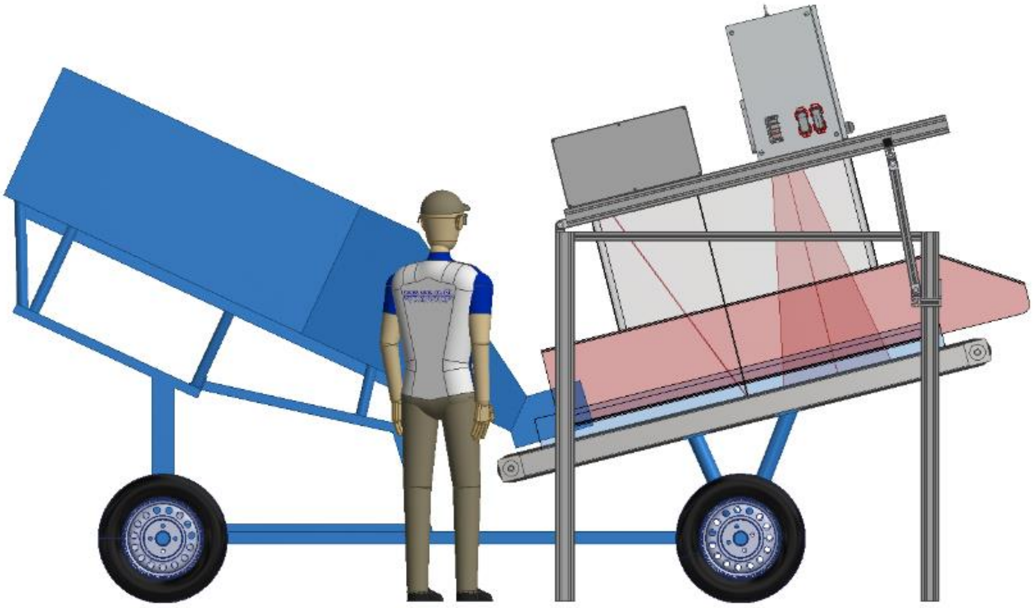

Figure 2 Concept of installation of the LIBS sensor at a conveyor belt material flow.

For the truck delivery inspection, a concept was worked out in cooperation with ArcelorMittal as shown in Figure 3. The delivering truck stops under a portal on which the LIBS sensor is mounted. While the truck stands at rest, the sensor is moved to scan the surface of the load. Depending on the dimensions in the individual use case, parts of the truck will be inspected at once and the truck moved forward to allow the access to the next part. The procedure is expected to be executed in several minutes. After this, the truck can be directed to a dumping position depending on the results on the composition measurements.

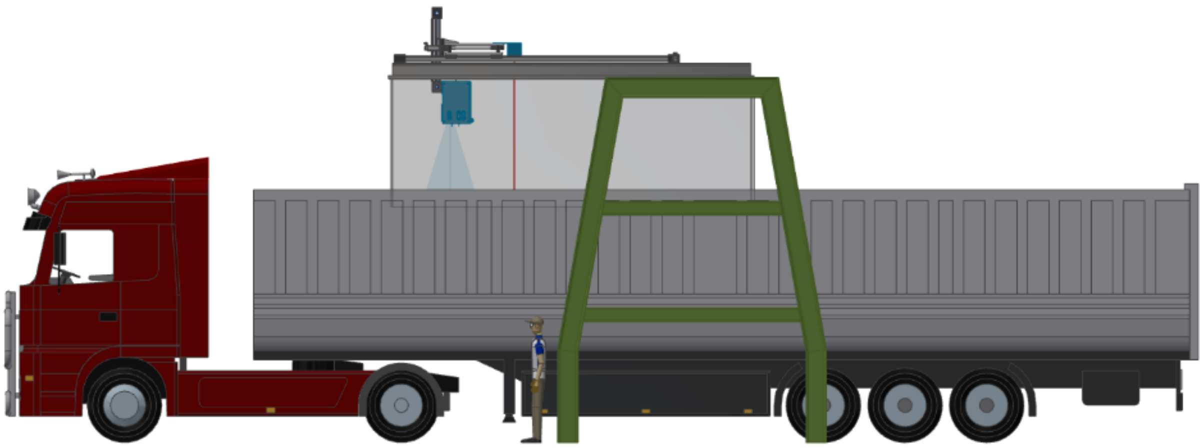

Figure 3 Concept of installation of the LIBS sensor for material delivered and analysed on a truck.

4. LIBS sensor setup

In the design of the LIBS unit, particular emphasis was placed on the robustness of the optical setup. The LIBS unit consists of two modules connected with a supply line. The optics module is placed above the conveyor belt, the control module is placed nearby. The length of the supply line is limited to approx. 10 m for various technical reasons.

Figure 4 shows the external view of the optics module of the LIBS sensor. It contains all optical elements for performing LIBS measurements, except for the optical spectrometer, which is mounted in the supply module and connected via an optical fiber. The bright lettering on the access door indicates the components inside: laser head, scan head, optical beam guide and control electronics. The module is temperature-stabilized and dust-tight for use in harsh environments. The laser radiation emitted by the laser head in the optics module is guided by an optical beam guidance unit through the scanner optics and deflected downwards by the latter, where it then leaves the module through an exit window. This also serves as an entrance window for the plasma radiation. Furthermore, the optics module is equipped with industry standard crane hooks, and connection sockets. It can be fixed on a support frame with three adjustable feet.

Figure 5 shows the bottom of the optics module with the radiation exit/entry window and the connection for the water hoses for the cooling unit.

Figure 6 shows the control module of the LIBS sensor. This module is equipped with several user interfaces, including a graphical display and operator interface (HMI), as well as standard controls for resetting fault and interlock conditions. Furthermore, a module for remote access is integrated.

Figure 7 shows the optical module during setup, with the scanning module already installed. Figure 8 shows the backside of the module with dismantled alignment hatches.

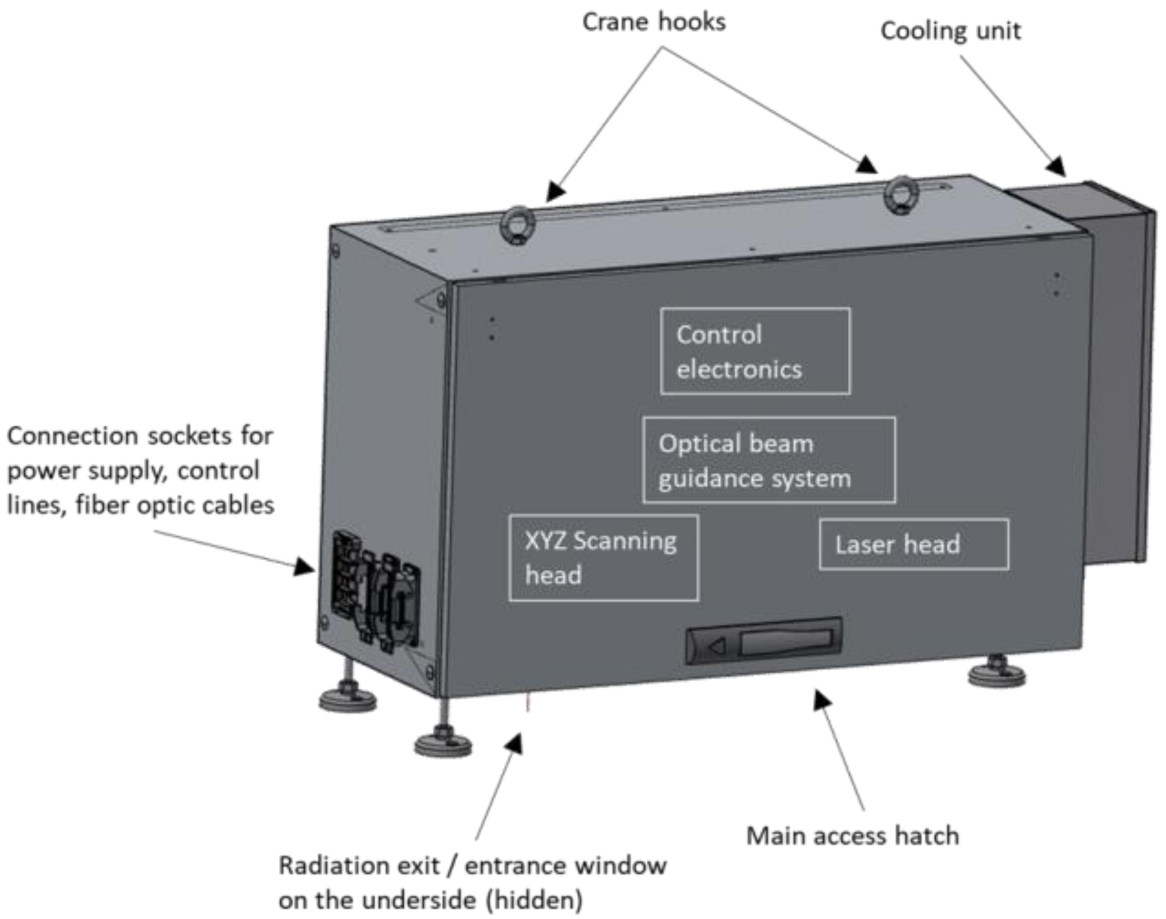

Figure 4: Overview of the optical module of the LIBS sensor.

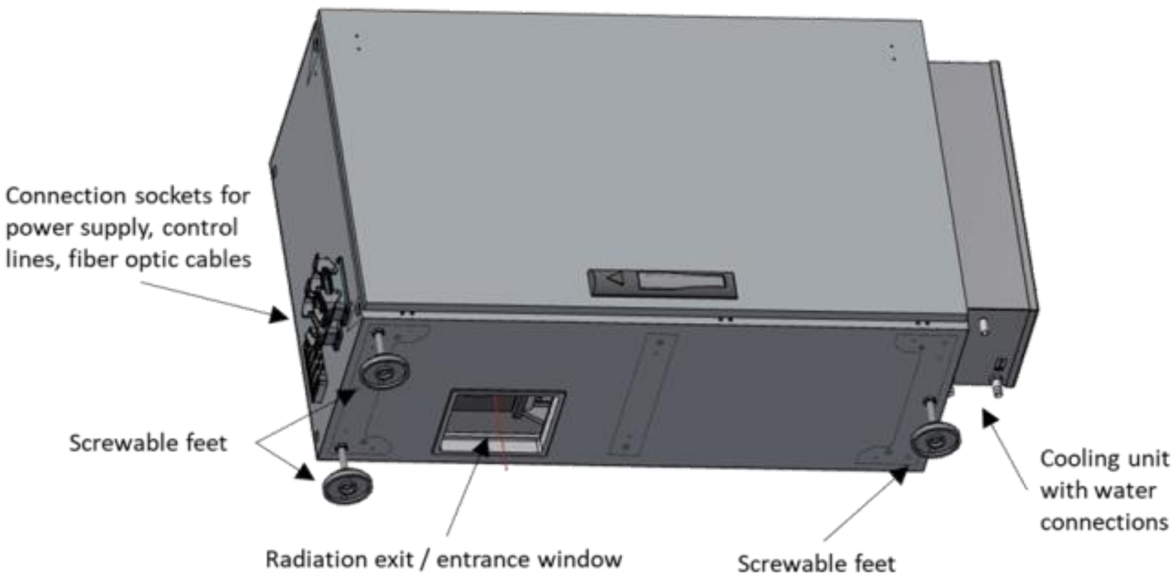

Figure 5: Optical module of the LIBS sensor, bottom view with the laser exit / plasma radiation entrance window. The thin red line indicates the beam pathway.

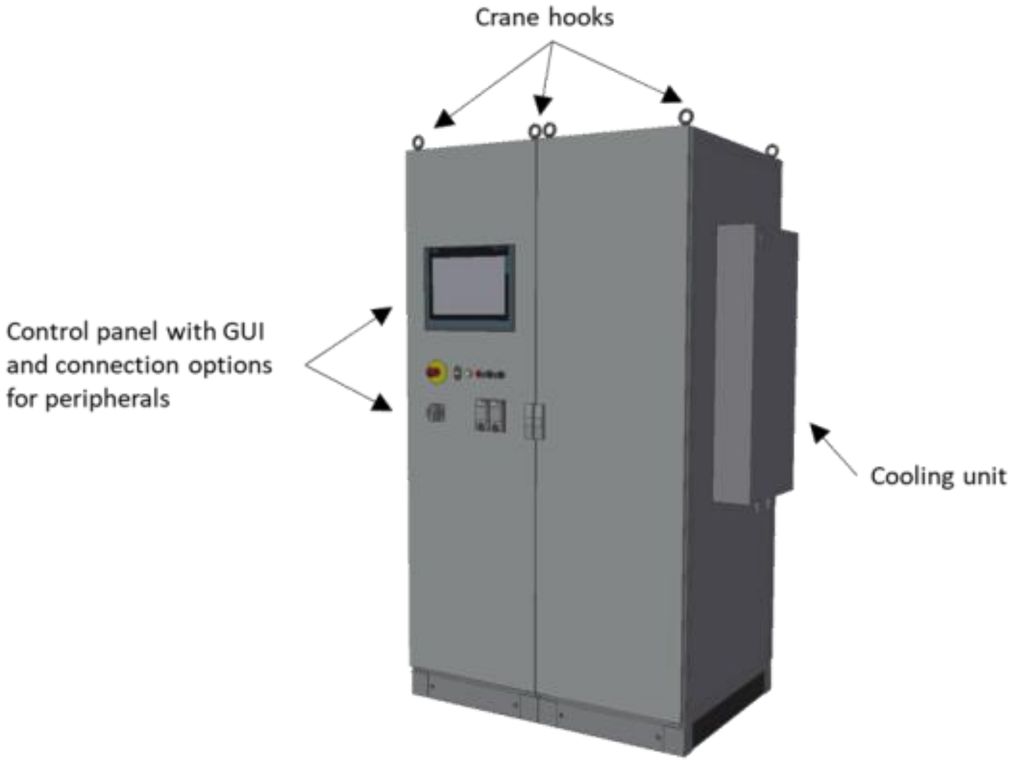

Figure 6: Control module of the LIBS sensor.

Figure 7: Optical module of the LIBS sensor during setup at LSA premises.

Figure 8: Optical module of the LIBS sensor during setup at LSA premises, back view with access hatches for alignment purposes.

The construction of the modules was in part considerably complicated by the difficulties in the supply chains that have existed worldwide since the last calendar year. In addition to general electronic components, such as those used in the laser beam source, the scan module and the spectrometer, this particularly affects standard automation components, such as the industrial control PC, input/output, connection and bus modules. Only a few of these elementary modules could be supplemented from stock or replaced by components similar in construction, which represents a significant additional expense. An additional complicating factor is the limited availability of support due to tight personnel capacities at the suppliers. For these reasons, the construction of the modules is considerably more complex, both in technical terms and in terms of time.

Figure 9 shows an ignited plasma on a test sample. The conveyor belt can be seen in the background.

Figure 9: Ignited plasma on a test sample, ignited with the test setup of the LIBS module.

5. System configuration

In addition to the challenges of material access, the sensor generally also needs a flexible design considering the material composition (main material, alloying elements of interest), material surface condition (clean, dusty), measurement geometry (distance, angle, piece size).

All components of the LIBS sensor have been chosen in order to allow a high flexibility. The optics are adjustable for measuring distance up to 1 meter at least.

The pulsed laser used for excitation uses a patented technology for temporal beam shaping. This is used to optimize the analytical quality of the measurements depending on the material condition. For materials with significant surface contamination, a part of the laser pulse energy can be used for surface pre-cleaning limited to the measurement spot, thereby avoiding disturbing influences of the deviating composition of the contamination layer.

The spectrometer for detection and evaluation of the plasma emission is chosen to be both broadband and of high resolution. This will cover most of the expected materials in the considered applications. Due to its variable design, it can be reconfigured to meet additional needs if necessary.

6. Summary and Outlook

6.1. Summary

The REVaMP partner LSA and ILT have developed, based on consideration of universal retrofitting applications in different processing plants, a design for a LIBS sensor. The design allows operating the sensor in plants which require material analysis on a truck before unloading, as well as plants where material is transported internally by means of a conveyor. The sensor was constructed and implemented.

6.2. Outlook

Within the further course of the REVaMP project, it is planned to operate the LIBS sensor at three different plants. It will be tested at one plant each for the different use cases considered in the project, i.e., aluminium, steel and lead. Through these installations, the different installation concepts and operation modes of the LIBS sensor for retrofitting will be evaluated.

7. Abbreviations

LIBS – Laser-induced breakdown spectroscopy

HMI – Human machine interface