Deutsche Forschungsgemeinschaft (German Research Foundation)
Information for Researchers

Call for Proposals

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Priority Programme "Engineered Artificial Minerals (EnAM) – a geo-metallurgical tool to recycle critical elements from waste streams" (SPP 2315)

In May 2020, the Senate of the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) established the Priority Programme "Engineered Artificial Minerals (EnAM) – a geo-metallurgical tool to recycle critical elements from waste streams" (SPP 2315). The programme is designed to run for six years. The present call invites proposals for the second three-year funding period (starting approx. in mid-2024).

The megatrends we are facing today can be summarised under the question: "How can we as part of society become more efficient in coming to a sustainable use of all the natural resources?" This question comprises the CO_2/energy as well as the raw materials/recycling challenges. Nowadays, recycling technology and application are at a crossroads. In developed countries, recycling technologies have evolved to recover those elements and materials that represent the main mass of waste, but we are lacking technologies to address the essential and often rare elements of a modern society, which become dissipated in the waste streams. Examples of such elements include indium (In) in touch screens, lithium (Li) in batteries, raw earth elements (REE, e.g. Nd, Dy) in magnets, semiconductors and batteries, germanium (Ge) and gallium (Ga) in high-frequency chips, silver (Ag) in RFID chips, PGM (Pd, Pt) in electronic waste (WEEE), tantalum (Ta) in capacitors and further specialised spice and alloy elements in high-performance metallic materials. One significant aspect for a large number of these elements is the thermochemistry of pyrometallurgical processes. These processes primarily allow access to noble metals that typically hold economic importance and serve as the main motivation for using these methods. Meanwhile, all non-functional elements are compelled to migrate to the second liquid phase, known as the slag phase or flue dust. The slag phase consists of oxides, phosphates, carbonates and even sulfides of metals and metalloids. It separates the gangue material (e.g. CaO, SiO2, Al2O3) from the melting phase and is also responsible for the absorption of impurities (e.g. S, O, P, Li, Ta). Thus, the slag becomes the carrier of a broad number of valuable elements in the non-ferrous metallurgy.

SPP 2315 EnAM addresses the slag phase as an important source of critical technology elements. When the slag solidifies, it can either form a homogeneous amorphous structure or generate crystals. These crystals can be seen as artificial minerals and ores, respectively. The crystallisation can potentially be able to concentrate diluted elements by orders of magnitude and/or efficiently separate gangue from target elements in the slag structure. To generate these crystals, it can be required to add further species (e.g. fluxes) adapting the slag design and experimental conditions, e.g. by controlling the solidification performance or the oxygen partial pressure, for the formation of

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those defined mineral structures, called engineered artificial minerals (EnAM). The formation itself depends on the thermodynamics of the complex multi-component slag system. In this context, thermochemical and statistical or data-driven modelling are able to predict potential crystal species when sufficient fundamental data of the system is available.

The identification of an EnAM crystal is only the first step in the processing route. It has to be crystallised to a sufficient size (e.g. > 10 µm) and a mechanically stable phase, which may be liberated from the remaining sometimes partially amorphous solid matrix. Finally, the mechanical separation of the EnAM particles leads to a new artificial ore concentrate. Since slag processing is still considered waste processing, we also lack strategies and process laws, e.g. breakage laws or flotation strategies for the quantitative description and modelling. All new model approaches developed within the framework of the SPP should be suitable to be integrated in process simulations, e.g. flow sheet simulation tools.

The entire process chain from the multi-component slag formation to the liberated and concentrated mineral crystals further requires new and enhanced characterisation methods, which can trace elements and structures along their way. One special focus is on the formation and properties of the crystals, i.e. thermochemical stability and particles generated during solidification. It is worth noting that crystal composition and physical properties like size, shape and durability determine the success of further mechanical processing downstream.
The main technical research questions of the Priority Programme 2315 therefore are:

- How to identify a potential mineral species in which a target element accumulates, and how to influence the composition and the crystallisation process of the slag system to enable the formation of that EnAM (slag thermodynamics, phase diagrams, chemical processing parameters in the smelting process, quantitative models)?
- How to enhance the thermochemical and physical stability as well as the efficiency of the target mineral formation to promote target element accumulation? How to design the crystallisation process (non-equilibrium crystallisation, kinetics of crystal growth) to generate the right EnAM species with the desired particle properties (structural, elementary analysis) in a technologically relevant time scale?
- How to describe and model the liberation of EnAM from the solidified partially amorphous slag system (breaking laws as a function of composite and crystal structure, selective comminution, quantitative models, structural analysis), ensuring a sufficiently large particle size for down-stream processing?
- How to mechanically/chemically separate the EnAM from the gangue material (identification/generation of a separation attribute, application of separation process, quantitative models)?

The quantification of these individual steps requires the development and application of suitable formation and characterisation methods. These have to be adopted to provide the data sets that allow the quantification and modelling of the individual process steps. Material modelling supports both the solidification as well as the solids processing. The particle-based process data should reflect the latest findings in particle characterisation to allow a multi-dimensional description of particles in crystallisation, grinding, liberation and separation processes (higher dimensional tromp curve). The research data itself obeys a jointly developed ontology, which helps to sort and access these research data sets. Reuse of the scientific data generated has to be ensured beyond all cooperation within the SPP itself.

The research programme within the framework of the SPP consists of three main pillars:

- Projects A: Thermodynamic modelling/experimental screening of slag state and prediction of solidification
- Projects B: Processing of liquid slags/crystallisation
- Projects C: Processing of solidified slags/particle technology

In the second phase of the SPP, Projects A should shift their focus and aim to move from the simple identification of specific potential slag systems to the quantitative analysis of these systems. Thermodynamic and predictive modelling should support strategies for the formation of desired crystalline phases based on specific characterisation methods and thermochemical data. At least in this second phase, some of the Projects A should be able to provide additional EnAM systems as new reference systems for Projects B and C.

Projects B and C work on quantitative process properties and laws, which either experimentally/empirically or on a simulation basis contribute to new process models. Now, in the second phase of the SPP, the investigations and process models should become more generalised and consider the applicability of their correlations to more than one slag system.

In the second funding period, the SPP will continue its central project focused on slag generation of model systems capable of providing sufficient slag material to the projects working on the downstream steps. This central project will also develop and provide 3D geo-metallurgical characterisation of the slags and support the projects with geo-metallurgical data.

In order to achieve a high coherence of the research work, the target elements should come from the EU list of critical elements or have a recently increased economic importance. All modelling projects require a validation part within the SPP and should address a technically relevant question.

The coordination group prefers submitting single or a limited number of tandem projects; it further favours and supports networking and collaboration throughout the SPP.
Proposals must be written in English and submitted to the DFG by **14 February 2024**. Please note that proposals can only be submitted via elan, the DFG's electronic proposal processing system.

Applicants must be registered in elan prior to submitting a proposal to the DFG. If you have not yet registered, please note that you must do so by **5 February 2024** to submit a proposal under this call; registration requests received after this time cannot be considered. You will normally receive confirmation of your registration by the next working day. Note that you will be asked to select the appropriate Priority Programme call during both the registration and the proposal process.

If you would like to submit a proposal for a new project within the existing Priority Programme, please go to Proposal Submission – New Project – Priority Programmes and select "SPP 2315" from the current list of calls. Previous applicants can submit a proposal for the renewal of an existing project under Proposal Submission – Proposal Overview/Renewal Proposal.

In preparing your proposal, please review the programme guidelines (DFG form 50.05, section B, see link below) and follow the proposal preparation instructions (DFG form 54.01, see link below). These forms can either be downloaded from our website or accessed through the elan portal.

The proposal review process will include a colloquium with direct presentations and discussions between applicants and reviewers, scheduled to take place on 6 June 2024. The date and location of the colloquium as well as any other relevant updates will be communicated in due course via the official DFG channels and the Priority Programme website.

Further Information

More information on the Priority Programme is available under:
https://tu-freiberg.de/en/institut-fur-mechanische-verfahrenstechnik-und-aufbereitungstechnik/spp-2315

The elan system can be accessed at:
https://elan.dfg.de/en/

DFG forms 50.05 and 54.01 can be downloaded at:
www.dfg.de/formulare/50_05
www.dfg.de/formulare/54_01

For scientific enquiries, please contact the Priority Programme coordinator:
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