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D11.4 Report on cooperation with research and educational programs

ReSoURCE

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Executive Summary

The ReSoURCE project advances innovative solutions for refractory recycling and circular economy strategies, while strongly integrating education and student engagement into its mission. To achieve these goals, ReSoURCE has been systematically integrated into a range of educational programs across partner institutions, which is the focus of D11.4 “Report on cooperation with research and education programs”. The work reported in this deliverable refers to ReSoURCE project (*Resource - Refractory Sorting Using Revolutionizing Classification Equipment*) in the framework of WP11 – Dissemination and exploitation.

By embedding ReSoURCE themes into academic curricula, the project ensures effective dissemination of results and the development of future experts in refractory recycling. ReSoURCE is incorporated into a range of study programs, from bachelor’s degrees like Mineral Processing and Circular Engineering to master’s and doctoral programs such as PROMISE and the Doctorate in Mining Sciences. Several lectures, including Environmental and Waste Mineralogy and Fundamentals of Mineral Processing, feature project-related content and case studies.

The project is also actively promoted at educational and outreach events, such as the PROMISE Summer School, Long Night of Research, and the Youth Entrepreneurship Week. These activities raise awareness, attract future talent, and emphasize broader themes like climate action and gender equality. Through this educational focus, ReSoURCE strengthens its impact beyond research, fostering a skilled workforce ready to address sustainability challenges in the raw materials sector.

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Introduction

The ReSoURCE project aims to foster innovative approaches for refractory recycling and circular economy strategies. In addition to its research objectives, ReSoURCE emphasizes strong collaboration with educational institutions and student engagement as key pillars of its implementation. By actively integrating the project's themes into academic programs and events, the ReSoURCE consortium ensures both dissemination of its outcomes and cultivation of future professionals in the field.

To this end, the project has been systematically embedded in the curricula of multiple study programs at partner institutions. These range from bachelor's level programs such as Mineral Processing, Circular Engineering, and Responsible Consumption and Production, to advanced master's courses like Environmental and Climate Technology and PROMISE (Erasmus Mundus Joint Master in Sustainable Mineral and Metal Processing Engineering). Doctoral studies, especially within the Doctorate in Mining Sciences, also serve as a platform for in-depth research directly aligned with ReSoURCE's objectives. This deliverable focuses on that in the chapter "Scientific young people".

Several key lectures have incorporated content and case studies from ReSoURCE. Notable examples include "Environmental and Waste Mineralogy," "Fundamentals of Mineral Processing," and the "Seminar on Environmental Technology." These courses not only raise awareness about sustainable resource management but also allow students to engage critically with real-world challenges and data arising from the project. Furthermore, numerous student theses at various academic levels have been developed within the scope of ReSoURCE, evidencing its academic integration and impact. The lectures are introduced in the chapter "lectures" of this deliverable.

Beyond traditional classroom settings, the project has been presented at a range of outreach and academic events. These include the PROMISE Scientific Exchange Day and Summer School, as well as public-facing initiatives like the Long Night of Research and the Youth Entrepreneurship Week hosted by RHI Magnesita. The project's participation in the Ecoality EU initiative further highlights its commitment to addressing broader societal themes such as climate change and gender equality. Events are detailed described in the chapter "Events" oh this deliverable.

The ReSoURCE research partners will present the project in their institutes and related educational programs. Besides raising awareness of the project topic, it will attract students for future vacant positions related to the work program. The project was presented in several lectures which correspond to several study programs. In the study programs theses were written by students, which belong to ReSoURCE project. Furthermore, some events were joined, where the project ReSoURCE was presented.

By embedding itself deeply within educational programs and public engagement activities, ReSoURCE ensures that its scientific contributions reach out beyond the immediate research community. It nurtures a new generation of experts equipped to advance sustainable resource solutions, aligning academic development with the urgent global challenges of environmental stewardship and circular economy transition. Future educational plans are described in the chapter "Further educational plans" of this deliverable.

Scientific young people

The ReSoURCE project has successfully contributed to the development of a new generation of scientific professionals by supporting numerous early-stage researchers (ESR1 and ESR2), as well as guiding students through bachelor's and master's degree programs. Through targeted integration into academic curricula, supervision of theses, and active involvement in research activities, the project has provided valuable training and hands-on experience, equipping young scientists with the skills needed to address future challenges in sustainable resource management.

In the context of research projects, ESR1 and ESR2 refer to Early Stage Researchers at different stages of their academic or professional development:

- ESR1 typically denotes a researcher in the early phase of their career, often a doctoral (PhD) candidate who has not yet been awarded a doctoral degree and has less than four years of research experience.
- ESR2 usually refers to a researcher who is slightly more advanced, possibly a postdoctoral researcher or advanced PhD student, with additional experience beyond the ESR1 level.

These roles are commonly used in European research projects, particularly in programs like Horizon Europe or Marie Skłodowska-Curie Actions (MSCA), to structure researcher training and career development.

- **ESR 2, postdoctoral researcher**
  Karl Friedrich
- **ESR 1, doctoral researcher**
  Florian Feucht
- **Master theses**
  Sheikh Saimon Ahamed Abir, Yannick Conin, Markus Brechlmacher, Zixuan Zhang, Mersal al Halabi and Alireza Razzaghianarmarzi, Andreas Klöckl
- **Bachelor theses**
  Maximilian Sturm, Jens Schindele
- **Internship**
  Zixuan Zhang, Joseph Franklyn

The following tables describe in detail the research and the thesis, which were conducted and written by the people above, starting with ESR 2 postdoctoral researcher and ending with internship.

ESR 2, postdoctoral researcher

Type	ESR 2, postdoctoral researcher
Study program	None; associated to Chair of Mineral Processing
Research area	Electrodynamic fragmentation
Title	Implementation and Continuation of Research area at the chair of mineral processing
Student	Karl Friedrich
Supervisor	Helmut Flachberger
Project partner	MUL
Abstract	Karl Friedrich continued and developed the scientific research area of electrodynamic fragmentation at the Chair of Mineral Processing at Montanuniversitaet Leoben, working on innovative approaches in alternative comminution technologies. A key focus of the research is the upscaling of electrodynamic fragmentation—moving from a laboratory-scale, closed-system batch operation to a semi-industrial, open-system with continuous throughput. In addition, the research included a systematic comparison of electrodynamic fragmentation with conventional comminution methods, evaluating performance, energy efficiency, and material selectivity to assess its industrial applicability.
ReSoURCE-relation	Within the ReSoURCE project, electrodynamic fragmentation was applied specifically to the processing of refractory materials, exploring its potential as a more efficient and selective fragmentation technique.

ESR 1, doctoral researcher*

Type	ESR 1, doctoral researcher (doctoral thesis)
Study program	Doctoral programme in Mining Sciences- Industrial Environmental Protection, Waste Disposal Engineering and Recycling
Research area	Environmental Remediation and Mineral Waste
Title	Chemical and mineralogical characterization of spent refractories
Student	Florian Feucht
Supervisor	Roland Pomberger
Project partner	MUL
Abstract	This thesis investigates strategies to optimize the recycling of spent refractories in Europe through a three-part research framework. The first component focuses on identifying underutilized material flows, including those currently processed internally or landfilled, to enhance resource availability for recycling. A geospatial analysis of refractory waste generation across Europe is conducted to determine optimal locations for deploying the mobile, automated, sensor-based sorting unit constructed during the ReSoURCE project. The second component emphasizes the importance of detailed material characterization to inform the development of a tailored sorting solution. Comprehensive chemical and mineralogical analyses, including scanning electron microscopy of contaminated regions, are performed to assess impurity distributions. Additionally, leaching tests under natural and adjusted pH conditions evaluate the effectiveness of washing treatments to refine processing strategies.

	The final component of this thesis focuses on optimizing the performance of the pilot sorting plant, with particular emphasis on improving particle singularisation, which impacts conveyor belt occupancy, robotic picker utilization, and sorting accuracy. To enable on-site evaluation, a temporary camera system was installed upstream of the sensor array; however, high pixel information density posed challenges for automated analysis. To address this, a segmentation model (YOLO8n-seg) was trained using laboratory images of spent refractories from steel casting ladles and cement rotary kilns. While these training images may not fully represent real-world conditions, the model facilitates automated analysis of particle interactions, enabling data-driven improvements to singularisation and overall system efficiency.
ReSoURCE-relation	The research presented in this thesis was primarily conducted within the framework of Work Package 3 (WP3) of the ReSoURCE project, with additional contributions and insights from other work packages. The primary objective of WP3 was to develop a comprehensive waste management strategy for refractory recycling. This goal was addressed through four main tasks, which are also reflected in the structure of the research chapters in this doctoral thesis. These tasks included: (1) analyzing the waste management system, (2) designing a waste management concept, (3) characterizing spent refractories both chemically and mineralogically, and (4) evaluating the performance of pilot sorting plants.

* This work is still in progress; therefore, the title may change. The abstract should be read as a summary of the work conducted so far, and does not yet reflect ongoing assessments or all relevant details.

Master thesis

Type	Master thesis
Study program	Process, Energy and Environmental Technology
Title	Development of Circular Economy Routes for Refractory Waste
Student	Sheikh Saimon Ahamed Abir
Supervisor	Chandana Ratnayake
Project partner	SINTEF
Thesis Link	https://openarchive.usn.no/usn-xmlui/handle/11250/3079008
Abstract	In this thesis, the focus was on testing cross flow air classification as a direct sorting method for fine powder of spent refractory material from steel and cement industries. Direct sorting was conducted using a cross-flow air classifier and sieving was used for particle size distribution analysis. The performance of the classifier was evaluated at three different air velocities (8, 12, 14 m/s) and it was found that the separation performance was good when the sample had a size range of 5 mm to 0.25 mm. However, the classifier's performance degraded when performed on a narrow size range (1 to 3 mm and 0.5 to 1 mm) for both cement and steel samples. This particle size distribution analysis is important for later chemical analysis and testing to understand the waste materials' properties and enable recycling for further use.

ReSoURCE-relation	The work performed in this thesis was part of Task 7.1 (WP7) in ReSoURCE project to identify and develop suitable direct sorting methods for fine powder of spent refractory materials.

Type	Master thesis
Study program	Data Science in Mechanical Engineering
Title	Conceptualization for sensor fusion of 3D camera, HSI, and LIBS in the recycling of refractory bricks
Student	Yannick Conin
Supervisor	Cord Fricke-Begemann
Project partner	Fraunhofer ILT
Thesis Link	ongoing
Abstract	A variety of different methods and sensors can be used to identify and classify used refractory bricks. In this thesis, the interaction of Laser-Induced Breakdown Spectroscopy (LIBS), Hyperspectral Imaging (HSI) and 3D geometry sensors was investigated. For this purpose, a concept was developed that combines the different sensors by means of sensor fusion. This concept initially involves scanning the surface of the bricks using the 3D geometry sensor and the HSI sensor. Based on this, a decision is made as to where exactly on the surface the LIBS sensor should test the material composition. The measurement results of the HSI and LIBS sensors are analysed using machine learning methods for classification. It is shown that there is a small correlation between the HSI measurements and the predicted LIBS accuracy. Through combination of the sensors, a slight improvement in accuracy and throughput rate can be achieved compared to previous methods based purely on LIBS and 3D geometry.
ReSoURCE-relation	The work performed in this thesis was part of Tasks 6.2 and 6.3 (WP6) in ReSoURCE project to develop suitable software for identification and classification of material.

Type	Master thesis
Study program	Raw Materials Engineering
Title	Coarse Comminution of Refractory Bricks as preparation for Sensor-Based-Sorting: Efficiency Validation of three different Comminution Technologies in Target Particle Size < 120 mm, Energy Demand and Wear Conditions
Student	Markus Brechlmacher
Supervisor	Helmut Flachberger
Project partner	MUL
Thesis Link	ongoing
Abstract	In this thesis, different kinds of primary and secondary refractory raw materials were comminuted by using various crushing equipment. Regarding comminution manner these were done on industrial scale. The aim was to classify three different crushers or rather comminution products considering energy demand and wear conditions. After pre-crushing to an output size of < 120 mm, different kinds of secondary refractory raw materials were comminuted < 40 mm under conditions by using a jaw crusher, cone crusher und impact crusher. On the basis of these findings, the most appropriate crushing equipment was selected for an industrial trial regarding estimated least mass of fines (< 5

	mm). Furthermore, individual primary refractory materials were comminuted by using a laboratory jaw crusher. Carrying on grain shape of defined fraction classes were analysed and evaluated.
ReSoURCE-relation	The work performed in this thesis was part of Task 4.1 (WP4) in ReSoURCE project to validate the comminution efficiency and the grain shapes of refractory breakout particles (< 120 mm) after different comminution processes.

Type	Master thesis
Study program	PROMISE (Erasmus Mundus Joint Master in Sustainable Mineral and Metal Processing Engineering)
Title	Refractory breakouts: Comminution technology validation for MgO-C refractories
Student	Zixuan Zhang
Supervisor	Helmut Flachberger
Project partner	MUL
Thesis Link	https://pure.unileoben.ac.at/en/publications/refractory-breakouts-comminution-technology-validation-for-mgo-c-
Abstract	The recycling of used refractory bricks into high-quality, secondary raw materials can help to reduce the consumption of primary raw materials and thus conserve deposit reserves as well as significantly reduce the CO2 footprint resulting from extraction, preparation and further processing. However, because of their complex compositions and combinations, spent refractory materials are not sorted in an automated manner, but manually instead. The investigations carried out in the course of this master's thesis focused on MgO-C, which is frequently used as a refractory material. During the relining of kilns, a not inconsiderable amount of these used refractory bricks accumulate as waste, which is currently mainly sent to landfill. Since dumping brings up costs, recycling the MgO-C refractory breakouts is also significant from an economic point of view. In this thesis, the focus is on recycling of MgO-C in order to create sufficient liberation conditions for subsequent sorting by applying five different comminution technologies, including electrodynamic fragmentation on lab-scale, electrodynamic fragmentation on semi-industrial scale, impact crusher, cone crusher and jaw crusher. In order to detect apparent colour differences, the samples were examined separately under a microscope before and after the density tests. Preliminary investigations showed that the first completely free phases of MgO-C could already be present from a size of less than 4 mm. The final particle fractions used in the course of raw material characterisation and for separation tests are 4 - 3.15 mm and 3.15 - 1 mm respectively. Float/sink analyses were performed by using the density differences of the phases contained in MgO-C. In order to detect apparent colour differences, the samples were examined separately under a microscope before and after the float/sink analyses. The samples were then investigated for Magnesia and Carbon enrichment using XRF and LECO. Finally, it was determined which is the most suitable for comminuting these refractory bricks. It also defines the particle sizes and density ranges that are best for generating enriched MgO and Carbon.

	As expected, the Henry-Reinhardt diagrams show that carbon is enriched in < 3.0 g/cm^3 while Mg is enriched in > 3.0 g/cm^3. Extensive fractional class analyses were applied to some of the produced fractions of the comminution products in order to determine the comminution technology that best favours the liberation of the contained phases and the subsequent separation. The results suggest that both jaw crushers and cone crushers are suitable aggregates for this essential process step.
ReSoURCE-relation	The work performed in this thesis was part of Task 4.1 (WP4) in ReSoURCE project to validate the liberation of refractory breakout particles (< 4 mm) after different comminution processes.

Type	Master Group Project
Study program	Faculty of Technology, Natural sciences, and Maritime Sciences
Title	Development of sorting/separation methods for refractory wastes – Circular Economy for Refractory Industry
Student	Mersal al Halabi and Alireza Razzaghianarmarzi
Supervisor	Chandana Ratnayake
Project partner	SINTEF
Abstract	Sorting and separating particles into different streams and sizes contributes to the circular economy and, as a result, reduces the carbon footprint produced by raw materials. The goal of this project is to create sorting and separation methods for refractory waste materials with sizes less than 0.5 mm. Cross-air flow classification technology in addition to sieving technology were used to classify and know the size distribution of a sand material with size ranging from 0.2 to 1mm. Two different air flow rates, as well as three different sand flow rates, were tested to see how they affected the classification process. The results demonstrated that sieving technology is a good and acceptable method for determining the size distribution of a material with a wide range of particle sizes. Furthermore, the flow rate in the cross-air flow classification technology was observed to have a significant impact on the distribution process. The process is influenced not only by the air flow rate, but also by the plate orientation and sand density. As a result, these variables are mutually dependent, and knowing the ideal flow rates and angles for testing a refractory waste material is vital.
ReSoURCE-relation	The work performed in this project was a preliminary study related to the Task 7.1 (WP7) in ReSoURCE project to identify and develop suitable direct sorting methods for fine powder of spent refractory materials.

Type	Master thesis (ongoing)
Study program	Environmental and Climate Protection Technology
Title	Conceptualization of an evaluation scheme for separation aggregates in spent refractory recycling
Student	Andreas Klöckl
Supervisor	Philipp Sedlazeck Roland Pomberger Simone Neuhold Florian Feucht
Project partner	MUL

Abstract	As part of this master's thesis, a framework will be developed to evaluate the singularization of input materials in a sorting system. The thesis is conducted within the scope of the EU-funded project ReSoURCE ("Refractory Sorting Using Revolutionising Classification Equipment"), which focuses on the automated, sensor-based sorting of used refractory materials. Within the project, a sorting system is being designed and constructed, and various parameters, such as material singularization, are to be assessed. The first step involves a literature review to identify the parameters that influence both singularization and subsequent sorting performance. To enable the evaluation of singularization, data acquisition is required. For this purpose, a camera setup will be developed that is easy to assemble and disassemble while ensuring sufficient data quality for subsequent analysis. Additionally, a framework will be designed to assess the singularization of input materials, taking into account factors such as the reach radius of robotic pickers responsible for the actual sorting process. For data analysis and evaluation, open-source software (e.g., ImageJ) will be utilized, with a focus on enabling simple automation. Initial automation attempts, such as macros or scripts, will also be developed. The proposed evaluation framework will be tested for its applicability through a series of experiments conducted on the sorting system.
ReSoURCE-relation	The work performed in this thesis was part of Task 3.4 (WP3) of the ReSoURCE project. The trained segmentation model, along with the subsequent data evaluation, supports the assessment of Demo A and contributes to its optimization.

Bachelor thesis

Type	Bachelor thesis
Study program	Mineral Resources Engineering
Title	Evaluation of separation processes for MgO-C and Hercynite leftovers, as well as MgO-C and Hercynite crushed material in the grain size range < 5 mm.
Student	Maximilian Sturm
Supervisor	Karl Friedrich
Project partner	MUL
Abstract	This bachelor thesis deals with the separation methods of samples that arise from refractory breakouts in steel casting ladles and cement rotary kilns. These samples consist of various components such as magnesium oxide (MgO), graphite (C), spinel ($MgAl_2O_4$), calciumsilicate ($CaSiO_3$), and silicon oxide (SiO_2). The thesis investigates the separation methods employed in the research project ReSoURCE, including air separation tables, lab shaking tables, corona drum separators, flotation and weak-field magnetic separators in order to separate the samples into their individual components. Separation attempts using the air separation table did not yield meaningful results, as the material was only separated by particle size for both of the materials. No results could be achieved with the weak-field magnetic separator. The separation method using the corona drum separator achieved separation only for the MgO-C fraction. Hercynite could not be separated using this method.

	Despite extensive literature research, the hercynite sample could not be separated through flotation. However, the MgO-C sample was successfully separated using flotation. The lab shaking table also successfully separated the material into both fractions (Hercynite and MgO-C). However, after evaluating the results, it was determined through chemical analysis that separation occured, but it was not meaningful and the output materials were not separated into individual fractions.
ReSoURCE-relation	The work performed in this thesis was part of Task 7.1 (WP7) in ReSoURCE project to validate sorting technologies for refractory fine fraction < 5 mm.

Type	Bachelor thesis (ongoing)
Study program	Applied Geoscience
Title	Comparison of the leaching behavior of different refractory materials
Student	Jens Schindele
Supervisor	Florian Feucht Phillipp Sedlazeck Johann Raith
Project partner	MUL
Abstract	The aim of this bachelor's thesis is to investigate the leaching behavior of various spent refractory materials. Furthermore, the study seeks to determine whether differences in leaching behavior can be linked to the mineralogy of the materials and their original application site (e.g., rotary kilns in the cement industry). Refractory materials tend to get infiltrated by different elements depending on their application environment, some of which may be classified as "undesirable" in potential downstream recycling processes. These "undesirable" elements are likely derived from the raw materials used in production as well as from alternative fuels employed during operation. To address these questions, leaching tests will be conducted on different used refractory materials in accordance with the ÖNORM EN 12457-4 standard. The results will be compared with each other and with data derived from literature. Additionally, the origins of the elements identified as undesirable will be investigated by analyzing the chemical composition of the alternative fuels and raw materials used in the production process.
ReSoURCE-relation	The work conducted in this thesis was part of Task 3.3 (WP3) of the ReSoURCE project, focusing on investigating the leaching behavior of chemically distinct refractories. This work contributed to the detailed material characterization outlined in Task 3.3.

Internship

Educational level	Master student
Project partner	MUL
Person	Zixuan Zhang
Tasks	As part of the ReSoURCE project, Zixuan Zhang completed an internship in which she actively contributed to the processing and data evaluation of the semi-industrial electrodynamic fragmentation trials. Her work focused on supporting the practical implementation of this comminution technology, including the preparation and handling of refractory materials, as well as the

	systematic analysis and interpretation of process data. Through her involvement, she gained hands-on experience with advanced fragmentation methods and contributed valuable insights to the ongoing research within the project.
ReSoURCE-relation	The work performed in the internship was part of Task 4.2 (WP4) in ReSoURCE project to validate data and further process the refractory fraction after the semi-industrial trial of electrodynamic fragmentation

Educational level	Master student
Project partner	CPI
Person	Joseph Franklyn
Tasks	The main task related to ReSoURCE involves the LCA/TAE topic, supporting data gathering and cataloguing from multiple deliverables. This initial check ensures that all aspects have been considered while performing some basic engineering calculations needed before determining the final model.
ReSoURCE-relation	The work performed was mainly dedicated to WP2 and directly used in the two deliverables to be prepared towards the end of the project, namely D2.2 and D2.3.

Lectures

Within the ReSoURCE project, key topics and research findings were actively integrated into academic teaching across various study programs. By incorporating ReSoURCE-related content into lectures, the project not only contributed to knowledge transfer but also inspired student interest in sustainable raw material processing and circular economy approaches. These lectures served as platforms to present real-world applications, case studies, and current research challenges directly linked to the project. Below is a list of lectures in which ReSoURCE was introduced or used as a reference within the academic curriculum.

Type	Bachelor program, graduate program
University	MUL
Study program	Circular Engineering, Responsible Consumption and Production
Lecture	Introduction to processing of particulate solid matter
Description	The principles of separation and separation processes to recover valuable products from mechanically comminuted primary and secondary raw materials using differences in physical and physico-chemical properties are explained, following the unit operations well known from mineral processing: comminution, classification, sorting and solid liquid and solid gas separation respectively. The principles are based on a number of selected exercises and experiments during the integrated lecture to increase the understanding as well as to introduce basic processing calculus (mass balancing, slurry description, property distributions) necessary to write and understand processing reports. A focus is put on processing circuits and energy expense. Each unit operation will be illustrated by a significant industrial upgrading process circuit.
ReSoURCE-relation	Basic knowledge of the principles in processing of primary and secondary solid matter; its physical and physico-chemical background, ability to do simple processing calculus and understand the principles of processing circuits for upgrading particulate solid matter

Type	Master program, undergraduate program
University	MUL
Study program	PROMISE
Lecture	Project study mineral processing
Description	Comprehensive treatment of a mineral processing problem according to the standard of an industrial pre-feasibility study, beginning with the evaluation of the feed properties and finally leading to an economic assessment of the project.
ReSoURCE-relation	Practical laboratory and technical facility work with processing aggregates that are used in primary and secondary raw material processing.

Type	Master program, graduate program
University	MUL
Study program	Raw Materials Engineering
Lecture	Fundamentals of mineral processing
Description	Characterization of dispersed mineral matter: Composite and fractional analyses. Generalized Henry-Reinhardt Diagram. Separations: Balances of mass flow and contents. Tromp partition curves. Comminution physics. Motion of particles in fluids and suspensions. Kinetics of the various separation processes.
ReSoURCE-relation	Knowledge in fundamentals of minerals processing.

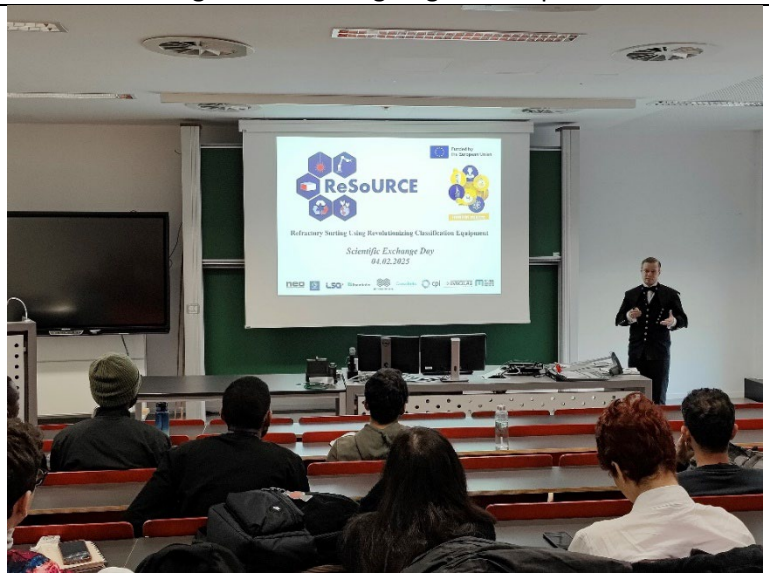
Type	Master program, graduate program
University	MUL
Study program	• Environmental and Climate Protection Technology • Applied Geosciences
Lecture	Environmental and Waste Mineralogy
Description	Introduction to environmental and waste mineralogy of natural minerals and synthetic mineral phases, applications in contaminated site remediation and landfill technology, mineralogy of metallurgical slags, secondary waste materials, and rocks as waste (e.g., tunnel excavation), as well as polarization microscopy.
ReSoURCE-relation	This lecture explores the integration of waste processing technologies and waste management with advanced methodologies commonly employed in mineralogy. This approach enables the detailed characterization necessary to address waste-related challenges effectively.

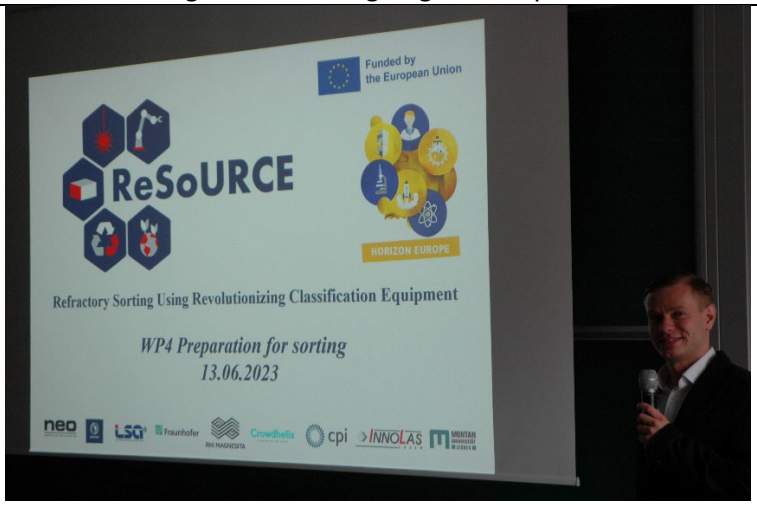
Type	Master program, graduate program
University	MUL
Study program	Environmental and Climate Protection Technology
Lecture	Seminar on environmental technology
Description	Presentation and discussion of ongoing research and project work (dissertations, master's theses, and selected commissioned research) conducted by the Chairs of Process Technology and Industrial Environmental Protection as well as the Chair of Waste Processing Technology and Waste Management.
ReSoURCE-relation	The ReSoURCE project, with a focus on the work carried out in WP3, was presented. The methodologies employed were outlined, and future challenges were discussed with professors and students.

Type	Master program, graduate program
University	RWTH Aachen University in cooperation with ILT
Study program	Mechanical engineering and physics
Lecture	Basics and design of optical systems
Description	Basic, modeling and realization of optical systems, using geometric and wave optics, and ray tracing tools
ReSoURCE-relation	Multi-Sensor-System from ReSoURCE as an example for complex optical system layout

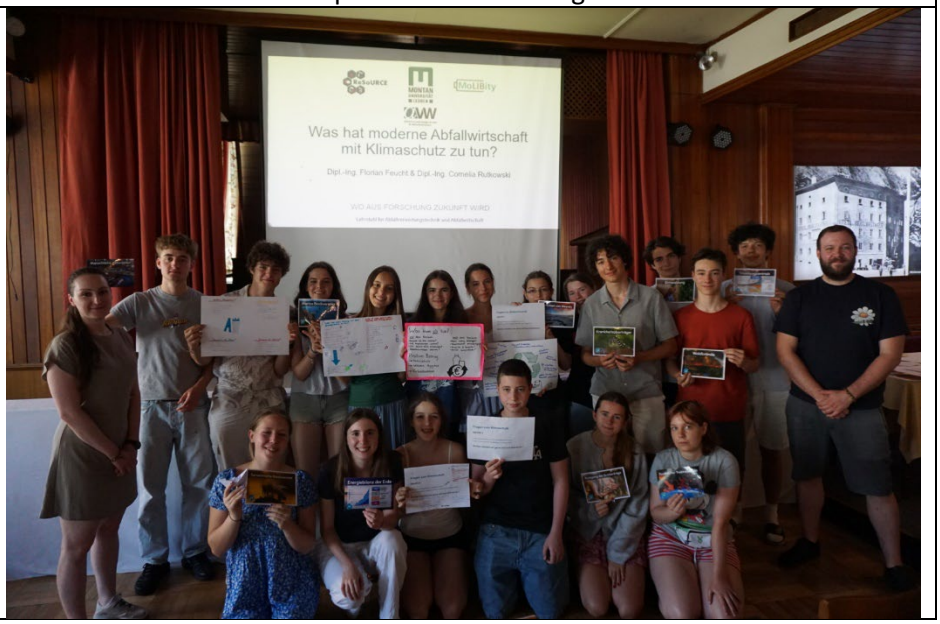
Events

As part of the ReSoURCE project, a variety of events were organized and attended to promote the project's objectives, share research outcomes, and engage with both the scientific community and the broader public. These events played a key role in raising awareness about sustainable raw material use, circular economy practices, and innovative processing technologies. They also provided valuable opportunities for knowledge exchange, student involvement, and interdisciplinary collaboration. Below listed are events related to the ReSoURCE project, including scientific, educational, and public outreach activities.

Type	International event
Event name	PROMISE scientific exchange day
Project partner	MUL
Duration	07 February, 2023; 13 February 2024; 04 February 2025
Description	The PROMISE scientific exchange day at Montanuniversitaet Leoben is a central event within the Erasmus Mundus Joint Master Programme in Sustainable Mineral and Metal Processing Engineering (EMJM PROMISE). Held during the program's welcome week, it provides an interactive platform for students to engage with current research activities at the Chair of Mineral Processing. This exchange fosters interdisciplinary dialogue and encourages students to apply their learning to real-world challenges in sustainable mineral processing.
ReSoURCE-relation	The event features presentations on ongoing projects, including innovative topics like electrodynamic fragmentation and refractory recycling, offering students firsthand insights into cutting-edge developments in the field.
Image	

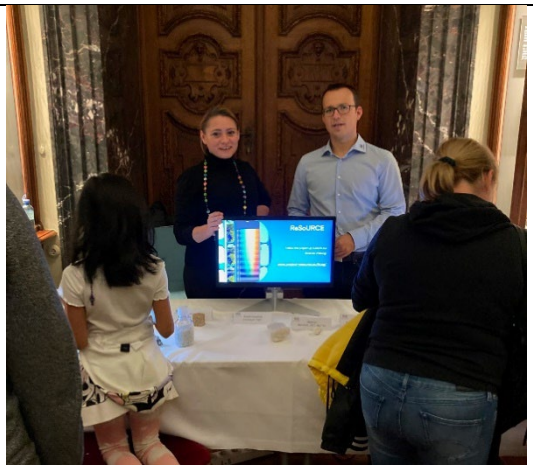
Type	International event
Event name	PROMISE summer school
Project partner	MUL
Duration	23 June, 2023
Description	The PROMISE Summer School at Montanuniversitaet Leoben is an intensive educational program designed for students enrolled in the Erasmus Mundus Joint Master Programme in Sustainable Mineral and Metal Processing Engineering (EMJM PROMISE). Hosted by the Chair of Mineral Processing, the summer school offers a combination of lectures, hands-on laboratory sessions, and site visits, providing participants with practical experience in advanced mineral processing techniques. Topics covered include sustainable resource management, innovative comminution methods, and circular economy principles. The program fosters interdisciplinary collaboration and equips students with the skills necessary to address current challenges in the mineral and metal processing industry.
ReSoURCE-relation	The event features presentations on ongoing projects, including innovative topics like electrodynamic fragmentation and refractory recycling, offering students firsthand insights into cutting-edge developments in the field.
Image	

Type	National event
Event name	School Climate camp as part of the EU-funded Ecoality project
Project partner	MUL
Duration	13 – 17 June 2025 15 June 2025 (Participation duration for MUL)
Description	The EU-funded Ecoality project ("Youth and Local Authorities Together for Climate and Gender Justice") was developed to foster collaborative solutions to global crises. The project addresses global crises by highlighting the interconnectedness of environmental and social issues, such as gender inequality and climate change, which disproportionately impact vulnerable populations. It emphasizes the need for collaborative solutions to tackle these multidimensional inequalities. The project unites youth and local authorities from 10 European countries to examine the links between gender and climate justice. Through this collaboration, young people and local government representatives work together to advocate for greater equity in both gender and climate-related issues. The project is being implemented in Austria, Italy,

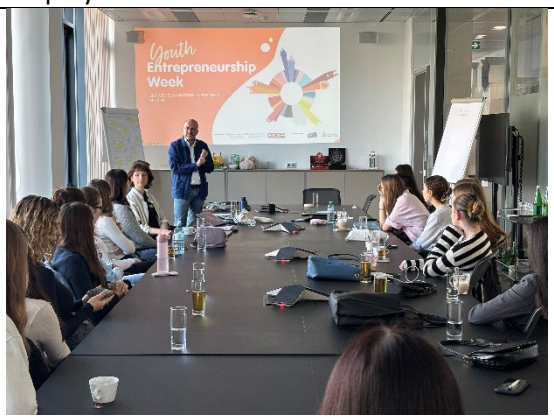
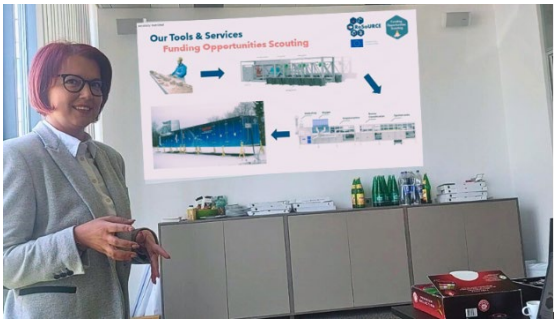
	Greece, Portugal, France, Finland, Hungary, Romania, Croatia, and Poland through a partnership between NGOs and local authorities. As part of the initiative, the Austrian organization Südwind organized a climate camp for pupils in collaboration with local organizations from the Salzburg region of Pongau. The Chair of Waste Processing Technologies and Waste Management was invited to contribute and led a session titled "How is waste management connected to the circular economy and environmental protection?" The session will feature the interactive "Climate Fresk" workshop, followed by a brainstorming phase where pupils will propose solutions. A concluding lecture highlighted current research projects, such as the ReSoURCE project, and their contributions to climate and resource protection. The aim was to emphasize the importance of these efforts and inspire pupils to consider studies in environmental and climate protection technologies at Montanuniversität Leoben.
ReSoURCE-relation	The ReSoURCE project was presented as a pioneering recycling-driven initiative that complements the goals of the Ecoality project. By highlighting its objectives, environmental benefits, and practical applications, the participation aimed to motivate pupils to consider academic studies at Montanuniversitaet Leoben, preparing them to tackle future challenges in climate and environmental protection technologies.
Image	

Type	National event
Event name	Thursday's Talk of the faculty of civil engineering (Technical University Graz)
Project partner	MUL
Duration	10 April, 2025
Description	Together with other projects from the Chair of Waste Processing Technology and Waste Management within the working group "Environmental Remediation and Mineral Waste," the ReSoURCE project was presented during the "Thursday's Talk" series at the Faculty of Civil Engineering at the Technical University of Graz. The lecture, delivered by the working group leader Dr. Philipp Sedlazeck, emphasized the importance of advanced mineralogical methods in addressing waste management challenges. Detailed chemical and mineralogical characterization of individual waste streams

	forms the foundation for identifying potential recycling and utilization pathways in numerous projects. By thoroughly analyzing waste, its use as a secondary raw material can be promoted, enabling previously landfilled or underutilized waste streams to be repurposed as valuable resources.
ReSoURCE-relation	The ReSoURCE project, with a focus on the work carried out in WP3, was presented. The methodologies employed were outlined and discussed with professors and students.
Image	-

Type	National event
Event name	Long night of museums
Project partner	RHIM
Duration	1 October, 2022
Description	The Long Night of Museums in Vienna, including over 120 museums and cultural institutions across Vienna opened their doors to the public, offering a unique opportunity to explore a wide array of exhibitions and activities. The event had special guided tours, workshops, and interactive programs tailored for both adults and children. The Long Night of Museums in Vienna not only celebrated art and culture but also highlighted the importance of research and science. Many participating institutions showcased scientific advancements and research projects through interactive exhibits and workshops. The participant institutions provided visitors with a deeper understanding of scientific research and its impact on society. Details on the event are available also on the ReSoURCE blog, Outreach Tool Ideas for ReSoURCE.
ReSoURCE-relation	ReSoURCE project was part of the section dedicated to national and international cooperation projects. The aim was to show children, and young professionals, the importance of research and science, and its impact. Additionally, the participants had the chance to see raw materials RHIM is using and the actual waste that will be analysed as part of the project.
Image	

Type	RHIM internal event – regional initiative
Event name	Youth Entrepreneurship Week
Project partner	RHIM

Duration	12 – 16 May, 2025
Description	The Youth Entrepreneurship Week (YEW) is an initiative to introduce teenagers in Austrian education facilities to the topic of entrepreneurship to teach them self-efficacy and help them realize their potential. RHI Magnesita was hosting 2025 edition organised by AustrianStartups, which gave the opportunity of 25 young women to gain insights of how the entrepreneurial spirit is cultivated and valued in a corporate environment.
ReSoURCE-relation	ReSoURCE project was presented as a success story of how innovative minds from RHIM can join efforts with international universities and companies for building to live a disruptive equipment with high impact not only for the business, and technical advancement, but also to the quality of life of employees.
Image	 

Details on the events presented above will be available in deliverable D11.3 - Final report on dissemination, communication, and exploitation due at the end of the project.

List of publications

(1) Feucht, F., Moderegger, R., Neuhold , S., & Sedlazeck, K. (2025). Analysing material flows and final fate distribution of spent refractories from steel casting ladles and cement rotary kilns in Europe. Resources, Conservation and Recycling, 215, 108158.

Link: https://doi.org/10.1016/j.resconrec.2025.108158

(2) Feucht, F., Neuhold,, S., Leitner, A., Fricke-Begemann, C., & Hernandez, J. (2024). The heat is on! - From the material characterisation of spent refractory bricks to sensor training (practical examples from Project ReSoURCE). Conference proceedings of the 17th Recy & DepoTech conference (p. 517).

Link: https://pure.unileoben.ac.at/en/publications/the-heat-is-on-from-the-material-characterisation-of-spent-refrac

(3) Leitner, A., Neuhold, S., Heid, S., Gavagnin, D., Meschik, P., Stastny, R., Zocratto, B. Moraes, M. (2024). Enhancing Refractory Recycling: The Role of Automated Sensor-Based Sorting Systems. RHI Magnesita Bulletin, pp. 41-46.

Link: https://www.rhimagnesita.com/the-bulletin-blog/enhancing-refractory-recycling/

(4) Søiland, K., Hafenbrädl, F. O., Srivastava, A. K., & Ratnayake, C. (2024). Enhancing Recycling Efficiency of Residual Refractory Materials: Experimental Methods and Fine Particle Classification Techniques. Proceedings of the 11th International Conference on Conveying and Handling of Particulate Solids (p. 207). Edinburgh, UK: School of Engineering, University of Edinburgh.
DOI: 10.5281/zenodo.14034595

(5) Neuhold, S. F., Leitner, A., Feucht, F., Sedlazeck, K. P., Mörkens, V., Dargel, M., Makowi, J., Adamek, D., & Hernandez, J. (2024). Sustainable Refractory Recycling: Innovative Solutions for a Circular Economy. (D.-I. Thiel, Ed.) Mineralische Nebenprodukte und Abfälle 11 – Aschen, Schlacken, Stäube und Baurestmassen –, pp. 114-126.

Link: Fachbeitrag_Neuhold_MNuA11.pdf

(6) Feucht, F., Sedlazeck, P., Friedrich, K., Sattler, T., & Pomberger, R. (2023). At the beginning of Project ReSoURCE. Tagungsband 12. WISSENSCHAFTSKONGRESS (pp. 217-221). Innsbruck university press.
DOI:10.15203-99106-095-6 (Link)

(7) Flachberger, H., Friedrich, K., Feucht, F., Pomberger, R., Sedlazeck, P., Heid, S., Konigshofer, S., & Leitner, A. (2023). ReSoURCE: Ein Projekt um die Wertschöpfungskette in der Feuerfestindustrie zu schließen. In P. Gradischnig (Ed.), Forum Mineralische Rohstoffe, (p. 11). Link: Stein_Kies_184_web.pdf

(8) Friedrich, K., & Flachberger, H. (2023). Elektrodynamische Fragmentierung als alternative Zerkleinerungslösung für das Recycling von Feuerfestmaterial. agungsband „Tagung Aufbereitung und Recycling“ – 16. und 17.11.2023 (p. 23). Freiberg: UVR-FIA GmbH. Link: https://uvr-fia.de/wp-content/uploads/2024/01/Tagungsband-2023-11-09-23-b.pdf

Further educational plans

The ReSoURCE project has the potential to significantly influence the design and content of future study programs, particularly in the area of refractory recycling and sustainable raw material management. By demonstrating innovative approaches such as electrodynamic fragmentation, closed-loop material flows, and digital tracking of material streams, the project introduces advanced concepts that can be integrated into educational curricula. Future study programs—especially in fields such as mineral processing, circular engineering, and environmental technology—can benefit from these insights by incorporating dedicated modules on refractory recycling, sustainable comminution technologies, and lifecycle analysis of industrial materials.

Moreover, ReSoURCE promotes interdisciplinary learning by bridging materials science, process engineering, environmental impact assessment, and digital innovation. This integrated perspective prepares students for the complex challenges of resource efficiency and industrial sustainability. Through hands-on experience, real-world case studies, and the inclusion of current research outcomes in teaching, future curricula can offer students practical and research-oriented education. As industry demand for circular economy solutions continues to grow, graduates equipped with knowledge and skills developed through ReSoURCE-based content will be well-positioned to drive innovation and lead transformation in the raw materials sector.

Conclusion

The ReSoURCE project has demonstrated a strong and effective integration of its research themes into educational programs and activities across partner institutions. Through targeted cooperation with universities and research institutions, the project not only disseminated its scientific results but also contributed meaningfully to the training and development of future experts in the field of refractory recycling and sustainable raw material processing.

Over the course of the project, seven student theses—including five master's theses, one bachelor's thesis, and one group project—were successfully completed within the framework of ReSoURCE. Additionally, two early-stage researchers (ESR)—one ESR1 (doctoral researcher) and one ESR2 (postdoctoral researcher)—carried out in-depth research on innovative topics such as electrodynamic fragmentation, sorting technologies, and circular economy applications for refractory materials. These academic contributions highlight the project's strong alignment with educational advancement and skills development.

ReSoURCE content was also incorporated into at least six university lectures spanning bachelor's, master's, and doctoral study programs. These lectures covered topics such as mineral processing fundamentals, environmental and waste mineralogy, and sensor-based sorting, allowing students to directly engage with real-world research challenges presented in the project.

Beyond formal education, ReSoURCE was actively presented in five major events, including the PROMISE Scientific Exchange Day, PROMISE Summer School, Long Night of Research, Equality (EU project), and the Youth Entrepreneurship Week hosted by RHI Magnesita. These events reached diverse audiences—from international students to the general public—and served as important platforms for knowledge exchange, public engagement, and awareness-raising on sustainability and innovation in the raw materials sector.

Overall, Deliverable D11.4 demonstrates that the ReSoURCE project made a significant impact on education and capacity building, helping to cultivate a new generation of professionals prepared to address the challenges of circularity and environmental responsibility in raw material value chains. Its

success provides a strong foundation for shaping future study programs and fostering continued collaboration between academia and industry.