



# Mineral resources and material substitution (MISU)

## Research programme

**Programme memorandum**

## **MINERAL RESOURCES AND MATERIAL SUBSTITUTION (MISU)**

**A research programme by the Academy of Finland  
Programme memorandum**

### **Foreword**

The decision to launch the Mineral Resources and Material Substitution programme was made by the Board of the Academy of Finland on 24 September 2013. The programme's subcommittee was appointed by the Board on 10 December 2013. Professor Erno Keskinen (Research Council for Natural Sciences and Engineering) was appointed as chair of the subcommittee and Professor Mari Walls (Research Council for Biosciences and Environment) as the vice chair. Professor Heli Jantunen (Research Council for Natural Sciences and Engineering) and Professor Olli Mäenpää (Research Council for Culture and Society) were appointed as members.

A steering group was appointed for the programme. Besides the members of the subcommittee, the steering group was made to include Professor Kari Heiskanen (Aalto University), Chief Technology Officer Kari Knuutila (Outotec Oyj), Head of Department Kaj Lax (Geological Survey of Sweden) and Programme Manager Kari Keskinen (Tekes).

In late 2013, the Academy opened a targeted call within the programme in the field of primary mineral resources. In spring 2014, the Academy organised an exploratory workshop in order to produce a researcher-driven analysis of the programme's themes. The programme's first proper funding call is set to open in September 2014.

### **1 BACKGROUND**

Bedrock aggregate materials and minerals are central to the modern way of life. They are needed not only in building construction, but in virtually all instrumental activities from transport and industrial production to commerce and everyday consumer routines. Raw materials extracted from the earth are nonrenewable. Their unequal distribution means there are two categories of states: those that can earn substantial wealth by extracting and selling mineral resources, and those that are dependent on the mechanisms governing mineral resource access and pricing. Although effective mechanisms are already in place for the recycling of basic metals (such as iron, nickel, chromium, copper and aluminium), increasing consumption demand especially in developing economies means there will continue to be a need in the future for primary production. The production shortfall is most pronounced for precious metals and rare earth metals, which are crucial to new products in the energy, electronics and vehicle industries, but also used as catalysts in the chemical industry. Since access to these minerals is dependent on various political and economic boundary conditions, they have become listed as critical. Especially in the case of precious and critical metals, the production shortfall is being tackled by stepping up the exploration and mapping of mineral deposits, with a view to opening up new mines at a faster rate than before. Another way to ease the supply problem is to optimise the use and recycling of these materials, although low concentrations make this technologically highly challenging. The third solution is to develop an alternative material that will provide the functionality needed in the application. This is indeed a natural way to reduce dependence on minerals that are in limited supply. Within the European community, there is now a broader recognition of an impending resource problem in critical materials that will affect the whole economic area. One key way of tackling this problem is by means of strategic research within the Horizon 2020 framework programme, for instance.

Finland has a favourable location in terms of the potential for mineral deposits. The Finnish bedrock contains deposits of both basic and precious metals as well as rare earth metals. Due to their mechanisms of geological formation, these metals occur in part in the same mineral deposits, but in varying combinations. The main basic metals produced in Finland are nickel, chromium, copper and zinc concentrates, which are also processed into metals. In these processes, rare minerals may be left behind in side streams, leading to calls for the integrated separation of all precious metals. This requires special attention to the health and environmental effects of beneficiation processes. Ultimately, the aim is to have closed circuits for all in-mine and subsequent processing so as to eliminate any adverse impacts on waterways, as in other branches of advanced industrial production. One of the aims of the Mineral Resources and Material Substitution programme is to create models for a new generation of sustainable extractive industry that takes seriously its environmental and land use responsibilities as well as the relevant legislation around mining permit procedures. Another central issue is the profitability of mining operations across their life cycle, taking account of the measures and costs involved in mine closure and rehabilitation. Finland is well placed to become a pioneer in sustainable mining, but in order to realise this potential it will first of all have to resolve these questions on the basis of sound research evidence. The single most important and at once the scientifically most challenging issue is the exploration and effective utilisation of low-concentration, rare metals and above all the economical, energy-efficient and environmentally sound recovery and recycling of these metals. This is a problem shared in common by all plants that process metals and metals containing recycled fractions in connection with primary extraction and recycling.

The Academy of Finland has identified a number of strategic research themes associated with the grand challenges facing humankind. Sustainable mining and materials recycling touch upon many of these themes. Research can help discover and develop alternatives to the use of raw materials if their availability is scarce or if the benefits of mining do not outweigh the harms caused. In a situation where it is impossible to achieve complete self-sufficiency in raw materials and where the competition for natural resources is becoming increasingly unpredictable in its forms, this Academy Programme on mineral resources and material substitution has special current relevance. Research on the substitution of critical raw materials coupled with studies on the exploration and utilisation of mineral resources, new mining processes, materials efficiency and metals recycling constitute a unique cluster that has the potential to deliver new solutions and breakthrough technologies and products as well as new or improved core processes in extractive industries.

## 2 AIMS

The aim of this Academy Programme is to strengthen multidisciplinary and interdisciplinary approaches and to move towards a more systemic orientation in the research fields concerned. All projects under the programme's umbrella are encouraged to embrace multidisciplinary and interdisciplinary research collaboration.

Access to the rare minerals needed in new technology products has become increasingly difficult to manage. Mineral resources in general have become an increasingly complex area that calls for a stronger systemic approach. New solutions require exact information and multidisciplinary understanding that is grounded in sound basic research. This programme aims to provide a broad and in-depth coverage of the occurrence, properties, processing, use and recycling of rare, especially metallic minerals as well as alternative materials used as substitutes for metallic minerals. The programme will create a knowledge base that will facilitate responsible mining and recycling operations that are aware of their impacts on the natural environment and the surrounding society.

There are three research themes:

- Primary mineral resources
- Materials efficiency and recycling
- Material substitution

There are two research questions that cut across all these three themes: 1) How can the same functionality be achieved for different material solutions; and 2) How can interconnected metals be separated in connection with beneficiation and recycling as economically, energy-efficiently and environmentally soundly as possible?

#### *Primary mineral resources*

Under this research theme, the aim is to build a fuller and more detailed picture of Finland's metal deposits and how they have formed and to assess the potential for the use of the country's mineral resources, both basic metals, precious metals, rare earth metals and especially critical raw materials as defined by the European Union. An assessment of the sustainability of mining operations requires international comparative research data on the lifecycle impacts of the mine under different permit procedures, giving due consideration to the requirement of balance between environmental impacts, the societal dimension and financial profits.

#### *Materials efficiency and recycling*

There remain several unsolved problems in materials recycling that have to do with the properties, concentrations and interactions among different elements. Key objectives under this theme are to reach a systemic understanding of recycling processes in which the separation of valuable elements is integrated with the simultaneous processing of other fractions and with primary production processes.

#### *Material substitution*

Using a new, less critical synthetic or modified material to substitute a critical material, metal or other material is a major research challenge that requires new interdisciplinary research evidence. Under this theme, the aim is to gain a deeper understanding of what causes the functionality of a critical material used in a certain application, to find out how this same functionality can be achieved with another, synthetic or modified material, and to create the conditions for the industrial application of new, alternative materials. One of the key issues is the recyclability of alternative materials and their integration with primary production processes.

The programme's other aims include:

- establishing new multidisciplinary research groups and networks of national and international collaboration
- increasing the national and international mobility of researchers
- improving the international competitiveness of research and industry
- bringing Finnish research to the international forefront in selected research areas
- achieving broad societal impact for research into mineral resources and alternative materials.

### **3 THEMES**

The utilisation of raw materials involves multiple chains of complex processes from mine exploration through the processing of ores mined to materials recycling. These chains present both major challenges to science and



research and opportunities for new technology breakthroughs. Mining companies and the global technology industry that provides solutions to these companies need new research that will help make mining a more competitive industry and also improve the social acceptance of the industry through a more responsible approach. New solutions can contribute to increasing the functionality and reliability of mines, which will also reduce the environmental risks and increase the social acceptance of mining. Price formation in rare and critical metals is hard to predict, which further adds to pressures to develop energy-, cost- and materials-efficient beneficiation and recycling processes. The substitution of critical materials often leads to the use of thin coatings or corresponding fine structures and consequently to the need for nanoscale examinations. Micro- and nanostructures as well as various composites made out of organic compounds, metallic components and ceramics, for instance, can be tailored to have specific physical properties that are typically found in rare metals. One entirely new requirement in connection with recycling is that it must be possible to decompose these often hard to break structures in order to avoid the generation of hazardous waste with adverse health and environmental effects.

### 3.1 Primary mineral resources

A more detailed geological map is needed of the critical raw materials in Finland and its neighbouring regions in order to see how they coincide with other mineral resources. The development of ore exploration methods, the 3D modelling of deposits and ore concentrations and the development appropriate experimental and mathematical methods are crucial to producing an accurate assessment of the country's ore potential. These new modelling methods will allow for more accurate impact assessments and profitability analyses that cover the entire lifecycle of mining operations. The main research challenges in the area of beneficiation stem from the development of hybrid processes, in which part or all of the reprocessing could be done on-site. Rare and base metals bound in aggregates constitute a mineralogical entity from which individual mineral species have to be separated either stage by stage or in an integrated process, depending on the reprocessing requirements. At the same time, it is necessary to decide on the logistic handling of valuable substances on-site at the mine location and/or at the reprocessing site. The theme of primary mineral resources breaks down into the following component topics:

- Mineral exploration, deposits and utilisation
- Mining processes and beneficiation methods
- Impacts of mining operations

Fennoscandian ore deposits are typically multimetallic. There is a pressing need to develop new geological, geochemical and geophysical exploration methods that are based on new technologies, because the discovery of ore deposits depends on successful exploration. Likewise, there is a growing need for improved digital mapping of ore deposits and the development of GPS-based systems, both at the level of individual deposits and on a Fennoscandian scale. The main challenge, however, is to produce numerical assessments of relative metal concentrations in primary mineral resources in the form of a 3D map, which presents complex inverse modelling challenges. The information that can be gleaned from such a map is highly significant as the decision to open a new mine depends crucially on ore winning projections.

The mining chain from the exploration and excavation of stone through to separated concentrate consists of a series of unit processes that may be mechanical, hydraulic, chemical or biological in nature. It is important to investigate new unit processes and their combinations in order to facilitate the selective separation of valuable substances from waste materials. Since separation and grinding techniques are highly energy-intensive, it is also important to aim to reduce energy consumption. Furthermore, the isolation of harmful by-products and the economical use of process water in closed circuits represent significant research challenges. New process ideas must be scientifically well grounded. Scaling up for commercial production may also require systems-

level simulation. Integrated separation and beneficiation processes that are suited for multimetal mines require in-depth systems-level understanding so that the process can be optimised for maximum productivity. The handling of rock material within the mine area and at beneficiation plants must be based on logistically smart and energy-efficient solutions.

A mining complex ties up the land on which it stands for decades. Even after the mine is closed, the land has only very limited use. Since the solvents used in some beneficiation methods require extensive water use, there is a real risk of sludge escaping into the environment. There are some examples from around the world of such leaks into the natural environment, and therefore there is a pronounced need for research into closed-circuit processes. There is also an ongoing search for new end uses for stockpiled waste materials in the construction industry, for instance. Minesite remediation and landscape rehabilitation must be taken in account from the earliest stages of lifecycle planning. The start-up and closure of mining operations involve a range of challenging socioeconomic issues particularly with respect to regional economy, employment and social acceptability, and these issues tend to become more pronounced when lifecycle effects are not properly considered. A broad and diverse analysis of social and environmental effects is therefore one key area of research into primary natural resources.

### **3.2 Materials efficiency and recycling**

Precious metals as well as rare earth metals and critical raw materials are most typically used in energy technology and electronics industry products. Since the processing of precious metals is very expensive, most raw material needs in industry could well be met by intensified recycling. This principle is backed by the high rate of electronic scrap recycling. Another way of tackling the supply problem in critical raw materials is by means of system planning that takes account of the separability of materials in connection with scrapping. Other potential sources of precious metals recovery include waste stockpiles at disused mines and landfills. The key research questions under this theme are:

- Economical use of rare minerals
- Recycling of valuable substances
- Recycling-oriented design and manufacture.

Critical raw materials have special characteristics that can provide a given functionality for a given application. High price and/or limited availability have led to the use of thin film and particle structures that require micro- and nanotechnology-based production methods. Processes of film formation, particle-filled composites, and particle multiphase flows are areas of research that will require demanding experiments and heavy-duty scientific computation. New technologies may bring in new critical raw materials if the design of material functionality does not take account of the availability of raw materials. For this reason, there is a special need for this line of research, which will have special significance in solving the valuable minerals supply problem.

It follows from the typical uses and applications of critical raw materials such as precious or rare earth metals that at the recycling stage, these materials are often found in amongst electronic scrap. Other fractions include various plastics, semiconductors, ceramics and base metals such as copper. The recovery of precious metals is often integrated with the separation of copper. Since mechanical sorting does not give the desired end result, there is currently an intense research effort into separation methods based on various physical, chemical and biochemical effects. The design and optimisation of these kinds of processes that involve reject return cycles necessarily require systems-level examinations, such as process simulations. The corresponding systems-level method can be used in the reprocessing of old waste, whereby the principles at the unit process level must be deduced from the characteristics of the substances being separated.



Critical raw materials and alternative materials are often found in thin coatings or other interactive layers in between the process medium and the background structure. Industrial serial production requires that the product or application is developed simultaneously with the manufacturing technology. Fine structures also present a specific recycling problem: how to separate the interface layer embedded in the surface from the base material in connection with scrapping. At the same time as work is continued to develop new structures that maximise the effective surface area of materials as well as synthetic substitutes, this question of separability needs to be resolved. The recovery of precious metals is about resource efficiency, but in the case of synthetic substitutes the determining factor may be the management of the health and environmental risks associated with nanoscale particles.

### 3.3 Material substitution

Finland is one of the world leaders in the field of materials and nanoscience research. It has achieved this position by virtue of its physics, chemistry, computational science and modelling groups and, importantly, its up-to-date research infrastructure. This puts the country in an excellent position to produce cutting-edge research into new materials that can substitute for critical metals. In particular, Finland has world-leading research excellence in the fields of carbon materials, biomimetic materials, functional oxide materials, nanoparticles and thin ALD coatings.

Under this research theme, the aim is to achieve partial and/or full raw materials substitution, with a critical raw material replaced by some other, noncritical material that has the same functionality in specified applications. The subthemes listed provide examples of new materials that have the potential to become alternative materials and that are already being researched in Finland:

- Coatings and nanostructures
- Functional ceramics
- Organic structures and biomimetics

The use of new advanced coatings or multimetallic nanostructures as substitutes for critical metals, for instance carbon clusters as substitutes for palladium group metals in catalysis applications, results in a reduced need especially for precious metals and platinum group materials. The ALD method can be used to process materials that are used, for instance, in nanostructure solar panels and lithium-ion batteries.

Finland's extensive expertise in the field of functional ceramics provides an opportunity to functionally improve the mechanical strength of materials. Surface structures that react to environmental conditions can be produced by means of multimaterial tailoring.

In the field of biomimetics, natural materials are used on the one hand as models for artificial structures and on the other hand as base materials for organic structures. Organic structures can pave the way, for instance, to new ways of manufacturing transparent displays, corrosion-resistant coatings or various sensors by means of carbon nanostructures. Polymers can also be used to develop various conductive or visible-light-active coatings.

Another objective under this theme is to foresight the future of alternative materials, with special reference to the EU's list of critical materials ([http://ec.europa.eu/enterprise/policies/raw-materials/critical/index\\_en.htm](http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm)). All new alternative solutions must furthermore consider how the substituted material behaves at the end of the product lifecycle when it is scrapped. The choices of material for alternative solutions must allow for safe disposal and recycling of materials without any adverse health effects, environmental effects and undue costs. Under the alternative materials component, it is therefore also



necessary to have research focused on the choice of alternative materials, their lifecycle costs and system integration. Products containing alternative materials need broadly based scientific evaluation and systemic analysis so that the materials can be recycled together with other material flows.

## 4 IMPLEMENTATION

### 4.1 Funding and schedule

The Mineral Resources and Material Substitution programme is a four-year research programme funded and coordinated by the Academy of Finland. Through the programme, funding is provided to multidisciplinary research conducted by research projects and consortia with a view to supporting national and international cooperation and networking. A research consortium is a collaboration of independent fixed-term projects working under a joint research plan that combine different methods and research fields with a view to achieving greater added value than by normal project collaboration.

The programme includes two primary national funding calls. The first call, the one-stage Primary Mineral Resources call, was opened in autumn 2013 with a budget of four million euros. The funding decisions were made in May 2014. The projects funded in that call will start their funding periods on 1 September 2014. As a rule, the funding periods are for four years. The second funding call of the programme is a two-stage call to be opened during autumn 2014 and winter 2014/15. The preliminary budget of this second call is 9–12 million euros. As a rule, the four-year funding periods will start on 1 September 2015. The funding decisions are due in late spring 2015. Decisions on international collaborations and funding opportunities will be made separately.

A special characteristic of the programme's first main call is that the funding of four million euros is allocated with a view to supporting knowledge-based growth. This does not apply to the second main call.

For more information on the call and review schedules, see Chapter 5, Application guidelines and review criteria. Information on funding agencies, research topics, schedules and application processes of any supplementary calls will be published separately.

### 4.2 National cooperation

The Mineral Resources and Material Substitution programme has some points in common with other Academy of Finland programmes, such as the Arctic (2014–), Programmable Materials (2012–2016) and New Energy (2015–2018) research programmes.

The Mineral Resources and Material Substitution programme also aims to establish good interactions with Tekes' programmes, especially the Green Mining programme. There are also interfaces with the [Strategic Centres for Science, Technology and Engineering](#) in the fields of energy and the environment (CLEEN) and metal products and mechanical engineering (FIMECC).

The Finnish Ministry of Employment and the Economy has launched an action plan for making Finland a leader in sustainable extractive industry and the Finnish Innovation Fund (Sitra) has started a network for sustainable mining. The Academy of Finland's Mineral Resources and Material Substitution programme aims to take account of the Ministry's action plan and utilise Sitra's network. The programme will also try to promote cooperation with Finnish foundations that finance research. Where necessary, collaboration will be established with the University of Oulu Mining School.



### 4.3 International cooperation

The Mineral Resources and Material Substitution programme aims to selectively establish cooperation with research funding agencies in other countries that are committed to supporting leading-edge scientific research in the field and with whom collaboration could be beneficial for Finnish research. South Africa, Canada, Australia, Sweden and Chile, among others, have been identified as interesting target countries. The Academy of Finland also has bilateral agreements with some of these countries, such as with South Africa and Chile. In addition, the Chilean National Commission for Scientific and Technological Research (CONICYT) has launched the Mining Footprint programme.

As regards the EU's framework programme for research and innovation, Horizon 2020, the most important call for the Mineral Resources and Material Substitution programme is the Raw Materials KIC call, which closes in autumn 2014. Other key EU funding programmes include the LIFE programme in environmental and nature conservation as well as the European Regional Development Fund's programmes.

The Academy of Finland is also a funding partner in the International Continental Scientific Drilling Programme (ICDP), which will be taken into account in programme activities.

There are a number of very interesting collaboration opportunities with Sweden. At the Nordic level, NordForsk is an important funding organisation for Nordic research cooperation. Sweden's key funding agencies are Vinnova and Nordmin, of which the former is about to launch its own research programme in the field of mineral resources.

Decisions on other international collaborations will be made separately.

### 4.4 Steering group

The programme is run by a steering group composed of members of the Academy's research councils and other expert members. Additional experts may also be invited to the group. The duties of the steering group are:

- to prepare the programme and submit to the programme subcommittee a proposal on projects to be funded
- to make a proposal to Academy research councils and other funding bodies on any new calls and/or additional funding
- to manage and monitor the programme
- to steer programme coordination
- to be responsible for the final evaluation of the programme
- to promote the application of research results produced within the programme.

### 4.5 Programme coordination

The programme strives to promote the development of the selected projects into a coherent and cohesive structure through active cooperation and exchange of information. The steering group and the programme managers and project officer appointed by the Academy are in charge of programme coordination. They work closely with the projects to facilitate the attainment of the objectives set for the programme. The aim is to ensure that the projects reinforce each other and that the programme generates new multidisciplinary research knowledge. Consequently, the principal investigators (PI) of the projects will be required to commit

themselves to the programme objectives and to cooperate actively throughout the programme and during the programme evaluation upon its completion.

The PIs of the projects are required to:

- assume responsibility for and report on the scientific progress of the project and on the use of the funds in accordance with the instructions of the programme manager and relevant funding bodies
- see to that the whole research team attends all meetings, seminars and workshops organised by the programme coordination, and facilitate cooperation and exchange of information between the teams within the programme
- take part in producing reviews, syntheses and information material around the programme, and actively disseminate information about the programme's progress and results on public and scientific forums.

During the course of the programme, the research projects will participate in events arranged together with end-users of research results and in any other activities designed to provide information to stakeholders.

#### 4.6 Final evaluation

The implementation and results of the programme will be evaluated upon its completion. The implementation of the evaluation will be planned in detail as the programme progresses, but the evaluation will consider, for instance, the following issues:

- attainment of programme objectives
- programme implementation (coordination, role of steering group, programme participation)
- evidence of impacts pursued by the programme
- national and international cooperation
- publicity and visibility of research conducted within the programme.

The evaluation may be carried out as part of a more extensive evaluation of the Academy of Finland's programmes or other national programmes and in cooperation with other national and international actors.

The funded research teams are required to report on the progress of their projects in accordance with the decision of the steering group and to submit a research report to the Academy of Finland upon project completion. The reports must include information on, for example, scientific publications produced and theses and doctoral dissertations completed within the programme. For the projects funded in the first main call (see 4.1), the Academy may require a report on how the projects have promoted knowledge-based growth.

## 5 APPLICATION GUIDELINES AND REVIEW CRITERIA

The Mineral Resources and Material Substitution programme has a two-stage main call. At the first stage, applicants submit letters of intent including short plans of intent (see guidelines in the Academy's September 2014 call for applications). **The preliminary deadline for letters of intent is 24 September 2014 at 16.15. The deadline is non-negotiable** (check the final deadline in the September 2014 call for applications). The steering group will make a proposal to the programme subcommittee appointed by the Academy Board on projects that would best fit in with the programme aims on the basis of the letters of intent. The projects selected to proceed to the second stage (to submit full applications) will be notified of the steering group's decision in late 2014.

Applicants requested to submit full applications must prepare a complete research plan and submit it in the Academy's online services no later than **12 February 2015 at 16.15** (preliminary deadline). See the exact schedule and guidelines in the September 2014 call for applications. On the basis of the scientific review of the applications and considering the programme's aims, the steering group will prepare a proposal to the programme subcommittee on the projects to be funded. The subcommittee will make the funding decisions in June 2015 at the latest.

The letters of intent will be reviewed by a panel composed of members of the steering group and possible other experts. The full applications will be peer-reviewed by an international expert panel.

The applications will be reviewed in line with the Academy's general review criteria for research programmes (see [www.aka.fi/eng](http://www.aka.fi/eng) > Funding & Guidance > [Review of applications](#)). Besides these general review criteria, focus will also be placed on the objectives set for the programme, as described in Chapter 2 of this memorandum. This aspect will be considered on the review form under section "Relevance of the project to the research programme".

## 6 MORE INFORMATION

This programme memorandum is available as a PDF download at [www.aka.fi/misu](http://www.aka.fi/misu) > In English.

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