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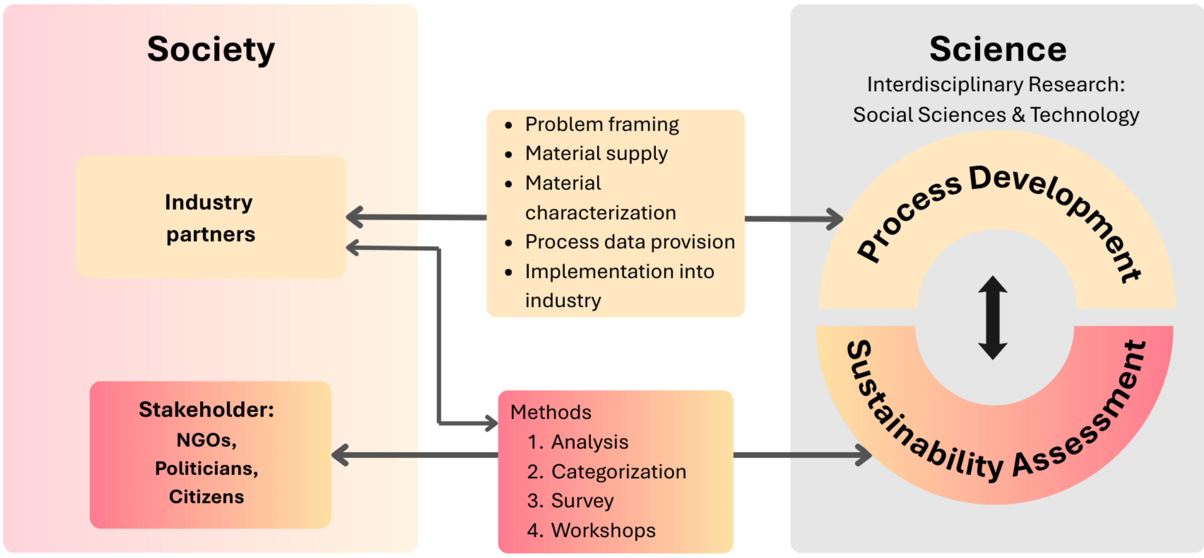
Transdisciplinary Research Approach

Resilient Recycling of Waste Materials

Due to resource scarcity, decarbonization, the need to minimize landfill volumes, and other current issues, it is becoming increasingly important not only to conduct interdisciplinary research into solutions but also to develop transdisciplinary research approaches to meet not only the needs of the industries but also the needs of the society. This approach is based on current projects.



Information Consultation Co-Creation

Transdisciplinary Approach:

Transdisciplinary Exchange

Phase 1: Problem identification and goal setting

Phase 2: Knowledge production

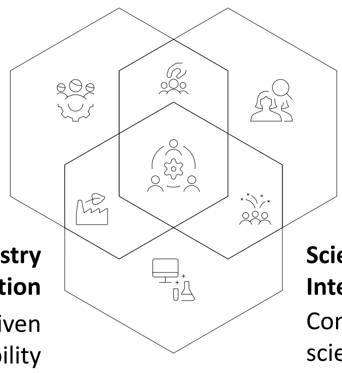
Phase 3: Implementation of new knowledge

Industry-Community Partnerships

Tailored solutions for local needs

Industry partners

Co-creation of knowledge in all 3 phases



Stakeholders

Information and consultaion level of participation

Science-Industry Innovation

Technology-driven sustainability

Science-Community Interaction

Community informed science

Science

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Montanuniversität Leoben | TPT Thermoprozesstechnik | SDS Safety and Disaster Studies

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Thermal Processing Technology

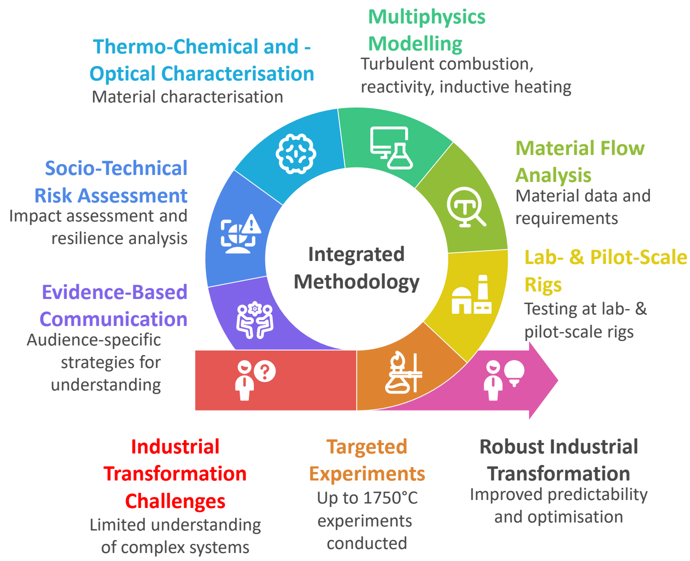
From high-temperature processes to safe, efficient industry – science powering sustainable transformation

The Chair of Thermal Processing Technology (TPT) designs, models, and optimises high-temperature processes and industrial furnaces to reduce CO_2 emissions, minimise air pollutants, and recover critical resources, ultimately delivering safer, more efficient, and circular technologies for energy-intensive industries.

Research groups – One Chair, Four Strengths

- High-Temperature Process Technology (HTPT): thermochemical treatment and scale-up from lab to pilot.
- Combustion and Furnace Technology (CFT): low-emission burners and hybrid heating for existing and new furnaces.
- Computational Engineering (CE): computational fluid dynamics (CFD), Fast-Calc and machine learning (ML) for real-time insight and optimisation.
- Safety and Disaster Studies (SDS): technical and social safety – from explosion modelling to risk communication.

End-to-End Methodology for Process Optimisation



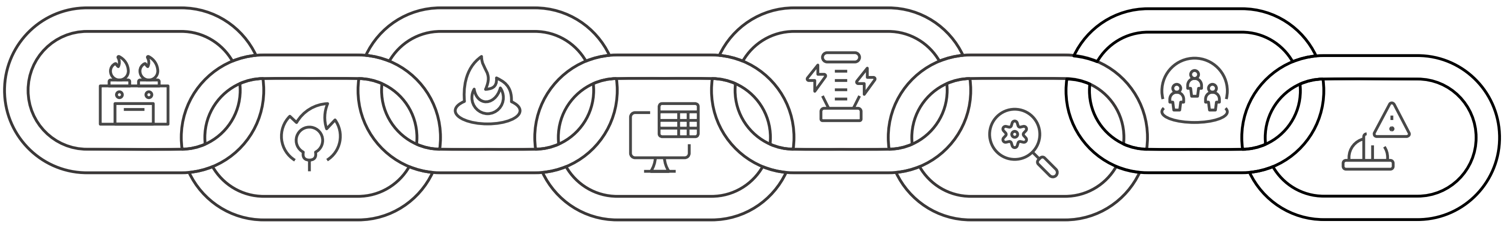
Key Innovations and Impact

Hybrid Heating
Combining electric and firing methods for renewable energy integration.

Next-Generation Burners
Developing advanced burner designs for hydrogen operation.

Thermochemical Treatment
Recovering valuable materials from residue streams.

Social Dimensions of Risk
Improving risk communication and participation.



NO_x-Smart Hydrogen Firing
Minimising NO_x emissions during hydrogen co-firing.

Fast-Calc + Machine Learning
Utilising physics and data models for rapid industrial optimisation.

Thermal Characterisation
Developing innovative methods for thermal analysis.

Safe Material Handling
Ensuring safe storage and transport of new materials.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High-Temperature Process Technology (HTPT)

High-temperature processing for material efficiency, emissions reduction, and circular value

Why high temperature?

- At > 500 °C reaction pathways become accessible and selectable, enabling full or selective conversions, target product quality, and higher energy/material conversion efficiency.
- Mission: reduce product material and CO_2 intensity and realise disruptive processes

High-Temperature Processes – Fossil fuel-dependent, CO_2 intensive

Sectoral Application – Iron & steel, non-ferrous, cement, glass, waste

Thematic Integration – energy & material efficiency, recycling, CO_2 reduction

Sustainable HTPT – Fossil fuel-free, CO_2 efficient

Research Highlights and Case Studies

1. Phosphorus Recovery – **PHOBOS**: Phosphorus recovery from sewage-sludge-derived materials
2. Lithium Recovery – **FuLiBatteR**: Lithium recovery from black mass
3. Zinc Recovery – **ReMFra**: Zinc recovery from steelworks dust via pyrometallurgy
4. Slag to Reactive Binder Material – **$GECCO_2$**: Utilisation of mineral residues into building materials
5. Material and Process Characterisation – **BitKOIN**: Thermochemical and -physical characterisation of mineral wool waste
6. Data- and AI-driven Utilisation Optimisation – **MINREC-HT**: Thermochemical treatment of mineral residues
7. Green Steelmaking – **H2PlasmaRed**: Development of a CO_2-free steelmaking routes

Core Pilot and Lab Rigs

- InduMelt: inductively heated crucible furnace, 1700 °C
- InduRed: inductively heated packed-bed reactor, 1700 °C
- RecoDust Flash-Reactor: natural gas/H_2/O_2-burner, 1800 °C
- Cooling/solidification: dry and wet granulation

Instrumentation and Analysis

- Resistance elevator furnace, 1750 °C
- Thermo-optical analysis (heating microscope), 1600°C
- Simultaneous thermal analysis (STA), 1750 °C
- High-T imaging: IR camera and video systems for real-time process observation

Methods – Data and Process

- Design of experiments
- Thermochemical and thermophysical characterisation and treatment
- Mass/energy flow analysis
- Predictive model development
- Real-time process characterisation

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H2PLASMARED – Funded by the European Union – Horizon Europe Grant Agreement No. 101138228

ReMFra – Recovering metals and mineral fraction from steelmaking residues – Funded by the European Union – Horizon European Clean Steel Partnership Grant Agreement No. 101058362

FFG Promoting Innovation.

BitKOIN

BatteR

PHOBOS – PHOSPHORUS RECOVERY & BINDER PRODUCTION

Residue2Binder

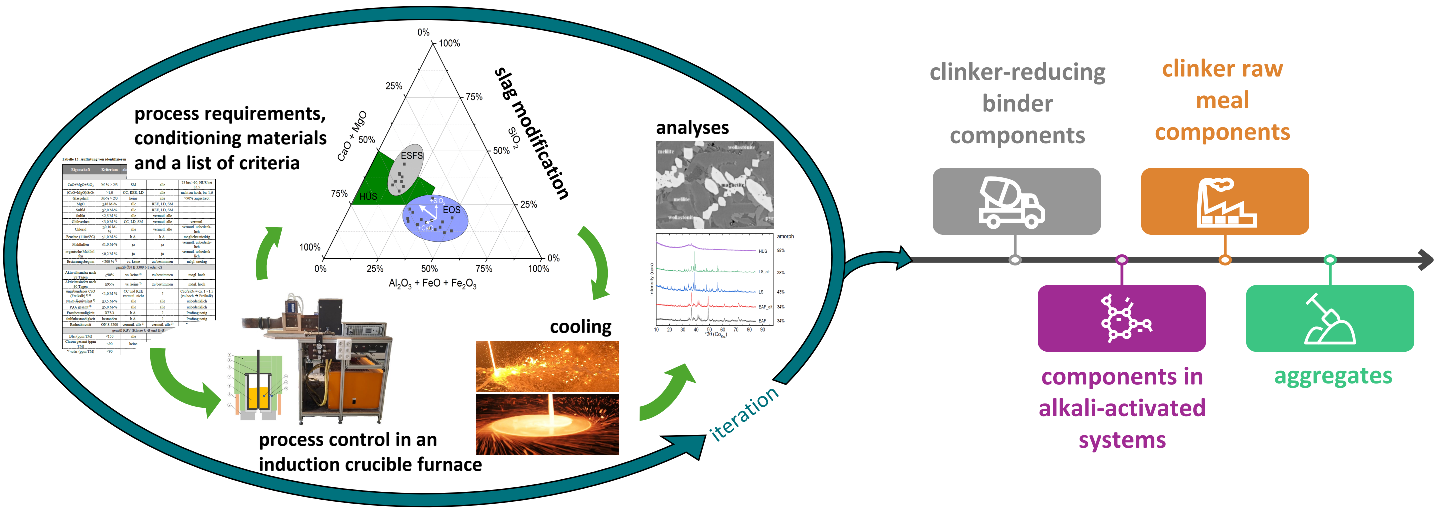
Valorising Mineral Residues into Secondary Raw Materials for the Building Material Industry

Introduction and Motivation

Europe's steel industry is moving from the blast furnace route to Electric Arc Furnaces (EAF) and Electric Smelter Furnaces (ESF), reducing the availability of traditional granulated blast furnace slag as a clinker substitute while demand for low-CO_2 binder components remains high. Residue2Binder shows how mineral residues can be conditioned, quality-assured, and transformed into secondary raw materials to strengthen domestic supply, reduce landfill, and support regional value chains.

Aims

- Define robust specifications and design windows for mineral residues, like steelmaking slags, to meet product performance and environmental targets in building materials.
- Develop four value-graded valorisation pathways from "residue to binder", with compliance-by-design and validation towards industrial practice.
- Establish an end-to-end process chain from thermal treatment, milling, analytics, and quality gates to ensure consistent secondary raw-material quality.



Evidence and Impact

- Analytic and Quality Assurance: Materials analytics (incl. thermo-optical and simultaneous thermal analysis) ensure reproducible characterisation
- Compliance-by-design: Specification window link composition/processing to binder and eluate performance including pass/fail gates before scale-up via key performance indicator (KPI) dashboard
- Impact: Reduced landfill, substitution of virgin raw materials and generates a stronger regional supply chain via quality-assured secondary raw materials

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Projects

- MINREC-HT
- $GECCO_2$
- PHOBOS
- CreeS
- BitKOIN

ReMFra – Recovering from Steelmaking Residues

Turning steel mill dust into valuable resources through high-temperature processing

Why Does ReMFra Matter?

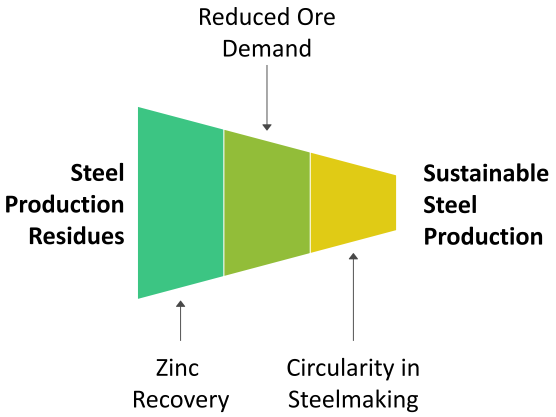
- Each tonne of steel produces ~20 kg of fine dust from the basic oxygen furnace (BOF) and the electric arc furnace (EAF); zinc rises with galvanised scrap. These residues hold recoverable iron and zinc (Zn).
- ReMFra closes loops, reducing primary ore demand and enabling circularity in steelmaking.

What is ReMFra?

- Clean Steel Partnership project validating industrial-scale, efficient pyrometallurgical routes for multiple residues.
- Two sub-processes:
  1. Plasma Reactor (coarse residues, sludge)
  2. RecoDust (fine BOF/EAF/HIsarna dusts)

RecoDust in a Nutshell

- Outputs: iron-rich RecoDust Slag (RDS) and zinc-rich Crude Zinc Oxide (CZO).
  RDS can substitute low-grade iron ore after high Zn removal; CZO is comparable to Waelz oxide for zinc production

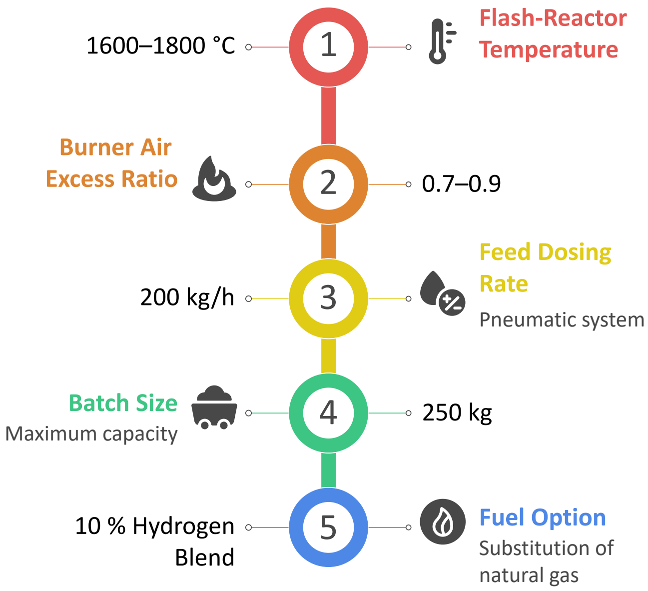


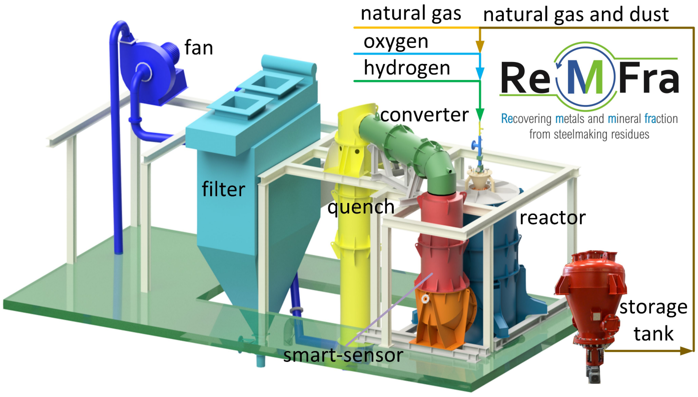
[1] Reiter, W., & Simoni, M. (2023). ReMFra – possibilities for residues from steel plants. In ESTEP Annual Event 2023-A Circular Economy driven by the European Steel

Proven RecoDust Performance

- Input material: fine steel mill dust from BOF/EAF
- Zinc separation above 99 % in the shown case.

RecoDust Pilot Plant





RecoDust Pilot Plant at the Chair of Thermal Processing Technology [1]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Co-funded by the European Union GA n. 101058362

CSP The Clean Steel Partnership
TPT Thermoprozesstechnik
K1 MET metallurgical competence center

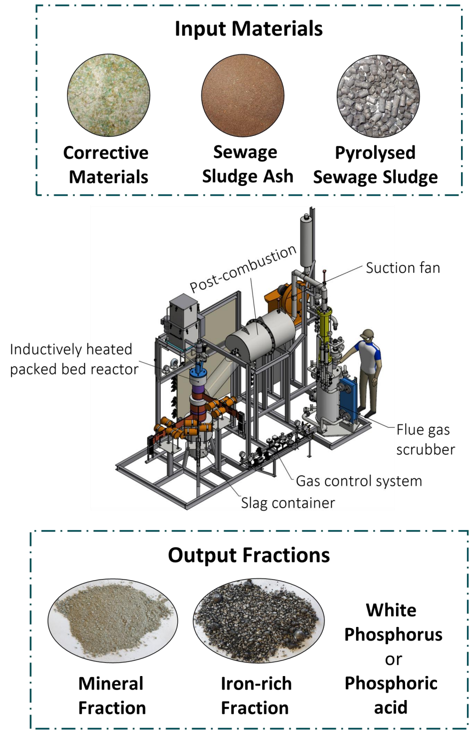
Further information:

PHOBOS

Phosphorus recovery and binder production as an economical recycling approach

Background and Motivation

Phosphorus, classified as a critical raw material by the European Commission, is essential for life on Earth [1,2]. The EU-27 meets most of its phosphorus demand through imports, often from politically unstable regions, while raw material markets are subject to strong price fluctuations [3,4,5]. Sewage sludge is a reliable and continuously available secondary phosphorus source and is gaining increasing attention due to amendments to the Waste Incineration Act. In Austria, legally binding phosphorus recovery targets must be implemented by 1 January 2033 for wastewater treatment plant operators with capacities exceeding 20.000 population equivalents [6]. Although various wet-chemical and thermochemical technologies for phosphorus recovery from wastewater, sewage sludge, or sewage sludge ash have been developed, large-scale industrial implementation has not yet been achieved [7].



PHOBOS
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION

Fig. 1

The **PHOBOS project (https://projekte.ffg.at/projekt/5138969)** investigates a zero-waste thermochemical recycling approach for the combined valorisation of sewage sludge ash and pyrolysed sewage sludge. The process (see Fig. 1) uses an **inductively heated packed-bed reactor**, in which thermochemical reactions generate **gaseous phosphorus**, a **mineral fraction** for the cement industry, and an **iron-rich fraction**. After post-treatment, the latter can be converted into a **precipitation salt for use in wastewater treatment plants**. At the same time, gaseous phosphorus is recovered from the exhaust gas line as **white phosphorus** or **phosphoric acid**. Through collaboration between research institutions and industry partners, PHOBOS evaluates key operating parameter to ensure industrial applicability and support future upscaling. The project also contributes to the **Sustainable Development Goals 9, 11, 12, and 13**. For more information scan the QR code below.

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[2] Directorate General for Internal Market, Industry, Entrepreneurship and SMEs (2023): Study on the Critical Raw Materials for the EU 2023 - Final Report,. doi: 10.2873/725585
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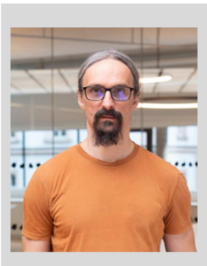

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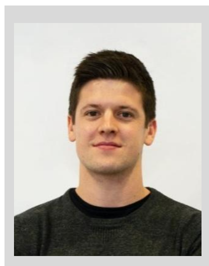

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Scan me...

How do shared narratives translate memory into everyday practice?

"At the Chair of Thermal Processing, we don't just study how things burn or break; we study how communities stay cool and hold together when the mountain moves, or the wave comes – be it heat or water!"

Problem
Current Early Warning Systems (EWS) focus on short-term "crisis response" but often fail to inspire long-term preparedness

Limitation
Technical, abstract risk data often lacks "cultural resonance," leading to passive receipt rather than active agency

Communication Gap
interrupted Knowledge Transfer
inaccessible Resources

Solution
Storytelling and participatory methods as a bridge between institutional expertise and lived experience

- **SLO**
- **HAZOP & PHA**
- **NaTech**
- **Long-term CCS**

Transgenerational Archives
Using geomyths, mining folklore, and first-person accounts as "hazard databases."

The Heuristic
Analyzing narratives through the **Aware → Prepare → Act** lens.

Key Concepts

- **Cultural Memory** Disaster knowledge embedded in local language and imagery.
- **Self-Efficacy** Moving from "I am at risk" to "I am capable of acting."
- **Temporal Bridge** Linking immediate alerts to long-term climate adaptation.

Methodology Participatory & Interdisciplinary, mixed methods.

Setting Stakeholder workshops in Alpine mountain regions.

Approach Connecting Folklore/Cultural Memory Studies and Environmental History of Disasters with Environmental Psychology and Risk Communication.

Building resilient Communities

Storytelling as "Action Scripts"
Narratives encode warnings and provide a psychological roadmap for what to do during a crisis

Trust & Credibility
Vernacular communication is often perceived as more credible than top-down technical data

Emotional Engagement
Stories foster social bonds and collective identity, which are essential for post-disaster recovery

Psychological Impact
Narratives increase collective efficacy, the community can face hazards together

Integration
Warnings should not be "isolated signals" but part of a broader cultural dialogue about risk and adaptation

Sustainability
Narrative methods create communication practices that are culturally anchored and psychologically effective

SLO…Social License to Operate
HAZOP…Hazard and Operability
PHA…Process Hazard Analysis
NaTech…Natural-Technical
CCS…Crisis Communication Strategy

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SDS SAFETY AND DISASTER STUDIES
EURECA-PRO
TPT Thermoprozesstechnik
Montanuniversität Leoben

Bridging Technical Rigor and Social Resonance with Integrated Safety

Holistic Safety and Disaster Management & Crisis Communication

Resilience & Social Sciences
Trauma & Recovery
Investigating the "Micro to Macro" transition of support and the prevention of re-traumatization in affected communities

Resilience & Social Sciences
Psychological Impact
Researching self-efficacy, collective trauma, and the long-term processing of mass technical accidents

Risk & Crisis Communication
Cultural Memory
Using archival research and historical disaster analysis to inform modern preparedness

Technical Safety & Engineering
Industrial Protection
Ensuring safety in complex thermal processing and mining-related environments

Risk & Crisis Communication
Narrative Approaches
Leveraging storytelling and "vernacular risk communication" to bridge the gap between experts and the public

SAFETY AND DISASTER STUDIES

Technical Safety & Engineering
Process & Plant Safety
Specialized research in gas and dust explosions, self-heating processes, and fire protection

Risk & Crisis Communication
Temporal Communication
Linking immediate early warning systems (EWS) with long-term climate adaptation strategies

Technical Safety & Engineering
Modeling & Simulation – Numerical investigation of particle effects and pollutant dispersion modeling

Resilience & Social Sciences
Analyzing disaster risk management through the lens of social networks, participation, and sustainable development

Multimodal Research
Combining qualitative social research, quantitative environmental psychology, and advanced numerical modeling

Global Context
Comparative international studies to identify universal and site-specific resilience factors

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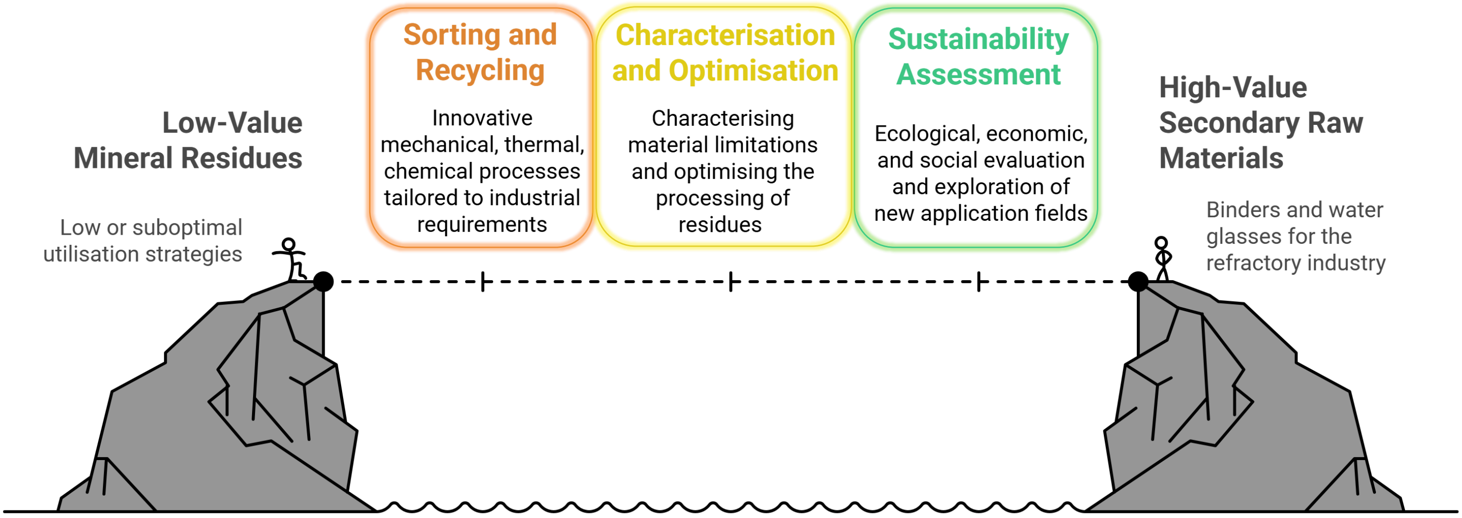
MINREC-HT

Innovative sorting and recycling processes for mineral residues for valorisation in high-temperature applications

The increasing scarcity of natural resources, rising landfill costs, and growing demands for sustainable resource utilisation pose significant challenges for the industry. Mineral residues, including mixed construction waste, metallurgical slags, and refractory industry production waste, are often underutilised, despite their considerable potential as secondary raw materials.

Objectives and Innovation Potential



Benefits for industry and environment

- Enhancement of resource efficiency through the substitution of virgin raw materials.
- Reduction of CO_2 emissions by material utilisation instead of landfilling.
- Implement a zero-waste approach through the complete material use of all residue streams.
- Methodological framework for integrating assessments of ecological, economic, and social sustainability into technological processing workflows.
- Promoting circular economy and enhancing the competitiveness of Austrian industry.

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The MINREC-HT project is funded by the FFG within the framework of the call *"Ressourcenwende 2025"* and will run from 05/2026 until 05/2029.

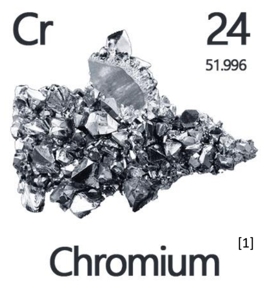
CreeS – Chromium-free Slag

Thermochemical treatment for chromium removal and circular slag utilisation

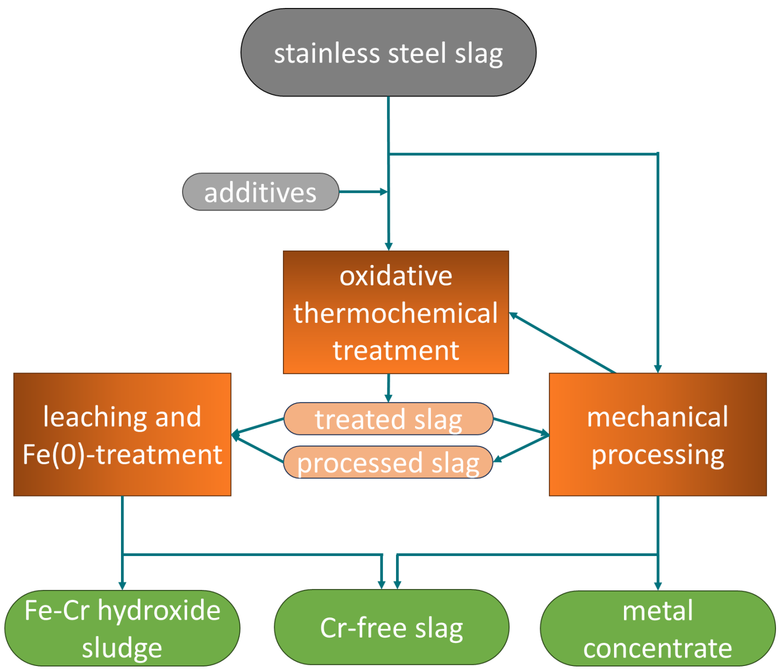
Transitioning industry toward sustainable production systems requires innovative technological solutions and circular economy approaches.

Cement production relies heavily on virgin raw materials and contributes significantly to global industrial CO_2 emissions. Sustainable solutions focus on using secondary raw materials and supplementary cementitious materials to reduce environmental impact.

Stainless steel slags are abundant CO_2-free secondary resources, but their use is limited due to high heavy metal contents, especially chromium (Cr).



Research Goal
Developing technologies to reduce Cr levels below the relevant limit values for applications in cement production ("Cr-free"), while upgrading slag quality to unlock its potential and support resource efficiency and CO_2 reduction.



Objectives and Methods

- Characterisation of stainless steel slag through chemical, mineralogical, and thermal analysis combined with microscopic methods to determine phase composition and element distribution.
- Thermochemical treatment to oxidise Cr and to control the formation of mineral phase using targeted cooling and solidification processes.
- Mechanical processing and separation to isolate and concentrate iron-chromium (Fe-Cr) bearing phases from the slag.
- Selective leaching and recovery of Cr, followed by reduction and recovery using zero-valent iron.
- Developing and assessing Cr-free slag as a potential secondary raw or supplementary cementitious material for the cement industry.
- Integration into circular material flows, which includes recycling recovered metal concentrates and sustainable managing remaining process residues.

Sources: [1] https://www.vedantu.com/evs/facts-about-chromium

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