Enhanced By-product Recovery through the lOnometallurgy
of primary sources

Acronym: BRIO

Abstract / executive summary:
Ores and concentrates often contain enrichments of scarce or critical elements such as Te, Bi and Sb, but there are few financial incentives or competitive technologies that allow their recovery. They may be lost to tailings or roasted off (becoming an environmental liability), or can incur smelter penalties. Even when recovered during smelting and refining, the value may not be returned to the producer. Recovery of these elements, along with the main commodity (Au, Cu, etc.) would add value for producers and secure supply of elements that are key to European infrastructure, industry, and innovation. U.Leicester has demonstrated the potential of Deep Eutectic Solvent (DES) ionic liquids in the rapid and mineral-specific selective dissolution of gold and sulphide minerals and the subsequent recovery of major metals and by-products from solution. DESs (unlike many ionic liquids) are environmentally benign, chemically stable and the components are already produced in bulk at low cost, potentially making an industrial process feasible. This commitment is to develop this application, optimising by-product recovery so as to achieve a resource- and cost-efficient alternative to current practices. BRIO consortium has estimated that mineral ores amenable to BRIO currently encompass 90% of Cu, Ni, PGE, Pb, Zn, Sn, W worldwide production, which implies that the BRIO potential market for adopting by-product recovery from current identified reserves is up to 240.713 M€/year (current value of products detailed above).

Expected results:
- Evaluation of potential by-products in primary sources through geological database analysis and sample characterization
- Production of a workflow/toolkit for industrial companies to better assess by-product availability in future resource assessments
- BRIO process development, optimisation, scale-up to TRL5 (prototype in mining company partner of the consortium) and replication to other partner companies
- Sustainability assessment of BRIO

Links to the Strategic Implementation Plan:
• I. Technology Pillar
  ○ I.B Priority Area: Technologies for primary and secondary raw materials’ production
**Action area n° I.4: Processing and refining of raw materials**

1) **Innovative and flexible processing**
2) **Metallurgical systems**

**II. Non-Technology Pillar**

II.A Priority Area: Improving Europe's raw materials framework conditions

- **Action area n° II.2: Access to Mineral Potential in the EU**
  1) Elaborate the detailed definition and qualifying conditions of the concept of mineral deposits of public importance
  2) Examine how to incorporate the concept of mineral deposits of public importance
  3) Intensify the general exploration/public identification of mineral potential

Coverage of the Action Areas referred to above:

The BRIO project addresses some important Priority Areas from the Strategic Implementation Plan of the EIP Raw Materials. Specifically, the project mainly addresses I.B. Technologies for primary and secondary RM production and subsequent I.4. Processing and refining of raw materials through BRIO process development; and II.A. Improving Europe’s raw materials framework conditions and subsequent II.2. Access to minerals potential in the EU through by-product potential mapping activities. International cooperation where BRIO is framed addresses III. International cooperation and subsequent III.1. Technology. SIP targets cooperation at bilateral and multilateral level, promoting synergies with countries such as the US, Japan, Australia, Canada, Latin America and African Union across the different areas covered by the EIP. The BRIO project consortium joins together partners from 11 countries worldwide: Spain, UK, France, Germany, Sweden, Poland, Finland, Turkey, Peru, Philippines and Belgium. Other countries such as Australia, Canada and USA are present in the Advisory Board. Also, BRIO promotes collaboration between the public and the private sector, and between SMEs and large companies, sharing best practice and commercial collaboration.

**Objectives of the commitment:**

BRIO objectives are to map by-product potential and to develop a novel and sustainable ionometallurgical process to cost-effectively recover by-products from primary sources, i.e. ores and concentrates. This process is based on the use of innovative, environmentally-benign and biodegradable Deep Eutectic Solvents. Targeted by-products are tellurium (Te), selenium (Se), bismuth (Bi), rhenium (Re) and molybdenum (Mo), as well as Critical Raw Materials such as germanium (Ge), indium (In), cobalt (Co), palladium (Pd), platinum (Pt), antimony (Sb) and tungsten (W). In addition, co-occurring major metals such as gold (Au), silver (Ag), copper (Cu) and zinc (Zn) could also be recovered. The project will increase by-product availability, thus reducing dependency on imports, while minimising the environmental impact of mineral processing with respect to conventional hydro- and pyro-metallurgy.

**Description of the activities:**

BRIO involves a set of activities to meet the proposed objectives. These activities will be supported by the creation of an Advisory Board (AB), composed of stakeholders in the by-product value chain, including mining, metal processing and end-user companies. Four workshops are planned between BRIO partners and the AB in order to exchange feedback about BRIO process development, and obtain first-hand information from all main stakeholders.

The following actions are planned:
1. By-product potential mapping:
   a) Desk-study of literature and available databases,
b) Selected analysis of ore from specific deposits, coupled with analysis of company data if available, to define relationship of by-product element to primary commodity and thus provide an estimate of by-product endowment from the known resource of primary commodity, c) Assessment of mineralogical deportment of by product elements in different ores, d) Development of workflow/toolkit for companies to be able to better assess by-product availability in future resource assessments.

2. BRIO process development, upstream and downstream activities will be developed as a first step toward process performance optimisation:
   a) Upstream processing. This will assess how crushing of ore and production of concentrates by gravity, flotation etc. can be optimized, not only for recovery of primary commodity, but also to retain by-products that could be recovered by DES.
   b) Downstream processing. This will address issues of economic recycling of DES from post-processing residues, and removal of contaminants from solid and liquid residues to allow safe disposal.

3. The ionometallurgical process will be developed firstly at lab scale and then upgraded to TRL5. Planned actions at lab-scale include:
   a) Scope out how amenable different ores are to selective mineral dissolution with DES taking into account mineralogy, mineral composition, grain size and texture,
   b) Perform bulk leach tests on concentrates to assess amenability for economic development to bench-test scale,
   c) Investigate fundamental properties of solutions such: as solubility of different minerals, speciation in both simple and complex solutions, variations in properties as functions of temperature and trace water - this will give predictive capability of solution and recovery,
   d) Perform tests of recovery of by-products (and major metals in some cases) from solution by different processes to determine the most economical method.

4. Results from these actions will be used for process optimisation and design. Optimisation will be carried out through the production of process mathematical models and application of Multidisciplinary Design Optimisation strategies.

5. The result of this activity will be used for the design of a prototype to be installed in one of the partners’ real industrial environments in order to upgrade BRIO concept to TRL5. In parallel, replication of the BRIO process will be conducted for the rest of mining and mineral processing partner companies thanks to the production of a conceptual design of the process implementation at theoretical full-scale.

6. Finally, a sustainability assessment will be carried out, involving: environmental impact analysis - LCA, economic analysis and technical assessment - integration with a mining facilities strategic development.

7. The whole set of activities planned for BRIO are completed with clustering activities and a exploitation and dissemination plan that will communicate project results to EU society, including industry, government and the public.

**Description of the expected impacts:**

- Increased mining revenue: BRIO will unlock reserves of unexploited elements. By-product mapping will enable identification of new resources, and the companies’ toolkit will allow identification of potential by-products in existing and new mines.
- Improved economic performance: BRIO provides higher material-, and energy-efficiency with flexibility in processing. The advantage of BRIO with respect to a hydrometallurgical process is the use of a low-cost solvent (DES) that is recycled in a closed circuit, instead of reagents which generate large volumes of aqueous waste that need treatment before discharge. BRIO may reduce steps as several metals can be electrolytically recovered from the same solution. This would reduce capital expenditure (CAPEX) by <75% and operational expenditures (OPEX) by <50% according to
partner estimates.
- Security of supply: BRIO will identify routes to increase the EU raw material supply, improving accessibility, trade conditions and lowering dependency on EU-external markets e.g. China. Metals will be sourced in the EU and there will be a chain of custody that allows them to be guaranteed ethically sourced.
- Environmental improvements: Compared to hydrometallurgy, BRIO will reduce up to 95% of liquid effluents. DES is biodegradable, and has a lower environmental impact compared with other leaching agents. BRIO will reduce the amount of potentially hazardous elements in tailings. For Au recovery, BRIO offers a cyanide-free processing route. Cyanidation is controversial in the EU; a viable alternative will allow environmentally- and socially-acceptable mining development.
- Contribute to the future CRM list: Project results will provide information on the availability of potential by-products within the EU for the CRM List update.

**Expected innovation outcomes:**
New processes
New technologies
New business models

**Comments:**
First action to implement this commitment has been the submission of the proposal “BRIO – Enhanced By-product Recovery through the IOnometallurgy of primary sources” to the topic SC5-13b-2016. BRIO addresses main topic scope of providing a user-driven, sound systemic solution to by-product recovery from primary sources and is supported by an Advisory Board that includes additional mining companies along with recovered materials end-users such as the Minor Metals Trade Association (MMTA). The interest created by the project can be explained by the business potential of the process: while there are currently few financial incentives for the producer or competitive technologies that allow by-product recovery (and usually taking place externally at refiner facilities), BRIO allows mining companies to fully exploit by-product potential by recovering them at their own facilities.

**Name of the coordinating organisation:**
IDENER (Optimización orientada a la sostenibilidad S.L.)

**Country:**
Spain

**Entity profile:**
Private sector - SME

**Role within the commitment:**
IDENER will support metal recovery activities and will later use this knowledge to conduct mathematical modelling, process optimisation and conceptual design. IDENER will deliver basic engineering documents for prototype implementation. In parallel, the company will replicate BRIO process to other companies. Finally, IDENER will produce a decision support system with the information produced regarding by-products potential and mapping.

**Other partners:**

**Name of partner:**
University of Leicester

**Country:**
United Kingdom

**Entity profile:**
Academia

**Role within the commitment:**
Main process developers. Further contribution in by-product potential mapping is planned and also in upstream processing due to expertise in ore mineralogy. In order to supervise BRIO process upgrade, Univ. Leicester will participate in process design and optimisation and also in prototype operation. Contributions is also expected in the study of BRIO amenability to secondary resources.

**Name of partner:**
GTK - Geologian Tutkimuskeskus
**Country:**
Finland
**Entity profile:**
Other
**Other:**
RTO

**Role within the commitment:**
GTK will coordinate by-product potential mapping and assessment. The information to be produced here will be later used in clustering activities and shared with other EU projects. GTK will contribute to results exploitation and dissemination, especially to the decision support system to be developed.

**Name of partner:**
Technische Universitaet Bergakademie Freiberg (TUF)
**Country:**
Germany
**Entity profile:**
Academia

**Role within the commitment:**
Main contribution of TUF will be related to the study of redox potentials of relevant elements as a function of solvent composition, solution speciation, and leaching mechanism of mineral phases. In addition, TUF will support US in the development of DES recycling strategies. This knowledge will be then provided for process optimisation and design.

**Name of partner:**
Natural Environment Research Council - British Geological Survey (BGS)
**Country:**
United Kingdom
**Entity profile:**
Other
**Other:**
RTO

**Role within the commitment:**
BGS will contribute to by-product potential mapping and assessment, supporting GTK activities. Specifically, they will act as assessment of by-product endowment estimates leader.
Participation in analysis and mineralogical characterisation of ore (Automated SEM WDS and LA-ICP-MS) is also expected. They will also contribute to the development of the decision support system.

Name of partner: A3i SARL  
Country: France  
Entity profile: Private sector - SME  
Role within the commitment: a3i will conduct process sustainability assessment. Main activities will be the environmental impact of BRIO process assessment and contribution to economic and technical analysis. The knowledge of the company related to environmental aspects will be very useful in process optimisation.

Name of partner: Bjorkdalsgruvan AB  
Country: Sweden  
Entity profile: Private sector - large company  
Role within the commitment: BJ main task is the implementation of BRIO process at their facilities. They will support prototype construction and will operate it in order to get evidence of BRIO process upgrade to TRL5. Feedback will be provided for process optimisation and design. Additional information will be provided to Process sustainability assessment.

Name of partner: Cobre Las Cruces S.A.  
Country: Spain  
Entity profile: Private sector - large company  
Role within the commitment: CLC will provide samples for characterisation, analysis and upstream activities optimisation, as well as exchange of feedback about CLC ore mineralogy. The company will also participate in BRIO process replication in order to further develop a conceptual design of a theoretical full scale implementation of the process.

Name of partner: ZGH Boleslaw S.A.  
Country: Poland  
Entity profile: Private sector - large company
Role within the commitment:
ZGH will send samples for characterisation, analysis and upstream activities optimisation. They will exchange feedback about ZGH ore mineralogy as well. The company will also participate in BRIO process replication in order to further develop a conceptual design of a theoretical full scale implementation of the process.

Name of partner:
Scotgold Resources Ltd
Country:
United Kingdom
Entity profile:
Private sector - large company
Role within the commitment:
SG will send samples for characterisation, analysis and upstream activities optimisation and will provide feedback about ore mineralogy. The company will participate in BRIO process replication in order to further develop a conceptual design of a theoretical full scale implementation of the process.

Name of partner:
Eramet Ingénierie
Country:
France
Entity profile:
Private sector - SME
Role within the commitment:
ERI, as engineering partner of BRIO consortium, will provide support to process optimisation and design to be carried out by IDENER. Then, they will conduct detailed engineering of the prototype, construction, assembly and deployment at BJ. ERI will support the activities to be done at BJ facilities and will provide feedback about lessons learned for process sustainability assessment.

Name of partner:
Helmholtz-Zentrum Dresden – Rossendorf EV (HIF)
Country:
Germany
Entity profile:
Other
Role within the commitment:
HIF main role is to conduct mineralogical characterisation of bulk materials before and after leaching using MLA coupled with SEM and associated support techniques. The information to be provided this way for process development is very important in order to understand how BRIO process works.

Name of partner:
University of Seville (US)
Country: Spain  
Entity profile: Academia  
Role within the commitment:  
US will lead the development of process downstream activities. These activities will be mainly focussed on solid/DES filtration, solid cleaning and treatment and DES cleaning and recovery. The knowledge to be generated and gained will be later used in replication tasks where US will define main strategies for process outputs management.

Name of partner: Wardell Armstrong International Limited  
Country: United Kingdom  
Entity profile: Private sector - SME  
Role within the commitment:  
WAI will take care of upstream activities development. Main activities will be mineral processing (physical) tests, geochemical characterisation and optimisation of mineral processing (beneficiation) options. This information will be used for the prototype design.

Name of partner: Cumbres Exploraciones SAC  
Country: Peru  
Entity profile: Private sector - SME  
Role within the commitment:  
CUM, as main representative of Peruvian deposits, will provide information and samples. Then, CUM will select one of the deposits where they conduct their activities and will participate in BRIO process replication in order to further develop a conceptual design of a theoretical full scale implementation of the process.

Name of partner: Lepanto Consolidated Mining Company (LCMC)  
Country: Philippines  
Entity profile: Private sector - large company  
Role within the commitment:  
LCMC will cooperate with partners by sending samples and providing feedback about their main ore deposits mineralogy and characteristics. The company will also participate in BRIO process replication in order to further develop a conceptual design of a theoretical full scale implementation of the process.
**Name of partner:**
5N Plus UK Limited

**Country:**
United Kingdom

**Entity profile:**
Private sector - SME

**Role within the commitment:**
5NP, as potential end-user of the recovered by-products, will assess the quality the bismuth and tellurium produced through the prototype implemented at BJ. As an additional potential adopter of BRIO process, the company will participate in exploitation activities as well.

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**Name of partner:**
EUROMINES - European Association of Mining Industries, Metal Ores and Industrial Minerals

**Country:**
Europe

**Entity profile:**
Other

**Other:**
Non-profit organisation

**Role within the commitment:**
Euromines, thanks to its tight link with main European stakeholders that could beneficiate from BRIO project results will lead exploitation activities. Moreover, the association will be involved in the development of the decision support system as they understand very well the needs of the sector.

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**Name of partner:**
Ariana Resources PLC

**Country:**
United Kingdom

**Entity profile:**
Private sector - SME

**Role within the commitment:**
Ariana will send samples for characterisation, analysis and upstream activities optimisation, and will exchange feedback about their ore mineralogy. The company will also participate in BRIO process replication in order to further develop a conceptual design of a theoretical full scale implementation of the process.

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**Name of partner:**
D'Appolonia S.p.A.

**Country:**
Italy

**Entity profile:**
Private sector - large company

**Role within the commitment:**
DAPP, thanks so its background as engineering company will lead process technological assessment and legal compliances and standardisation activities in order to ensure process sustainability. Moreover, thanks to its multidisciplinary team, DAPP will take care of exploitation plan development, focussing on market analysis.

**Existing EU contribution:**
No

**Period to implement the commitment:**
Sunday, 1 January, 2017 to Friday, 1 January, 2021