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ERA·MIN 2

RESEARCH & INNOVATION PROGRAMME ON RAW MATERIALS
TO FOSTER CIRCULAR ECONOMY

Acronym: ERA-MIN 2
Title: Implement a European-wide coordination of research and innovation programs on raw materials to strengthen the industry competitiveness and the shift to a circular economy
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DELIVERABLE D4.5

REPORT ON FINAL ASSESSMENT RESULTS OF CO-FUNDED PROJECTS

WP 4: Follow-up and monitoring of co-funded projects and co-funded call implementation
Task 4.3: Monitoring and assessment of funded projects from the co-funded call
Task Leader: UEFISCDI
Lead beneficiary: UEFISCDI
Type: Report
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ERA-MIN 2 comprises a progressive, pan-European network of 21 public research funding organisations from 18 countries/regions (Argentina, Belgium-Flanders, Brazil, Chile, Finland, France, Germany, Ireland, Italy, Poland, Portugal, Romania, Slovenia, South Africa, Spain, Spain-Castilla y Léon, Sweden and Turkey).

Built on the experience of the EU project ERA-MIN (2011-2015), **ERA-MIN 2** aims to enhance and strengthen the coordination of research and innovation programmes in the field of non-energy, non-agricultural raw materials (construction, industrial and metallic minerals) to support the European Innovation Partnership on Raw Materials, the EU Raw Materials Initiative and further develop the raw materials sector, in Europe and globally, through funding of transnational research and innovation (R&I) activities.

ERA-MIN 2 will support demand driven research on primary and secondary resources, and substitution of critical raw materials under a circular economy approach, to give the opportunity to the R&I community to apply to world-wide coordinated funding, gaining access to leading knowledge and new markets, while reducing fragmentation of R&I funding across Europe and globally. This will be achieved through one EU co-funded call for R&I proposals in 2017 and two additional calls, in 2018 and in 2019, designed and developed specifically for the non-energy, non-agricultural raw materials sector.

Publishable summary: The report assesses the final progress reports of the 16 projects co-funded by the European Commission under the ERA-MIN Joint Call 2017 following the methodology jointly agreed. It includes the analysis of the answers of the project coordinators to an online questionnaire that will inform how the projects have progressed towards the indicators established at the beginning of the project. It contains the final summaries of final project reports that are made public on ERA-MIN website.

Contents

1. Introduction

Raw materials are particularly essential for the development of innovative environmentally friendly technologies and for the manufacture of the new and innovative products used in our modern society, such as batteries for electric cars, photovoltaic systems and devices for wind turbines. Without raw materials, there wouldn't be any roads, houses, computers, smartphones, vehicles or airplanes. Economic sectors such as construction, chemicals, automotive, aerospace, machinery and renewable energy correspond to more than 30 million jobs in the EU depend on the sustainable supply of raw materials. Considering this, ERA-MIN 2 was established as a progressive, pan-European network of research funding organisations that aims to support the European Innovation Partnership on Raw Materials (EIP RM) and further develop the raw materials sector in Europe through funding of transnational research and innovation (R&I) activities. This will be achieved through calls: one co-funded call in 2017, as well as two additional calls in 2018 and in 2019, designed and developed specifically for the non-energy, non-agricultural raw materials sector.

WP 4 *Follow-up and monitoring projects and co-funded call implementation* aims at assessing the results of the ERA-MIN 2 project in terms of evaluating its contribution towards the development of Raw Materials in the European Research Area. It will assess the co-funded projects.

The objectives of this WP are:

- ✓ Definition of the monitoring indicators and ex-post assessment methodology;
- ✓ Implementation of a monitoring tool;
- ✓ Follow-up on the progress of the co-funded projects;
- ✓ Assessment of their outputs and outcomes.

Task 4.3 *Monitoring and assessment of funded projects from the co-funded call* aims at assessing the outputs of the co-funded projects at mid-term and final term and serves a dual purpose by verifying that all allocated resources are timely deployed to the research teams and by providing up-to-date progress information that can be used for administrative actions and strategic planning.

The current report assesses the final progress reports of the projects funded under 2017 call, and is part of the work carried out in Task 4.3 of ERA-MIN 2 Description of Action (Part A).

2. Methodology

The methodology was the same as used in the 1st and 2ndannual reporting: the project coordinator (PC) of each 2017 funded projects, upon the request of the respective Project Officer (PO), reported, in English, via the ERA-MIN 2 Tool (developed using survs.com facilitated by FCT), summarizing the results of the entire consortium taking into consideration that:

- ✓ The beneficiaries were instructed to immediately contact the coordinator, the Funding Organisations involved and the Joint Call Secretariat (JCS) with any contingency that may have arised;
- ✓ Besides reporting at ERA-MIN 2 level, each beneficiary in a selected funded project reported to their respective national/regional funding organisation, according to their administrative funding rules;
- ✓ In addition, the beneficiaries were asked to participate and contribute to any communication activity initiated by ERA-MIN 2 in the funding period and beyond;

- ✓ Beneficiaries were instructed to ensure that all project publications, etc. include a proper acknowledgement to ERA-MIN 2, the European Commission, and the respective Funding Organisation.

3. EU Co-funded ERA-MIN Joint Call 2017

3.1 General implementation of the call

The EU Co-funded ERA-MIN Joint Call 2017 was successfully launched with a 2-step submission procedure with a provisional call budget of € 15 million (including European Union contribution) and the participation of 17 countries/regions: Argentina, Belgium/Flanders, Brazil, Chile, Finland, France, Germany, Ireland, Italy, Poland, Portugal, Romania, Slovenia, Spain, Spain/Castille and Léon, Sweden, South Africa, and Turkey.

In order to secure a sustainable and responsible supply of raw materials to the economy and industry, the EU Co-funded ERA-MIN Joint Call 2017 addressed three segments of the non-energy, non-agricultural raw materials:

- ✓ Metallic,
- ✓ Construction, and
- ✓ Industrial minerals.

The ERA-MIN Joint Call 2017 in figures:

- ✓ 94 pre-proposals submitted;
- ✓ 493 applicants involved (of which 133 enterprises)
- ✓ 5 main call topics on “Raw materials for the sustainable development and the circular economy”;
- ✓ 35 full-proposals submitted;
- ✓ 16 transnational R&I projects funded;
- ✓ 88 beneficiaries (of which 34 enterprises);
- ✓ 12.3 million € of public (national, regional and EU) funds;
- ✓ 16 million € of total project costs.

The following 16 projects were selected for funding (in alphabetical order of the acronyms):

1. AMTEG - Advanced Magnetic full TEnsor Gradiometer instrument
2. BIOMIMIC - Innovative biotechnological methods for effective mining of secondary material
3. BASH-TREAT - Optimization of bottom ash treatment for an improved recovery of valuable fractions
4. Deasphor - Design of a product for SUBSTITUTION of phosphate rocks
5. FLOW - Lightweight alkali activated composite foams based on secondary raw materials
6. Gold_Insight - Tracing Gold-Copper-Zinc with advanced microanalysis
7. INSTAnT – Innovative sensor technology for optimized material recovery from bottom ash treatment
8. LIGHTS - Lightweight Integrated Ground and Airborne Hyperspectral Topological Solution

9. **Li+WATER** - Membrane electrolysis for resource-efficient lithium and water recovery from brines
10. **MaXycle** - A novel circular economy for sustainable RE-based magnets
11. **MetRecycle** - Recycling of metals using functionalized magnetic nanoparticles (FMNP)
12. **MINTECO** - Integrated eco-technology for a selective recovery of base and precious metals in Cu and Pb mining by-products
13. **MONAMIX** - New concepts for efficient extraction of mixed rare earths oxides from monazite concentrates and their potential use as dopant in high temperature coatings and sintered materials
14. **RecEOL** - Recycling of End-of-Life Products (PCB, ASR, LCD)
15. **REWO-SORT** - Reduction of Energy and Water consumption of mining Operations by fusion of sorting technologies LIBS and ME-XRT
16. **SUPERMET** - Recovery of Precious Metals from Spent Catalysts by Supercritical CO2 Extraction Assisted by Polymers.

3.2 Funded consortia

The 16 projects selected for funding had starting dates in April/May 2018 and 14 of them with 36 months implementation while 2 of them with 24 months. As these projects were implemented during the COVID-19 pandemia, 4 projects were granted extensions upon request.

The total budget allocated to the 16 projects was 12.241,517 euros with an average of requested budget per project of 765.095 euros, and the project with the highest budget was Deasphor with 1.405.498 euros (coordinated by Portugal). Almost all countries/regions participating in the call have a representative funded, except for Castille and Léon Spanish region and South Africa. France, Germany and Slovenia coordinate altogether the majority of the selected projects (9 out of 16) but the largest number of funded partners was found in Germany, Sweden followed by France (Figure 1). It should be noted that a Hungarian company participating with own funds is a partner in one of the projects.

Country	No. of coordinators	Coordinators - total funding	No. of partners	Parteners - total funding	Total count of partner role	Total sum of funding
Argentina	1	100.000	1	50.000	2	150.000
Belgium	1	300.684	4	461.873	5	762.557
Brazil	0	0	1	165.000	1	165.000
Chile	0	0	1	85.840	1	85.840
Finland	0	0	1	271.000	1	271.000
France	3	697.271	7	687.991	10	1.385.262
Germany	3	809.796	17	3.563.225	20	4.373.021
Hungary (observer)	0	0	1	0	1	0
Ireland	2	310.401	3	285.812	5	596.213
Italy	0	0	4	280.000	4	280.000
Poland	0	0	4	372.500	4	372.500
Portugal	1	250.000	2	127.500	3	377.500
Romania	1	162.750	6	602.000	7	764.750
Slovenia	3	552.820	1	74.700	4	627.520
Spain	0	0	2	251.803	2	251.803
Sweden	1	221.175	15	1.222.876	16	1.444.051
Turkey	0	0	2	334.500	2	334.500
Total	**16**	**3.404.897**	**72**	**8.836.620**	**88**	**12.241.517**

Figure 1 – Data on projects funded under 2017 Joint Call: number of coordinators/partners and budget distribution

The average size of the consortia was 4.5 partners and 3 of the 16 consortia were formed with 2 partners; project BIOMIMIC is the project with the largest number of partners, not counting with the coordinator is 10 (Figure 2).

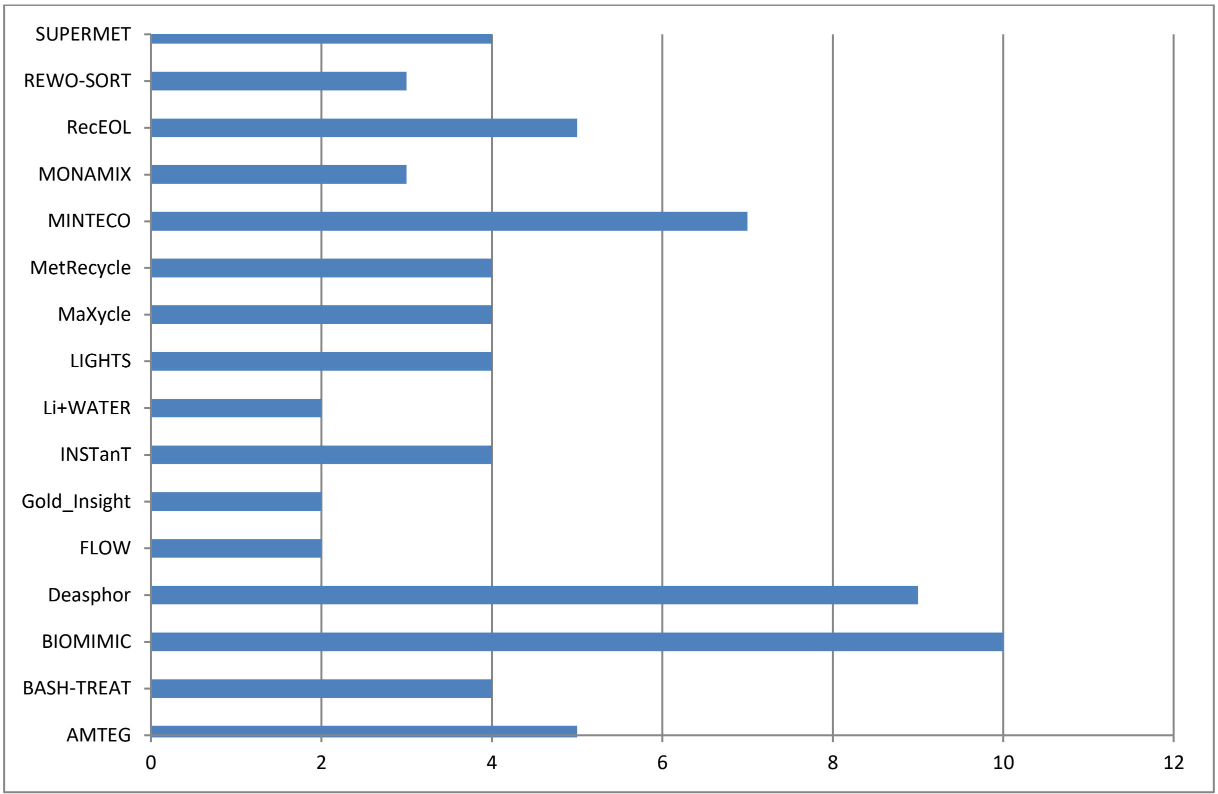


Figure 2 – Distribution of partners per consortium, not counting with the coordinator institution.

In terms of topics, the 2017 Call had 5 main topics and 17 subtopics. The subtopics addressed by the funded projects are presented below:

1. Supply of raw materials from exploration and mining
    - 1.1. Exploration ***(AMTEG; LIGHTS; GOLD_INSIGHT)***
    - 1.2. Mining operations ***(REWO-SORT)***
    - 1.3. Mine closure and reclamation
2. Design
    - 2.1. Product design for increased raw material efficiency ***(MaXycle; MONAMIX)***
    - 2.2. Product design for reuse or extended durability of products ***(MaXycle)***
    - 2.3. Product design to promote recycling ***(MaXycle)***
    - 2.4. Product design for critical materials substitution ***(Deasphor; MONAMIX)***
3. Processing, Production and Remanufacturing
    - 3.1. Increase resource efficiency in resource intensive production processes ***(BIOMIMIC; Li+WATER; BASH-TREAT; MINTECO)***
    - 3.2. Increase resource efficiency through recycling of residues or remanufacturing ***(MaXycle; BIOMIMIC; FLOW; BASH-TREAT; Deasphor; MINTECO; MetRecycle)***

3.3. Increase resource efficiency using information and communication technologies ***(MaXycle)***

4.1. End-of-life products collection and logistics ***(MaXycle)***

4.2. End-of-life products pre-processing: pre-treatment, dismantling, sorting, characterisation ***(MaXycle; INSTAnT)***

4.3. Recovery of raw materials from End-of-life products ***(MaXycle; BIOMIMIC; RecEOL; INSTAnT; SUPERMET; MetRecycle)***

4.4. Increase recycling of End-of-Life products through information and communication technologies ***(MaXycle; INSTAnT)***

5.1. New business models ***(MaXycle; BIOMIMIC; RecEOL)***

5.2. Improvement of methods or data for environmental impact assessment ***(MaXycle; BIOMIMIC; BASH-TREAT)***

5.3. Social acceptance and trust/public perception of raw materials ***(BIOMIMIC).***

In terms of the topics & subtopics of the funded projects:

- ✓ all 5 main topics are covered by the funded projects;
- ✓ 7 out of 16 projects cover only one subtopic (AMTEG; Li+WATER; FLOW; LIGHTS; GOLD_INSIGHT; SUPERMET; REWO-SORT), while 9 of them are multidisciplinary/cross-cutting projects, with 2, 3, 6 or 11 subtopics covered; this is in line with ERA-MIN 2's objective of covering the entire raw materials value chain, from sustainable exploration, exploitation, processing, substitution of critical raw materials and resource efficient production to short-term economic feasible and low environmental impact recycling;
- ✓ subtopic *3.2 Increase resource efficiency through recycling of residues or remanufacturing* stands out with 7 funded projects, when compared to the other subtopics (Figure 3).

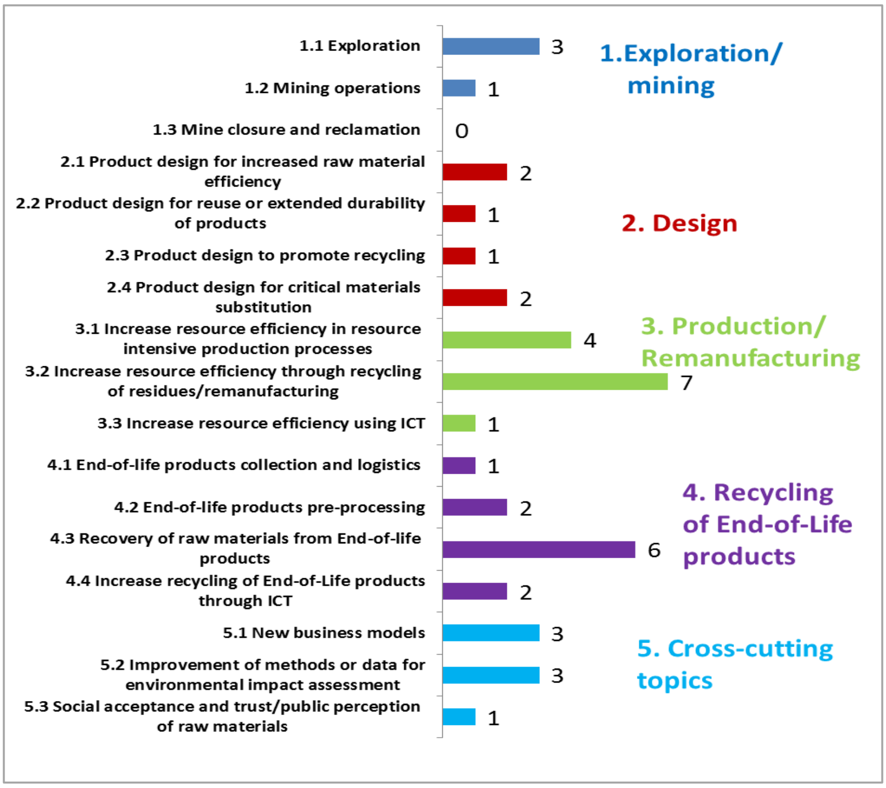


Figure 3 – Subtopics addressed by the 16 funded projects (Source: D3.5. List of projects selected for funding)

In terms of the distribution of consortia coordinators and partners by type of organization:

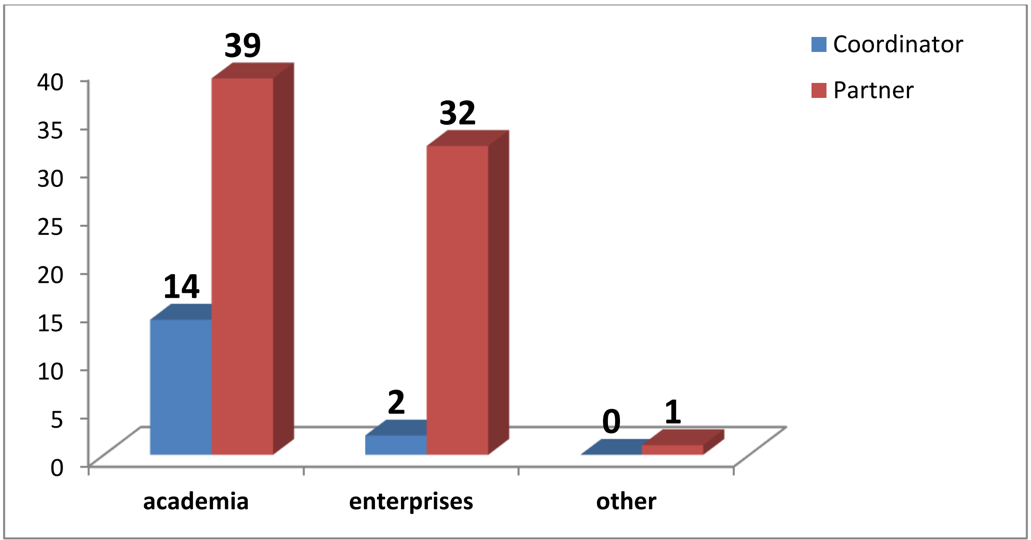


Figure 4 – Distribution of consortia coordinators and partners by type of organization

3.3 Consortium forming

The main objective of ERA-net calls is to attract new transnational research collaborations. Regarding this, in ERA-MIN 2017 Call:

- ✓ 31.25% of the consortia never had collaborated before,
- ✓ 50% were formed by a mixture of existing and new collaborators; and only
- ✓ 18.75% were composed solely by existing collaborators.

The figures above confirm the high potential of this kind of projects to enhance collaboration and reduce fragmentation of the European Research Area (ERA) in European Union.

For the ones that found new partners for this call, 2 projects used our online Partner Search Tool on ERA-MIN website, 7 found them in networking events including workshops, seminars, scientific conferences (e.g. 2017 InnoMine Chile workshop) and 4 through web search, social or professional networks.

For the ones that collaborated before 2017 call, 7 of the projects submitted previous grants for transnational research projects (to H2020 Twinning, EARTO, ERA-MIN 2014 and 2015 calls, EU-H2020-SC5, Bilateral project Slovenia – Argentina (2013 -2014), COST action MP1202 (10/12/2012 to 09/12/2016), H2020-H-CCAT project, KIC RawMaterials, DT-NMBP-19-2019).

4. Final Results

At ERA-MIN 2 level, the data on the 16 projects were made available through a catalogue of projects with a list of project summaries, a list of consortium partners, and the summaries of first and second year progress reports at the ERA-MIN 2 website (https://www.era-min.eu/results):

- ✓ ERA-MIN Joint Call 2017 - Catalogue of projects[1] (also available on YouTube)

[1] https://www.era-min.eu/sites/default/files/docs/2018_09_20_eramin2_brochura_web_0.pdf

- ✓ 2017 – ERA-MIN Joint Call on Raw Materials for Sustainable Development and the Circular Economy[2]
- ✓ ERA-MIN Joint Call 2017: Publishable Summaries - First Year Project Reports[3]
- ✓ ERA-MIN Joint Call 2017: Publishable Summaries - Second Year Project Reports[4].

The results analysed below are based on final reports provided by the project coordinators of all 16 funded projects.

4.1 Consortium collaboration and sustainability

During the implementation period, the projects continued their collaborations and tried to be successful in other initiatives as follows:

- ✓ new collaborations were established:
  - 3 national collaborations (e.g. MetRecycle "*IOS is collaborating with the national waste industry representatives, such as Surovina d.o.o., Saubermacher Slovenija d.o.o., and Snaga d.o.o., to establish appropriate extraction of various metals from electronic waste. SLU has established collaboration with the company EasyMining Sweden AB, a part of Ragn Sells Concern. SLU is discussing possible implementation of new adsorbents in recycling technologies in Scandinavia and help the company with electron microscopy and XRD studies.*")
  - 3 international collaborations (e.g. MetRecycle "***CNRS collaborates with University Autonoma de Barcelona, Pr Roser Pleixats on the development of new cyclens-based ligands"***)
  - 2 projects collaborated with other initiatives: MetRecycle&Flow (e.g. ***MetRecycle "IOS is involved in EUROSTARS project E!113543 »Recycling of the heavy metals from wastewaters – HMRecycle«);***
  - 1 collaboration with other ERA-MIN 2 projects (e.g. NEXT-LIB project).
- ✓ consortia applied to other 63 new national/transnational calls (out of which there were mentioned one ICGM = ADEME PhD grant, one IFS = CITEO SUPERPE, one ICT H2020 REMADYL) out of which 17 were funded (e.g. CE_NCC_FCUP_AD/20A007).

The successful networks built under ERA-MIN Call 2017 will continue the cooperation after the end of the project is in place, namely:

- ✓ 7 projects applied for another project;
- ✓ 10 projects mentioned there is an intention to further collaborate but the partners did not identify yet the relevant form of collaboration or relevant support scheme;
- ✓ one project will continue on commercial terms, together also with two of the partners;
- ✓ 11 projects will explore further collaboration with parties outside the consortium as well.

As COVID-19 crisis took place during the implementation of these projects, most of the projects were affected by this pandemia, which resulted in extensions requests in some cases, but also other kind of deviations/changes were reported by 4 projects:

[2] https://www.era-min.eu/sites/default/files/docs/era-min_funded_projects_2017_table.pdf
[3]https://www.era-min.eu/sites/default/files/docs/era-min_call_2017_first_year_of_funded_projects_summaries.pdf
[4]https://www.era-min.eu/sites/default/files/docs/call_2017_publishable_summaries_second_year_project_report.pdf

- ✓ Initial enterprise left the project because of unrelated financial difficulties and was replace by another company;
- ✓ Due to the impossibility to sign the contract with the Brazilian funding agency, another partner of the project took over the activities;
- ✓ One company was restructured, so the new resulting company was the new partner;
- ✓ Changes in personnel.

The mobilization of resources is also reflected in the number of staff people involved in the 16 projects, a total of **346 researchers** were reported to be working with an average of 22 persons per project; **35%** are **young researchers**. In terms of gender dimension, **42%** of persons involved in projects are **women**. In terms of balance of genders in management of the projects:

- ✓ There is a very good balance of project leaders: 42% Females and 58% Men;
- ✓ Out of the 88 beneficiaries: 32 have female leaders (36%) and 56 have men leaders (64%);
- ✓ Project FLOW has only females as project/partner leaders;
- ✓ Projects LIGHTS and REWO-SORT have only men as project/partner leaders.

For the whole implementation period, projects also reported creation of **24 permanent** and **121 temporary jobs**.

4.2 Impacting society through dissemination and exploitation

Regarding dissemination and exploitation activities, all projects participated in dissemination activities, carrying out popularization of the aims of the projects and their results. All funded projects implemented web pages for dissemination purposes, but the dissemination plans are sometimes unbalanced between projects, one of them using multiple channels (social networks, media, etc.), other just webpages and scientific channels. (*Annex 1 – Promotion of activities*).

Effective communication is crucial for the success of transnational collaborative projects, such as those funded under ERA-MIN 2017 Call. Dissemination is crucial for providing visibility to the project to various stakeholders, such as members of the scientific community, public and media. Moreover, it allows for increased distribution of the results and outcomes of the project, as well as its potential impact.

During the implementation period, the projects and results were promoted as widely and as effectively as possible to all the relevant stakeholders, scientific publications and media by relevant movie clips on YouTube or another video channel, social and professional networks and blogs, other (popularization magazine, day of open door etc.)

Regarding the scientific results, a total of **100 publications** were reported, out of which **57** following **open access** principles, 29 publications dedicated to general public, 146 oral communications and 48 posters.

4.3 Exploitable results (outreach to companies)

The Call included topics focused not only on the generation of new knowledge, but also to the development of new products, methods, models, processes, services, equipment and prototypes enabling thus proposals with innovation character and facilitating the participation of Funding Organisation's funding the industrial sector. **37%** of the partners participating in the consortia were private companies/private non-profit research organisations, thus made possible the design of the outputs with a higher potential for knowledge transfer and creating impact in the economy sector and society.

Exploitable results of different nature were delivered by the projects, mainly in the form of publications. Regarding results that required IPR actions, the patents and licences reported in the 3rd year reports were:

- ✓ 7 submitted patent applications;
- ✓ 2 national granted patents;
- ✓ 2 licences;
- ✓ 2 spin-offs.

We also wanted to evaluate the outreach to companies, or stakeholders, on the developments/results obtained in these projects. All projects mentioned that they have approached, or have been approached, by companies or stakeholders, most significant are:

- ✓ a research consultancy contacted one of the projects to introduce a market-mature version of solution resulted from the project(aim with TRL 8-9);
- ✓ Project presentations were made for many and different companies: AngloAmerican (UK), Alrosa (Russia), DIAS (Canada) and Southern Geoscience Consultants (Australia), company EasyMining,
- ✓ some interested parties from the following countries Scandinavia (3), South America (2), Africa (1) and Asia (3) approached the partners of one project. A potential customer in Norway has already been acquired for the volume flow stand-alone device, with whom a paid study has already been carried out;
- ✓ Projects were approached by: Supracon AG - SUP, Institute of Photonic Technology – IPHT, Ingenieur-Gesellschaft fur Interfaces – IGI, Geognosia S.L. – GEO, Nordic Iron Ore AB – NIO the enterprise Güres Energy (Turkey), Swedish Research Institute for Mining, Metallurgy and Materials, IMC Exploration Ltd., and Agnico Eagle Ltd, Firecrest Resources, Arkle Resources, Dalradian Resources, Galantas Gold and Puma Exploration Ltd; : Magneti Ljubljana, d.d., and Saubermacher Slovenija d.o.o., Surovina d.o.o., Slovenian waste management institutions; Leading Edge Materials
- ✓ The project outcomes generated new industrial collaboration with a company;
- ✓ A French company specialized in the production of iron oxide particles from ferrous wastes has been contacted to introduce raw materials from circular economy in the project;
- ✓ A project has contacted a company for discussion of how a high-throughput reactor can be built up for industrial implementation of the proposed magnetic nanoadsorbents;
- ✓ A partner has contacted a company specialized in wastewater treatments for discussion;
- ✓ MONAMIX was one of the projects included as a business case in the COST Innovation Grant 15012 ITHACA (2019-2021);
- ✓ A partner has been approached by recycling companies and consultants working in the recycling sector and is now in contact with organisations in the US, Germany, Switzerland and Australia on the possibility to recycle pure and mixed plastic waste streams. These contacts are a direct result of our paper on mixed plastic recycling with molten metal and aluminium laminated plastic recycling;
- ✓ A new recycling strategy for Indium from LCD screens has been proposed and was awarded during the scope of the project. The novel route of LCD molten salts pyrolysis has certain

advantages over the commonly studied hydrometallurgical approaches such as direct treatment of the LCD glasses without dislayering. However, the process is in the early stage and need to be further developed before market use. Moreover, the current low prices of indium are making any type of recycling process unprofitable. The industrial interest is assumed to rise in the upcoming years, since indium is considered a critical metal;

- ✓ Another project has been approached by ETRA (European Tire Recycling Association) on a possible exploitation of the carbon fiber recycling process. Moreover, they have been invited to participate in a H2020 call on the recycling of lithium-ion pouch batteries for automobiles;
- ✓ Another project has approached a French SME for recycling of strategic metals from Li-ion batteries, and a PhD work has started on this topic in November 2021.

Also, 7 projects reported that results of the projects have been implemented by the industry to some extent, among which:

- ✓ Interpretation of the data in comparison with the existing information to apply in future exploration on the area;
- ✓ There is the intention to further replicate and further test at full-scale part of the activities developed within this project;
- ✓ There is an ongoing pilot scale project in Argentina, financed by 2 Argentinean companies;
- ✓ The results in using Finnish steel slag and mineral wool have been used to further develop the use of carbonated BOF and De-S slags in calcium silicate bricks. The hot-pressing technique applied for stone wool attracts attention from an industrial partner and led to a continuation work in this topic after the end of project;
- ✓ Research has led to new exploration strategies, with the modification of drilling programs in the search for Cu and Au deposits. Data and new genetic models for Cu and Au has led to the discovery of new resources along terranes;
- ✓ Hybridon company has been created, which is a spin-off of INS-UNSAM, in collaboration with ADOX, a local company dedicated to health; hybrid materials containing metal ions used as antibactericial agents. TECSAN company has an ongoing project with INS-UNSAM for exploiting technology linked to precious metal recovery.

4.4 Outreach to public and policymaking

As gaining public and policymaking trust in industrial activities is increasingly important in securing the raw materials supply in Europe from primary and secondary sources, funded projects were also asked to report whether policymakers where invited to project related events/networking. As a response, 5 projects reported having organised workshops for better uptake of the results by industrial partners.

It is also significant mentioning that:

- ✓ One project's results have led to the development of several analytical standards in stages of certification and review;
- ✓ Another's project results will be considered in the framework of ISO/TS22451, and have already contributed to the ERMA Action Plan on Rare Earth Magnets;
- ✓ The International Conference Nano4Circularity was organized by one of the projects and Chamber of Commerce and Industry of Styrian (ŠGZ) which is leading SRIP – Network for the Transition to Circular economy;

- ✓ One project's results have been presented to the State Secretary of Romanian Ministry for Research and Innovation, with the occasion of EmergeMAT conference and project meeting, 15 Nov. 2018, Hotel CARO, Bucharest;
- ✓ Dissemination work of a project was performed through Pollutec technical fair in France (Nov-2018).

5. Progress in terms of impact

After the implementation of the projects, the impact and achievements of the projects within the main challenges of research and innovation on non-energy, non-agricultural raw materials is shown in the Table 1:

	ERA-MIN 2 impact / achievements				
	Primary resources	**Design**	**Production /remanufacturing /use, reuse and repair/recycling**	**Production, remanufacturing /recycling**	**Material cycle**
AMTEG	X				
BASH-TREAT			X	X	X
BIOMIMIC		X	X	X	
Deasphor		X			X
FLOW	X			X	X
Gold_Insight	X				
Li+WATER			X		
LIGHTS	X				
MaXycle		x	x	x	x
MetRecycle			X	X	
MINTECO			X		X
MONAMIX		X			
RecEOL				X	X
REWO-SORT	X		X	X	X
SUPERMET					X

Table 1 – Impact/achievements of projects.

As can be seen, only 31% have results in one challenge, while the rest have addressed almost the entire raw materials value chain. The obtained results will mostly be used of R&D activities in their organisations and in other joint projects, but also 5 projects will use them for production and business operation in the institutions, and 7 projects have collaborations outside the project partners (see Table 2).

	How will the research results of the project be utilised?				
	For further R&D in our organisation/ company	**For production and business operations in our company**	**Other project participants will utilise the results**	**Parties outside consortium will utilise the results**	**Other joint projects**
AMTEG	x	x	x		x
BASH-TREAT	x			x	x

	How will the research results of the project be utilised?				
	For further R&D in our organisation/ company	**For production and business operations in our company**	**Other project participants will utilise the results**	**Parties outside consortium will utilise the results**	**Other joint projects**
BIOMIMIC	x	x	x	x	x
Deasphor	x		x		x
FLOW	x		x		x
Gold_Insight	x			x	
Li +WATER	x			x	x
LIGHTS	x	x	x	x	x
MaXycle	x		x	x	x
MetRecycle	x	x			x
MINTECO	x				x
MONAMIX	x				x
ReCEOL	x	x		x	
REWO-SORT	x		x		x
SUPERMET	x		x		x

Table 2 – Results utilisation

Also, among the biggest impact mentioned by the projects, it can be emphasized:

- ✓ Worldwide unique demonstrator with capability of full-tensor instrument gradiometer and AFMAG in parallel;
- ✓ Growing interest in the further recovery of metal and especially mineral fractions from incineration residues;
- ✓ New bioprocess that can treat cold mining water; the project has also demonstrated the ability to recover sulfides in a concentrated form;
- ✓ Proof of potential of extraction from laying hen manure;
- ✓ Confirmed the feasibility of investigated technology, i.e. that by means of alkali activation technology many waste materials or side stream can be utilized for the production of alkali activated products - in the future industrial partners can utilize this technology;
- ✓ The Gold_Insight project has created and developed an innovation platform for higher participation of EU institutions in the global exploration market and featuring a collaborative network of Trinity College Dublin, Lulea University, iCRAG, NordSim, and Geological Surveys. Most notably, Gold_Insight was instrumental in targeting West Avoca for Cu-Pb-Zn resources based on 4D modelling of the Avoca Belt. This has directly expanded Raw Material Resources/Reserves for Europe;
- ✓ A new process for lithium rich brine processing, with production of several by-products, including water. Process still under development;
- ✓ An integrated technology allowing the rational use of rare earths in design and obtaining thermal barrier coatings for gas turbine applications and sintered ceramics for potential SOFC.

Also, for reaching the proposed objectives, the projects also developed 22 new products, 38 methods, 20 models, 29 processess, 6 services, 9 equipments, 11 prototypes, 5 new organisation methods and new marketing concepts or strategies (Table 2).

ERA-MIN 2 Major developments									
	Product	Method	Model	Process	Service	Equipment	Prototype	New org. method	New concept/ strategy
AMTEG	1	2	1	1	2	1	1		
BASH-TREAT	4	1	1	2			2		
BIOMIMIC		3	2	3		1	3		
Deasphor	2	5	2	2			1		
FLOW	5	5	1	3	1	2	1		
Gold_Insight		1	2	1	1				
Li+WATER	1			1					
LIGHTS		2	5	1		2			
MaXycle	2	3	1	3		1		1	
MetRecycle	1	1		1	1				
MINTECO	1	3	1	3			1		
MONAMIX	3			4					
RecEOL		1		3		1	2	2	
REWO-SORT	1	4	1	1	1				1
SUPERMET	1	7	3			1			1
Total	**22**	**38**	**20**	**29**	**6**	**9**	**11**	**3**	**2**

Table 2 – Major developments

6. Project officer's inputs

According to ERA-MIN monitoring procedure, each funded project was assessed by the project officer coming from the funding agency of the coordinator, who was responsible for monitoring the project progress within that respective project. When asked about their impression on how projects reached their goals, 12 out of 16 expressed their agreement that projects met their planned objectives, while 2 had minor delays (COVID-19 or technical) and 2 other projects were not assessed yet.

7. Conclusions

This report refers to the monitoring of the last year of the 16 transnational R&I projects funded under ERA-MIN Joint Call 2017, in which projects were affected by the COVID-19 pandemia during their implementation. Extension of projects' duration were granted in many cases because the EU funded project ERA-MIN 2 was extended by 12 months thus reaching 72 months in total.

The influence of the pandemia was seen in the transnational collaboration where meetings were held virtually, just as communications in different conferences were done. Most affected were the staff exchange and restrictions in some labs/institutions. Nevertheless, the adopted mitigation measures (virtually participation to all events, extensions granted) helped these projects to achieve their results and finish their activities, as it can be seen from this report:

- Most of the projects will continue cooperation after the end of the projects, some having already applied for another project, others still searching for the right calls, while others also adding new partners in future projects;
- The majority has a dissemination plan where mainly social and professional networks and blogs were used, and in most of the cases, a dedicated website as well videos and participation in business fairs (Annex 1);
- In relation to the **major impact of the funded projects**, it includes the significant contribution to resource efficiency and promoting the recycling of raw materials; the novel recycling approach of REE from real process water samples for company Magneti Ljubljana, d.d..; the growing interest in the further recovery of metal and especially mineral fractions from incineration residues; the worldwide unique demonstrator with capability of full-tensor instrument gradiometer and AFMAG in parallel; a potential extraction of P from laying hen manure; the utilisation of many waste materials, or side stream, for the production of alkali activated products and this technology can be utilized by industrial partners in the future; new lightweight alkali activated foams based on secondary raw materials, such as slags were developed and the pilot products at laboratory and industrial-scale were developed and assessed from durability point of view and impact on environmental and human health with applications in wide range as thermal and acoustic insulating products and as other construction materials; an integrated technology allowing the rational use of rare earths in design and obtaining thermal barrier coatings for gas turbine applications and sintered ceramics for potential SOFC; the targeting West Avoca for Cu-Pb-Zn resources based on 4D modelling of the Avoca Belt expanding Raw Material Resources/Reserves for Europe; a new process for lithium rich brine processing, with production of several by-products, including water; a new bioprocess that can treat cold mining water to meet the requirements of the EU Water Framework Directive and national law; the new ongoing research in collaboration with new projects involving Raw Materials Exploration within the EU and worldwide;
- The 16 projects have developed new products (22); methods (38), models (20), processes (29), services (6), equipment (9), prototypes (11), 5 organisation methods and one new marketing concepts or strategies;
- Seven patents were submitted for approval, two national patents were granted, two licenses and two spin-off companies were created;
- A good record of different type of publications was achieved: 100 in total (out of which 57 following open access principles and 29 publications dedicated to general public);
- In terms of human resources, 346 researchers were involved of which 35% were young researchers. There was a good gender balance (42% were women) and 24 permanent and 121 temporary jobs have been created;
- The large number of communications already presented in scientific conferences (events used not only for networking but also for engaging with stakeholders and industry).

As we can see in this report, the variety and quantity of results shows the impact of these projects within the main challenges on non-energy, non-agricultural raw materials regarding research and innovation; Moreover, the majority of the projects have addressed almost the entire raw materials value chain. The obtained results will mostly be used not only for R&D activities in their organisations and in other joint projects, but also for production and business operation in the institutions (5 projects) and for collaborations outside the project partners (7 projects).

The publishable summaries of the final project reports are in Annex 2.

Annex 1 : Promotion of activities

1. Relevant project movie clips on YouTube or another video channel

Project	Clips on YouTube or another video channel
BASH-TREAT	https://www.youtube.com/watch?v=3zYqrLwE1KI
Deasphor	ERA-MIN3 & Call 2021 Launch event. DEASPHOR project video at https://youtu.be/G61yipkJloI Bioeconomy day. Italy. May 27, 2021. Elza Bontempi interview at: https://www.instm.it/news/bioeconomy_day_aires_esempio_di_collaborazione_fra_imprese_e_istituti_di_ricerca.aspx
FLOW	3 project's videos: https://www.youtube.com/watch?v=5URKVe9RI2g; https://www.youtube.com/watch?v=lXHIHuO6ebM; https://www.youtube.com/watch?v=JSsz1IYy-aY
Li+ WATER	https://youtu.be/HZyZPtK3_6U
MaXycle	https://www.youtube.com/watch?v=FZEQIZi1gpY
MetRecycle	Project MetRecycle on ERA-MIN3 youtube channel - https://www.youtube.com/watch?v=exQ-b2zaVog&t=20s&ab_channel=ERA-MIN3
MONAMIX	Monamix tutorial: https://www.youtube.com/watch?v=prfLAYOhE4w
SUPERMET	https://youtu.be/_FgS5RS_UC0, https://youtu.be/JfsjUPQJu3s , https://youtu.be/Wd0k7ELQWag

2. Dissemination on social and professional networks and blogs:

Project	Social and professional networks and blogs
BASH-TREAT	International Waste Working Group IWWG; ProcessNet-Fachgruppen Abfallbehandlung und Wertstoffrückgewinnung, Energieverfahrenstechnik, Gasreinigung, Hochtemperaturtechnik, Rohstoffe
BIOMIMIC	https://www.linkedin.com/company/biomimic/
FLOW	https://www.facebook.com/Eramin2FLOW
LIGHTS	LinkedIn pages from Beak & GeoRessources used for dissemination
MaXycle	EU Green Week Partner Event: Quantifying environmental impacts in rare earths value chains, Expert Roundtable discussion
MetRecycle	Facebook and twitter account "Inštitut za okoljevarstvo in senzorje"
REWO-SORT	Press release: https://www.iis.fraunhofer.de/de/pr/2018/20180709_EZRT_Rewo.html
SUPERMET	Linkedin, Institut Carnot Chimie Balard Cirimat network http://www.carnot-chimie-balard-cirimat.fr/fr/projet-supermet-recuperation-produits/ ICIA website https://icia.ro/2018/07/27/supermet/, IFS web site http://www.portail-fluides-supercritiques.com/Actualites-Archives.114.0.html?&annee=2019 , ICT website https://www.ict.fraunhofer.de/en/press_media/press_releases/2018/2018-06-14.html

3. Other:

Project	Other dissemination tools
AMTEG	day of open door for the public at Ludvika airfield during field campaign. See www.leibniz-ipht.de/abteilungen/quantensysteme/projekte/amteg
BASH-TREAT	BASH-TREAT project publication repository @TUHH: https://tore.tuhh.de/cris/project/pj01805?locale=en&type=null
Deasphor	Mid-term Seminar ERA-MIN Joint Call 2017, Brussels, Belgium 18 November 2019, Project DEASPHOR “Design of a product for SUBSTITUTION of phosphate rocks” GREEN NIGHT, 21-07-2021. European Researchers' Night project funded by the EC under HORIZON 2020 in the framework of the Marie Sklodowska Curie actions. Ege University, Izmir Institute of Technology was partner in the project, and presented the communication “Organik Atıkların Enerji ve Hammadde Olarak Değerlendirilmesi”.
MetRecycle	The project is presented in a promotional folder – SRIP (STRATEGIC RESEARCH AND INNOVATION PARTNERSHIPS) – Network for the Transition to Circular economy.
MINTECO	web pages of Brgm https://www.brgm.fr/production-scientifique/projets/liste-projets , INOE https://icia.ro/en/2018/07/27/minteco/ MEERI https://min-pan.krakow.pl/projekty/en/2019/02/19/minteco/
MONAMIX	COST Action CA 150102
SUPERMET	popularization magazine https://www.enviscope.com/des-metaux-precieux-recuperes-grace-au-co2-supercritique/ https://www.lesechos.fr/pme-regions/auvergne-rhone-alpes/pourquoi-les-pme-du-recyclage-se-ruent-sur-les-metaux-rares-1357176

4. Business fairs during which project results were showcased:

Project	Business fair	Partner participating
AMTEG	Prospectors & Developers Associaton of Canada, Annual Meeting 2019	Leibniz-IPHT, SUP
BASH-TREAT	IFAT 2018-2022 World's Leading Trade Fair for Water, Sewage, Waste and Raw Materials Management	P1-P4; P1
BIOMIMIC	IBS Japan, Open House RISE, Geoscience Industry, BIOMINING: “Microbial sulfate reduction for treatment of mine water from an old mine adit” and Academia Conference,	RISE, UL, GEOS
FLOW	How to approach the marketing of innovative products at different TRL levels; http://www.zag.si/ajax/DownloadHandler.php?file=2896	Slovenian National Building and Civil Engineering Institute
Gold_Insight	PDAC: Prospectors and Developers Convention	TCD-LTU
MaXycle	EIT RAW Materials (Expert Forum Sustainable Materials for Future Mobility); The REIA Conference on REE Sustainability and Criticality; The H2020 Technological Success Stories Session III of the Raw Materials Week; A virtual exhibition GZS Future Circles, Chamber of Commerce and Industry of Slovenia, 2019 Sustainable Industrial Processing Summit and Exhibition; Rare earth magnets in the Circular Economy, Circular Transformation Hub; Automotive Industry in Baden-Württemberg; TBMCE; Materials and Final Products – Chamber of Commerce; Innovations day; RSC’s Environment,	All (depending on event)

Project	Business fair	Partner participating
	Sustainability & Energy Division; Meeting with cluster management e-mobil BW; Quantifying Environmental Impact in Rare Earth Value Chains.	
MetRecycle	Tech'Innov 2020; Dubai Expo 2020	SiKEMIA; IOS
MINTECO	POLLUTEC, AQUATECH, Global Industry, CITEXT, TEXTIVAL, INNOVEIT	Ajelis (precited) / Meeri (EKOTECH) / BRGM (Pollutec2018)
MONAMIX	Traian Vuia	All
REWO-SORT	GEOMET PROCEMIN 2019	1,2
SUPERMET	POLLUTEC 2021 international fair, https://www.pollutec.com/fr-fr.html	IFS, ICGM

Annex 2 : Summary of the project progress and the results obtained at project closure (publishable abstracts)

AMTEG:

The most significant results of the AMTEG project include the realisation of a 3D vector magnetometer (3D-VM) that achieved a worldwide unpublished intrinsic noise levels of 10 fT/√Hz. The gradiometers developed in parallel for the full-tensor instrument (FTMG) also exhibit world-first noise levels of 125 fT/(m·√Hz) in the integrated system. Likewise, a dynamic range of 145 dB has been realised, which makes the system unique worldwide also with respect to the low noise values and high slew rates. Additionally, these properties enabled the system for the first time airborne AFMAG measurements even in anthropogenically disturbed environments during the project final measurement in Sweden. Significant steps were taken towards a high-resolution hybrid system for simultaneous measurement of full tensor gradients and 3D-VM, giving the AMTEG system a unique performance potential of passive geometry-imaging magnetics for high-resolution modelling of magnetic properties (magnetisation, remanence and susceptibility) and passive electromagnetics for determination of conductivity distribution in the subsurface down to depths of more than 1,000 m. In this context high performance components, like an innovative data acquisition system, sensor-near readout electronics and noise reduced cryogenic Dewar, play an important role for this innovation. In this research, all project goals were achieved and only the last integration step fell victim to pandemic conditions and was solved by a solution containing two separate demonstrator systems for FTMG and 3D-VM. The performance potential of the integrated system and the sensors used was picked up and extended by novel algorithms for data processing and inversion. In this process, noise influences could be reduced and the integral data quality improved, which significantly increased the inversion possibilities and their informative value with respect to magnetic and electromagnetic subsurface properties.

BASH-TREAT

BASH - TREAT

The production of Municipal Solid Waste generated in Europe was more than 250 Million Mg. An increasing quota of it is currently thermally treated (29 wt), therefore, the optimization of the recovery of secondary raw materials from incineration bottom ash is required. This involves reaching higher performances for the recycling of metals and different mineral fractions, as incineration is expected to play a key role in the transition towards zero landfilling.

In three full-scale industrial tests, BASH-TREAT aim is to 1) apply the latest treatment technologies for metal separation to coarse and fine bottom ash fractions, and 2) test beyond state-of-the-art technologies for the treatment of the treatment residues. For these purposes, firstly an advanced mobile dry treatment unit has been used as post-processing stage in operational plants in order to

assess the technological limit for dry bottom ash treatment. Secondly, coarse residual mineral fraction has been treated in a novel abrasion unit for the improvement of bottom ash leaching characteristics, while the mineral fine fraction has been reprocessed in a concentration table for the enrichment of base metals.
Results show the feasibility of the dry treatments extended to the entire bottom ash size range, included the often excluded 0 – 2 mm fraction. The abrasion process for the treatment of coarse mineral fractions is a promising approach for the reduction of soluble salts and potentially toxic elements which concentrate on the particle surfaces. Furthermore, the polishing effect of the abrasion may open to optical sorting technologies for the separation of different materials in ash (glass, ceramics), to date not implemented in bottom ash treatment plants. The Wilfley table treatment of bottom ash fine fractions at lab scale proved to be a viable method for the recovery of relevant metals from this material. The enrichment of valuables and grain density are positively correlated and both quadratically depended on the setting of the tilt angle parameter.
The energy balance and GHGs emissions required by the treatment of the currently untreated and unrecovered fractions of BA resulted in energy and GHGs emissions savings. Economic profitability was driven by iron and copper recycling and avoided landfill fees. Profitability was achieved by two thirds of considered countries with BA mass flow exceeding 0.02 Mt.
In conclusion, the recovery of metals and further mineral fractions such as glass, ceramics, iron oxides and further aggregates requires a holistic approach in which the proposed activities are combined in an ideal treatment “train”. This scenario will be assessed in an upcoming publication (ongoing activity) and it will be based on the economic and environmental analysis of the BA treatment through the optimized process deriving from the trial tests (WP2) + additional treatments performed at lab scale (WP3).

BIOMIMIC

The BIOMIMIC project has during the scope of 2.5 years developed innovative biotechnological methods for effective mining of secondary materials. The two core technologies developed have been **1)** biological sulfate reduction with metal precipitation from fly ash leachate and acid mine drainage and **2)** biosorption and metal precipitation from red mud leachate. A successful TRL leap has been taken for the biological sulfate reduction where the project has demonstrated the technology at TRL 5 at pilot sites both in Sweden and Germany. It has been shown that the sulfate reducing bacteria (SRB) can utilize acetate as a carbon source, but methanol is still the preferred carbon source. Effective stripping technology for H2S removal has also been shown at pilot scale. The demonstration of selective metal precipitation at pilot scale could not be performed due to the partner alteration, which resulted in the need of prioritizing the demonstration of the biological step and a non-selective metal precipitation was performed instead to facilitate the process. Metal removal from acid mine drainage has successfully been shown at pilot scale with mine water from a mine in the Freiberg region of Germany. At pilot scale a ≥99% removal of toxic metals and ≥90% precipitation of other metals was achieved.
The TRL development to pilot scale for the biosorbent technology was hindered due to the Covid-19 lockdown in Ireland. The pilot rig has been built and can be used as soon as the restrictions are lifted, but they were not lifted within the project lifetime. Experiments on lab scale on the red mud leachate shows that K stay in solution across entire pH range, Al, V, Ga are insoluble at certain pH’s. This permits for separation of the metals of interest prior to any biosorption process for their recovery. Modified biochar and seaweed hydrochar-KOH has a significant higher absorption capacity than for instance seaweed and seaweed hydrochar.
The environmental and techno-economic assessment shows critical implementation considerations and improvements possibilities. All developed processes are technically able to remove metal impurities from the considered EU waste streams, but making the metal removal a legislative

requirement is a key factor to get these processes into application. Both SRB processes and biosorption processes have to be improved regarding their environmental and economic performance in order to become a clearly environmentally superior and economically feasible alternative to mere chemical treatments of the waste streams considered in BIOMIMIC. For SRB processes, increasing energy efficiency is the most important measure to improve environmental and economic performance, followed by increasing the efficiency of methanol supply. Another important improvement potential is using waste streams for providing energy and methanol to the SRB process. For biosorption processes, biochar has a better environmental and economic performance than hydrochar, due to the necessary treatment of hydrochar with hydroxides. Besides the waste streams analyzed within BIOMIMIC, different EU waste streams might be treated with SRB leading to higher environmental benefits, especially with a higher concentration of metals and sulfide in case of SRB treatment.
The project has been successful in reaching almost all deliverables and milestones in time and has developed an effective reviewing process for the quality assurance of the results. We have also received feedback from our advisory board on the findings and future workplan. Some deliverables were delayed due to the Covid-10 pandemic and the project was extended for some months in order to deliver the last deliverables. Due to the extensive and long lasting lockdown in Ireland it was never possible to finished the last deliverable related to the upscaling activities.

Deasphor

Samples of rice husk poultry litter ash (RHPLA; Economizer fly ash) and laying hens manure ash (LHMA) from FBC using calcite sand were characterized and compared for phosphorus extraction.
The main elements composing the RHPLA are distributed between P- and Ca-, K- and Si-rich crystalline and amorphous phases, including sylvite, sodium dihydrogen phosphate, arkanite, crystalline and amorphous hydroxyapatite and Si-Al-Ca-K-Fe-rich amorphous phases. The elements P and Si A may be simultaneously recovered from the RHPLA via a leaching sequence with chloridric and sulphuric acid. The main elements composing LHMA are Ca, K, Mg, and Na, and its mineralogy is mainly composed of Ca-phases, calcite and hydroxyapatite, K-Na-Mg sulfates and K-(Na)-chlorides. Under optimal sulfuric acid concentrations about 90 wt% of phosphorous in the LHMA is leached. The conditions of the industrial incineration of laying hens manure under FBC (Gures Energy system) were investigated, including the heat and mass balance at each step from which a flowsheet was made to be used in the design a FBC pilot plant, environmental assessment, and further studies. After laboratory FBC tests using laying hens manure as fuel, a pilot scale Bubbling Fluidised Bed Combustion System was designed and installed at University of Ege. The environmental impact assessment of the technology at pilot level carried regarding atmospheric, water and soil pollution and distribution of the amount of ash generated is limited. The burning of laying hens manure on pilot scale FBC, using silica sand as bed, produces ashes with much less Ca-phases, but produces silica glass with K, Na, Al, quartz grains with rims, and a greater variety of phosphates including well crystallized apatite. Both increasing with trials temperature. For maximizing P-extraction from LHMA and RHPLA, thermal P-extraction and condensation was tested and recovery rates of P above 95% were obtained mainly as KPO_3. Further studies are already ongoing under the scope of ERA-MIN3 Call 2021 Project PHIGO. A dimensionless index, defined as SUBRAW index, was used to compare the environmental impact of phosphorus extraction technologies showing that the sulphuric acid-based wet process appears to be the most sustainable method for recovering P for fertilisers applications, but the leaching sequence chloridric acid-suphuric acid appears more promising. Meanwhile, thermo-reductive based dry processes appear to be more suitable to produce pure P_4. The studies aimed at separating a phosphate concentrate from poultry litter ash showed that density and flotation methods are not effective, but wet sieving can be considered as a method for phosphate concentration. Both the raw ash from LHMA incineration and the separated phosphorus concentrate (size-fraction <0.025 mm) can be used as a substitute for commercial fertilizer. In field cultivation, the application of obtained phosphorus concentrate at the

dose of 95 g/100 m^3 have a comparable yield as the use of commercial fertilizer at the dose of 75 g/100 m^3, while unprocessed ash had to be used in larger amount, i.e. 165 g/m^3 to have a comparable yield as commercial fertilizer.

Li+WATER

The continued availability of lithium can only rely on a strong increase of mining and ore processing, next to the development of methods to recover lithium from less optimal sources. Lithium battery production is booming because of electric vehicles, in addition to battery production for energy storage in support of the power grid. It would be an inconsistency if the increased production of lithium salts would be associated with nonsustainable practices. Lithium mining from brines, the most abundant source worldwide, evaporates, on average, half a million litres of water per ton of lithium carbonate produced, is chemical intensive, and delivers besides lithium only waste to be landfilled. Moreover, The evaporitic technology is sluggish, taking up to 24 months to produce lithium carbonate, carrying along severe economic implications. In the Li+WATER project we have developed an integrated membrane electrolysis concept to recover lithium salts from brines, relying on in depth analysis of ionic fluxes across membranes, crystallization research and overall life cycle and technical assessment. Our technology is based on a 3 stage process, each based on a water electrolyser with a side crystallizer. The chambers of the electrolysers are separated by anion or cation exchange membranes (AEM or CEM). At the anode, water is oxidized to oxygen, and/or chloride to chlorine gas. In the cathode, is reduced to hydrogen, with concomitant production of hydroxyl anions. The applied potential and the need to maintain electroneutrality makes cations and anions selectively move to the cathodic or anionic compartments.

In Stage 1, native brine is introduced into the cathodic compartment of a 2-chamber electrolyzer (AEM). As the pH increases, $Mg(OH)_2$ quantitatively precipitates, followed by $Ca(OH)_2$. Our results showed that it is possible to fully deplete Mg^{2+} and Ca^{2+} cations from the brine, leaving it ready for subsequent processing. The quality of the solids produced is yet to be optimized, since we have identified that mixed boron-calcium-magnesium compounds co-crystallize avoiding the production of the pure hydroxides. An ion-exchange pre-treatment proved to fully remove borates from the brine, and was key to allow production of 92 % purity $Mg(OH)_2$. In our latest development, we have identified a new strategy to fully avoid solid formation within electrolyzer, a methodology that we hope to incorporate in the subsequent stages.

In Stage II, the brine that was pre-treated in stage I was fed into the middle compartment of a 3-compartment electrolyzer (anode – AEM – middle compartment – CEM – cathode). Cations migrate to the cathodic compartment. While the complexity is maintained in terms of the cation composition, these are now paired with the same anions, OH^-, making borates and sulphates no longer an issue. CO_2 is bubbled into a side-crystallizer and pH is kept close to 8.3, so as to precipitate most of Na^+ as pure $NaHCO_3$.

Experiments have shown that upon drying, $NaHCO_3$ is transformed to Na_2CO_3, and purity was determined to be above 99.5%, that is no Li^+ cations are lost during this step. Most importantly, low salinity water was produced as a by-product of the processed (conductivity below 2.5 µS cm^{-1}). In the final process, Stage 3, the effluent from the cathodic compartment of Stage II is fed into the middle compartment of another 3-compartment electrolyzer, identical to that of stage II. Cations migrate again to the cathode, where CO_2 is bubbled again into the side-crystallizer and at pH above 11 pure Li_2CO_3 is precipitated. Our experiments showed that 97.5% Li_2CO_3 was crystallized, while again, low salinity water was produced as a by-product.

Our proposed technology is fast, not requiring time consuming evaporation. Because it is much less dependent on solution composition, it could render possible the exploitation of a large number of currently unexploited resources, both salar brines and geothermal or oilfield brines in Europe. In the time frame of this project, the technology was tested on three different continental brines of varying

compositions, yielding very similar results in terms of purity of the products. Tests on more diluted brines, e.g. geothermal, are yet to be performed.
Li+WATER has shown it is possible to produce several by-products: Mg(OH)2, Ca(OH)2, NaHCO3 (or Na2CO3), Cl2 (or HCl), H2. While all these by-products are of lower commercial value than Li2CO3, the co-production is perfectly aligned with circular economy principles. Most interestingly, the European Union has recognized both magnesium and magnesite as critical raw materials. Water of very low salinity is very important in this context, as it can be used as process water as required (e.g. steam generation), or delivered to local communities triggering the development of parallel water intensive activities, such as agriculture in desertic landscapes. Li+WATER does not imply water evaporation. Indeed, it can be classified in the antipodes of current practice, producing freshwater from the brine, instead of consuming water. Waste production is also minimal, in marked contrast with the current evaporitic technology.

FLOW

FLOW

The main objective of the FLOW project was to develop new lightweight alkali activated foams based on secondary raw materials, such as slags. To obtain highly porous structures, properly selected foaming agents and foam stabilizing agents were included in the basic compositions. Addition of fibers was used to overcome the main drawback i.e. high fragility, and thus help to produce materials with more elastic nature. By incorporating organic fibers from a bio based renewable source, and simultaneously using inorganic secondary resources as raw materials for alkali activated foams, a high performance in terms of energy efficiency and environmental impact was reached. Finally, the pilot products at laboratory and industrial-scale were developed and assessed from durability point of view and impact on environmental and human health.
The obtained materials will therefore find applications in wide range as thermal and acoustic insulating products and as other construction materials. The main goal for Slovenians partners was to utilize two types of slags supplied by two Slovenian's steel-manufacturing companies: Electric arc furnace slag and ladle furnace basic slag. In the first stage of research different dense alkaliactivated materials (AAMs) were developed varying in the solid/liquid ratio, type of activator and studying the main parameters influencing the final mechanical and microstructural properties of AAMs (e.g. curing regime, particle size). Further, into the dense AAM mixtures exhibiting the best performance (i.e. mechanical properties) the foaming process was introduced, where different foaming agents (H2O2, sodium perborate, sodium percarbonate), stabilizing agents (sodium dodecyl sulphate, triton, sodium oleate) and fibres (polypropylene, polyvinyl alcohol, Basalt, Cellulose, Steel fibres,…) were incorporated into the dense slurry. The resulting lightweight highly porous alkaliactivated composite foams showing the best performance were further developed into larger size panels (cca. 40 x 40 x 4 cm3) within the laboratoryscale pilot. Further, AAMs were also subjected to wide range of mechanical, microstructural analytical test methods as well as durability testing in order to prove their performance. In addition, also the Life Cycle Assessment (LCA) environmental impact of products was assessed from design to the end of production phase (so called cradle to gate), according to the ISO 14040 and 14044 standards.
In order to assess the feasibility of the chosen processing routes, the partners from Finland performed industrial-scale piloting, where the aim was to produce calcium-silicate masonry unit using a steel slag as a raw material, with a predicted total of 20 tons of material. The trial was run at Kiikala plant of Weber Finland (Saint-Gobain Finland Oy). This is the result of the collaboration between SSAB Europe Oy, Saint-Gobain Finland Oy, and Fibre and Particle Engineering Research Unit (University of Oulu). The processing and trial has shown the potential of using steel slag in CSU, although there are still research questions to be addressed (e.g., eliminate f-CaO content in the steel slag to produce sound products).
The Italian partners performed environmental impact study that evidenced the absence of ecotoxicity in terms of heavy cation release (leaching test in water according to EN 12457-4) and in terms of bio-

impact. Such kind of study is needed to convince the citizens that there are viable and safe alternatives to OPC-based concrete that can greatly reduce CO2 consumption in building practices as well. In particular, Slovenian slag-based geopolymers/AAMs exhibit an excellent antimicrobial activity against E. coli with respect to other strains for amounts above 100 mg. Further, a general trend for the Finnish slag-based geopolymers/AAMs (GP-CaO-rich AAMs) was observed, which were more effective against Gram-negative than Gram-positive bacteria. To add, no antibacterial properties were evident for stone wool-based geopolymers/AAMs for both bacteria tested. None of the tested samples also showed apparent toxicity to NIH 3T3 cells. In particular, the results revealed that none of the doses used, induced cell morphological changes, and did not interfere with the mitochondrial metabolism. These results confirmed, that even though the final formulations were 100% derived from waste or by-products they were perfectly safe for the end user.
Results of all three years of project duration have been communicated to the industrial partners, presented at numerous conferences, partially or fully contributed to 3 PhD, 4 Master and one Bachelor thesis and was published in 18 SCI papers.
More information is available at public web page and FB page:
http://flow.zag.si/en
https://www.facebook.com/Eramin2FLOW/?view_public_for=109848827237708

INSTAnT
Within the European Union, more than 400 Waste-to-Energy plants are currently in use to convert 88 million tonnes of waste (municipal, commercial and industrial) to generate energy and decrease the volume of these waste streams. This thermal process produces approximately 18 Mt of bottom ash which could be considered as the ‘final sink’ for many End-of-Life products. Important quantities of metals (ferrous and non-ferrous) and minerals (both industrial minerals and minerals for construction) are present in these bottom ashes offering a great opportunity for recycling and turning this complex waste into new raw materials.
In the INSTAnT project, five partners (SUEZ, TOMRA, Tescan-XRE, RWTH and VITO) combined their expertise in waste recycling, sensor-based technology and big data to close the material cycle of resources/materials present in bottom ashes. INSTAnT used smart recycling technologies to 1) optimise process conditions in bottom ash treatment plants to maximize metal recovery; 2) separate out a valorizable pure glass fraction, and 3) detect and remove impurities that hamper the high-grade recycling of the mineral fraction.
INSTAnT developed a bottom ash classification model based on Dual Energy XRT and 3D Laser technology images, able to identify 6 material classes (slag, glass, ceramics, ferrous, aluminium and copper) with an overall accuracy of 90%. Novel tools were created to interactively explore the digital twins of physical material streams, needed for quality control en build-up of material intelligence. Furthermore, INSTAnT demonstrated the potential of novel sensor-based sorting technology to separate glass from the mineral fraction of bottom ash, achieving > 99% pure slag fractions suitable for high value construction applications.
LIGHTS

Lights

Environmental, time and economic gains in multi-scale Lithium prospection through emerging geological concepts and innovative technological developments.
Lithium (Li) is one of the critical metals for our modern societies which are at the turning point of major technological and societal transitions to fight against climate change. Li is the main component in electric batteries, an essential cog in the transition from an hydrocarbon life style to an electric future. Li is thus booming globally and the LIGHTS project was designed to renew Li exploration targeting environmental, time and economic gains.

Traditional metal exploration methods rely on heavy field campaigns requiring the involvement of a large team over several years. These field campaigns are based on disparate initial data of varying qualities, from hand-drawn geological maps to satellite data, and scales, ranging from hundreds of kms to mm. The information obtained have then to be confirmed in the lab using various approaches that are time and money consuming, before a new cycle of exploration. The ambition of LIGHTS is the revolutionized exploration of Li of a multidisciplinary and multi-country team which has developed a unique expertise for Li exploration by bringing the laboratory on the field thanks to an innovative, integrative and multi-scale approach combining new instrumental (satellite, drone, tripods, handled devices) and technological (hyperspectral, Laser Induced Breakdown Spectroscopy, Artificial Intelligence) capabilities applied to a renewed geological setting.

Combining technologies, scales of application and updated geology for real-time exploration of lithium

The expected results are predictive maps indicating Li-rich areas. These maps are built on field using an IT solution combining spectral, geological and geochemical. For such, satellite (km to dm), drone (dm to cm), tripode (dm to cm) hyperspectral data are applied to selected geological areas and all combined by an analytical computation driven by Artificial Intelligence. The current operating solution works on a field computer and produce in a day time predictive maps assessing geological areas to check in-situ with geological information, handled LIBS and possibly new drone flights. Then, AI is applied on the updated dataset, updating on quasi real-time the prediction areas to be checked. This iterative loop makes it possible to very quickly and efficiently define the Li potential of an area. The thoughtful choice of non-destructive tools strongly limits the environmental impact of this exploration approach.

The team has unlocked several issues specific to the instrumental analysis of Li (calibration curves, reference spectral database, capabilities) or to the geological knowledge and discoveries of Li-rich areas (regional geological maps, digital stream sediment map, new chronological constraints and model) on the example of Portugal.

Highlights from the LIGHTS project are :

i) stream sediment maps and characterization of alteration halos around li-bearing pegmatites,

ii) spectral libraries and calibration curves for Li prospection by LIBS devices,

iii) new routines and algorithms for hyperspectral analysis and AI to enhance the performance of the computational all-in analysis software,

iv) predictive maps for li-bearing pegmatite detection,

v) creation of a multidisciplinary and multi-country team of experts which has developed a unique expertise for lithium exploration.

All the results will be a driving force for future lithium prospection around the globe.

Scientific production

International geological studies focused on lithium have been very visible worldwide due to several publications, mainly related to remote-sensing analysis and artificial intelligence.

New technological impacts

The lithium prospecting community also gets calibration curves for Li-rich minerals and spectral libraries for handled LIBS devices, files that can be used on LIBS devices. The advangeo@prediction and advangeo@ Field cap have been as well developed and are now functional with several types of data as input.

Discussion and conclusion

The global LIGHTS solution is not on near-real time yet, in fact two to three days are still necessary for processing and spot several targets to check during a single field campaign. The solution has not been tested as a whole yet due to travel restrictions in the current sanitary crisis period, that common test is the main bottleneck for a full validation. On another hand, on the data fusion side the use of artificial intelligence has proven its efficiency in identifying areas with a high lithium potential.

LIGHTS developed lightweight tools usable worldwide for lithium minerals detection. Some of them are already used by project members in academia through further collaborations (EU project, industrial collaboration), and also directly applicable under licence for prospecting.

MaXycle

Original task and scientific and technical status

Magnets are one of the most important materials necessary for modern Europe as an essential component of energy conversion in the fields of renewable energy and electromobility. Unfortunately, the alloy components of NdFeB magnets have been classified as EU Critical Raw Materials and 90% are produced outside the EU. Further, unfortunately, there is still no circular economy to reuse and add value to these types of materials. Another problem is that there is no classification system for the end-of-life (EOL) recyclate qualities of NdFeB magnets. The quality of NdFeB recovered materials varies widely, especially in terms of alloying constituents and corrosion state, as well as the corrosion protection used. The aim of the MaXycle project was to create a much more environmentally friendly "short" remanufacturing cycle for end-of-life magnets, enabling a circular economy. The focus was on: a) developing an eco-labelling system, b) using the highly effective HPMS process to reprocess extracted materials directly from the NdFeB alloy, c) better treatments to remove pre-processing residues, d) improving the magnetic properties of EOL NdFeB magnets by adjusting the microstructure, phase ratio and phase composition, and e) developing industrial upscalability, including a thorough life cycle assessment.

Progress of the project

The project was divided into 7 work packages, whereby the coordination of the tasks was divided among 5 project partners and two other cooperation partners contributed. At the beginning of the project, EOL magnets from different recycling sources were collected and classified with regard to recycling-relevant criteria. During this data collection, different analytical methods were identified that allow a standardised, fast and cost-efficient classification. A classification and corrosion-resistant labelling system was developed, which is quickly accessible and allows conclusions to be drawn about the chemical composition, manufacturing and coating methods, among other things. The project further investigated different methods for removing the corrosion protection from magnets before or during HPMS treatment and separating them from the recycled powders to ensure minimal contamination of the recycled powder and thus provide the optimal feedstock to the subsequent reprocessing processes. For example, the HPMS recycled powders were refined by reducing the particle size and adding Nd before being further processed in preparation for the sintering process. During the project, a database has been built up, parts of which will be made available to the public, thus ensuring the transfer of knowledge to industry.

Main results and, if applicable, cooperation with other research institutions

In the project, a very good overview of the qualities of permanent magnets currently used on the market in commercially available components containing magnets (motors, generators, sensors, loudspeakers, microphones) was obtained. The design-related effects of the NdFeB-containing components on recycling (in particular magnet type (sintered/polymer-bonded), fastening types (e.g. glued, pressed, etc.) and especially the corrosion protection layers on recyclability could be evaluated and defined and standardised measurement and test methods established for reprocessing in order to clearly characterise the magnets contained. The recycling-relevant attributes, such as the magnet type, the magnet class, the content of rare earths, the coating type, the oxygen content, but also the availability, could be determined, prioritised and transferred into an evaluation scheme that enables the calculation of a recycling factor. This then allows a quick identification of the recyclability of NdFeB-based permanent magnets. The recycling-relevant attributes could be transferred into a nomenclature

that enables the automated generation of a machine-readable data matrix code (DMC), which can be applied to the magnet itself or - preferably - to the magnet-containing component by means of suitable processes (e.g. inkjet printer or marking laser). Within the scope of the project, it was proven for the code applied by laser that it does not lead to any damage to the coating or to a reduction of the magnetic performance or the service life in a humid atmosphere of the inscribed NdFeB magnets.
Through the development of a process that includes the separation of magnets from component parts, the removal of adhesives and coatings as well as a 'shortened' reprocessing of the magnet material, it was possible to successfully reprocess magnets from recycled material that have a magnetic performance comparable to that of the original material (metal powder injection moulding).
All results on characterisation, qualities, installation and geometry parameters as well as all recycling-relevant data are available in a comprehensive database collection. In addition, the characteristic values of the HPMS powders produced from these magnets and the characteristic values of the recycling magnets produced from these powders are included. A software module was integrated into the database that automatically generates a DMC code from the available data, in which all recycling-relevant data is stored in alphanumeric nomenclature in a machine-readable form. By fully achieving all project goals, the very good starting point for the identification and classification of permanent magnets aimed for in MaXycle could be laid. The developed basics are an important prerequisite for entering into an economic, efficient recycling economy and thus securing the most critical raw material for high-tech products in electromobility, green energy and Digitalisation 4.0.

MetRecycle

Priority waste electrical and electronic equipment sectors (WEEEs) were identified in which recycling significantly impacts the most critical rare earth elements (REE); i) Permanent magnets and ii) NiMH batteries. The main REEs mostly contained in these two sectors that present a market potential are mainly Nd, Pr, Dy, and Sm, while La, Ce, and Eu to a lesser extent. Acidic leaching of permanent NdFeB magnets was performed using acidic aqua regia. EDS analysis confirmed the content of three REE elements in leached magnets, Nd, Ce, and Pr. The recycling strategy has to be further developed for efficient REE recovery.
We have successfully synthesized various advanced adsorbent nanomaterials (ANMs), such as chemically protected and surface functionalized superparamagnetic iron oxide NPs; core-shell FeOx@SiO2 nanoparticles (IO@MS), mesoporous silica/organosilica NPs and mesoporous aerosols.
Prepared materials were extensively characterized to obtain morphology, composition, and surface characteristics data.
The scale-up procedure of functionalized IO@MS has proven to be more economical and environmentally efficient than the lab-scale production of the same material, which was confirmed using LCA and LCC analysis.
Ligands, bifunctional molecules, which can, on one side, graft on the NPs surface and, on the other side, enhance immobilization of REE, have also been developed. The REE adsorption and desorption efficiency were tested for more than 25 different ANMs produced during the project duration. The selectivity of prepared materials towards REE and late transition metals (LTM) was also evaluated. Obtained results indicate that the most attractive combination of capacity and selectivity towards REE can be attributed to dense nanoparticles with the functionalized silica surface and iron oxide core / IO@MS. Best capacity towards LTM was demonstrated by cyclame-grafted materials and SBA-15 type functionalized mesoporous silica. Recommendation for the flow-sheet would thus be introducing separate adsorbent-guided steps for separating REE and LTM.

MINTECO

MINTECO project aimed to develop an integrated innovative, efficient and ecological technology for the recovery of base (Cu, Pb, Zn) and precious (Au, Ag) metals from Cu and Pb bearing mine waste. Main issues have been: developing hydrometallurgy technologies at lab-scale (TRL<4) on case studies, evaluating concentration pre-treatment step and performing preliminary environmental and economic assessment (LCA/CBA). An inventory of Polish mine waste namely Cu-waste was also performed. The consortium gathers 8 partners with complementary expertise from France, Romania, Poland and Turkey, composed of research institutes (BRGM, INOE, IMNR, MEERI), a university (ESOGU), and 3 SMEs (Romaltyn, AJELIS and TGM).

A case study involves 8.5 Mt of flotation tailings containing Au (0.57-0.7 g/t or ppm) and Ag (9-11 g/t), located in Baia Mare, Romania, where the cyanide process was first evaluated with operational facilities. As an alternative to cyanide, a general thiosulphate flowsheet was tested and optimized for several parameters; it includes sequential batch ammonium thiosuphate leaching, electrolysis, decupration and smelting steps. The extraction efficiency is about 70 % for Au and 80% for Ag. Recirculation steps are needed due to low Au concentration. Overall impact in Life Cycle Assessment (LCA) is dominated qualitatively by five main impact categories. Hot spots concern mainly leaching stage with ammonia and sodium thiosulphate consumption; and to a lesser extent catalyst preparation. Cost Benefit Analysis (CBA) calculations in line with the assumptions for Life Cycle Inventories (LCI) and LCA considered CAPEX and OPEX for a 5-year operation and 1.7 Mt annual waste processing. Investment cost was first evaluated at 13 M€ as a low estimation on the basis of a Polish installation of similar capacity and revenue from the sale of Au (and Ag, Cu) annually around 27 M€. The estimated results of financial analysis indicate a possible profitable operation at this stage of assessment. Hot spots are Au market price, investment and reagent costs. Investment cost could be higher and possibly double according to the detailed analyis performed on the Turkish case; with a decrease of possible profitability.

The other case study concerns 1 Mt oxidised Pb-Zn(Ag) flotation tailings in Turkey (Kayseri), containing 7.5 % Pb, 5.8 % Zn and 101 ppm Ag. The general flowsheet developed concerns 2 steps Zn and Pb leaching, and metal recovery from the two PLS obtained: on one hand recovery of Zn metal after purification of PLS (Fe, As namely), solvent extraction, scrubbing and stripping and electrowinning; on the other hand recovery of PbS concentrate precipitated using Na2S. Tested leaching parameters are: type and concentration of reagent, S/L ratio, temperature, leaching duration. Ag recovery was also tested by thiosulphate leaching method. Highest Zn extraction (90-92%) was obtained for three reagents with comparable yields: citric acid, malic acid, H2SO4; with some distinct co-dissolution (Fe, As and Pb).

Overall impacts of first LCA calculations is sharing qualitatively by six main impact categories. Hot spots mainly concern electrolysis with all the acids used and leaching to varying degrees depending on the variant tested. Reducing of reagents consumption could reduce significant environmental impacts. CBA calculations in line with the assumptions for LCI and LCA considered CAPEX and OPEX for a 20-year operation and 50,000 t annual treatment to recover Zn, PbS and Ag in solution. Investment was evaluated based on detailed process analysis at 50 M€ and revenue from the sale of metals Zn, Pb and in case of H2SO4 route Ag, annually around 13-16 M€ (best H2SO4 route). The estimated results of financial analysis for the best scenario indicate an unprofitable operation. Hot spots are market metal price, investment and reagent costs.

Given these results, further up-scaling at TRL>4 of the developed processes on these particular case studies were not considered. However, established methodology namely in hydrometallurgy and LCA/CBA assessment could be tested on other more favorable case study. Also, the work performed on metal recovery by synthetized materials opens new perspectives for metal separation from liquid effluents. On global view perception of the interest of possibly integrate retreatment option in rehabilitation scenario increases.

MONAMIX

Rare earths are fundamental elements in a number of stategic sectors for the EU economy: transport systems (hybrid, electric and fuel cell vehicles), renewable energy (solar PVs, wind turbines, thermal systems, etc.), battery storage, environmentally-friendly power distribution networks, energy or IT devices. In an effort to promote a critical transition to a carbon neutral Europe and a decarbonized economy, improved rare earths extraction and processing methods are required. In current technology, rare earths are separated and purified by hundreds of successive extraction operations making use of organic solvents. The MONAMIX project proposes a new concept and PROCESS/PRODUCT design for increased raw material efficiency by extracting rare earths from monazite concentrates and using them together as a dopant for advanced ceramics. This approach can reduce costs by 10-15%, together with a decreased environmental impact of the extraction processes by reducing chemicals and energy consumption.

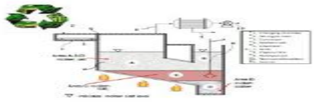
In the MONAMIX project, the monazite concentrates were processed by a hydro-chemical process to obtain a mixture of rare earth hydroxides in natural proportion, with analyzed mineralogical content. This mixture is then used as a dopant in zirconium oxide-based ceramics by means of a green chemistry process: the hydrothermal synthesis. Doped powders with controlled composition and granulation were used to demonstrate the potential for use in two high-tech applications.

The first application is in thermal barrier coatings (TBCs) used to increase the efficiency of gas turbines employed in the co-generation of electricity. The second application aims to obtain sintered products for combustion cells with solid electrolytes. Both applications are related to clean energy with minimal greenhouse effect.

TBCs were obtained by physical vacuum deposition processes using either electron beam evaporation or RF sputtering, ensuring micro-structures with low thermal conductivity. The thermal shock tests performed demonstrated the functionality of the barriers at temperatures up to 12000C. The pre-feasibility study showed that by implementing the integrated hydrochemical and coating technologies for application in thermal barrier coatings for gas turbines, the company may have a positive cash flow starting from the 4th year from the start of the investment.

The impedance spectroscopy studies of compact products obtained by spark plasma sintering have shown the potential for use as a solid electrolyte at average temperatures of 4000C due to lowering the ion conduction activation energy.

RecEOL



The objectives and expected outcomes of the RecEOL project were to demonstrate (i) the capability of the RecEOL process to recycle valuable metals including critical (indium) and special (tantalum) metals from PCBs, LCD screens, ASR and lithium-ion batteries, (ii) that all the metal recycling yields are significantly improved over current best technologies, (iii) that the process is economically viable and environmentally sustainable.

Project results achieved through a collaboration between industry and academia include:

1. Establishment of the pre-treatment requirements for pilot plant trials.

PCB's (post-shredding) are found in a mixed non-ferrous metal fraction. The RecEOL project has designed a sorting process to recover PCBs with 99% of PCBs being recovered with 80% purity of the fraction.

2. Multi-purpose pilot-scale pyrolysis reactor with molten metal or molten salt.

Experiments have been conducted on the following materials in the reactor:

- PCB recycling by molten metal or salt pyrolysis.

- Lithium-ion batteries recycling by molten metal pyrolysis (continuous commercial process can take 10 min vs current batch which takes 8 h).
- Carbon fibre recycling by molten metal pyrolysis.
- Aluminium-laminated plastics and Tetra-Pak cartons by molten metal pyrolysis (these are currently not recycled).

Outcomes of the experiments have shown that:
- The RecEOL recycling reactor is scalable: doubling the surface area doubles throughput. This is not possible with rotary kilns.
- Indium recycling from LCD screens is possible. The process is very fast process (~1 min), but is not economically viable as the value and quantity of indium is too low (Indium $150/kg vs Gold: $50,000/kg).
- Tantalum capacitor separation from waste PCB is possible following treatment in the RecEOL reactor with molten salt or metal. Tantalum capacitors are currently not recycled.
- Economics of commercial plant have been performed and published in 'Waste Management, 120: 698-707'.

The RecEOL project has advanced beyond the state of the art in relation to the following aspects of the project:

1. LCD recycling or indium recovery from touchscreens

Our experiments show that molten salts do not remove indium-tin-oxide from glass but it is possible to remove indium-tin-oxide with molten zinc. This removal reaction took place within one minute – it is, hence, very fast. The economics of doing this on an industrial scale are, however, poor, as the price of indium is too low. Moreover, even assuming indium having the same price as gold, it is still not economically viable to recycle it with the RecEOL technology as the indium concentration on touchscreens is too low for an economic operation.

2. Shredded printed circuit boards (PCBs) and low value PCBs

Shredded printed circuit boards are low value PCBs. All the electronic components are removed and the shredded PCBs pieces are between 1 and 5 inches in diameter.

An economic analysis based on the principles and the cost estimate spreadsheet developed for the project shows that the RecEOL shredded
- Automobile shredder residue (ASR) recycling by molten salt or molten metal pyrolysis.

PCB recycling process may be economically viable but further analyses are needed to confirm this.

3. Tantalum recycling from PCBs and high value PCBs

Preliminary studies indicate that tantalum – a critical metal – could be recycled with the RecEOL technology. A new treatment method to recycle tantalum capacitors from PCBs using molten metal recycling has been demonstrated by the project. This method has the advantage over other methods that it is scalable and that it increases the tantalum concentration. However, the economic prospects of tantalum recycling are poor because the value is too low.

4. Automobile shredder residue (ASR)

Molten metal could be used to separate the metals present in ASR. Moreover, an economic analysis appears to show that the RecEOL technology may be profitable – but this requires more work beyond this project.

Recycling these wastes will minimise their impact on the environment while realising the business opportunities. Recycling of E-waste is still low, but RecEOL technology demonstration/ validation can promote it, and contribute to the Circular Economy.

REWO-SORT

REWO-SORT

In recent years, mineral exploration has had a tendency to focus on near-mine targets and on adding resources and reserves to known ore bodies, towards zones with generally decreasing ore grades. One way to counteract this depletion is to pre-concentrate the material stream by sensor-based sorting. In this process, gangue material is removed early in the process chain. Since the crushing and grinding of the rocks in the mining operation requires large amounts of energy, there is great potential for savings here. The basis of such sorting is a sensor system that makes a prediction of the concentration of the desired mineral or element for each individual particle. Of the possible sensor technologies for sorting, ME-XRT (multi-energy X-ray transmission imaging) and LIBS (laser-induced breakdown spectroscopy) were selected, as they can provide complementary compositional information. By fusing the data from both sensor systems, the gain in accuracy in the prediction of the concentration should be demonstrated.

First, suitable samples were selected in the consortium. On one hand, ore samples from Rafaela mine located in the region of Valparaiso (Chile) allowed testing both MEXRT and LIBS techniques. Additionally, iron-ores coming from two small mine sites named Mariposa and La Estrella were also evaluated with both techniques. With the help of the reference analysis carried out in the laboratory, both the ME-XRT and LIBS system could then be calibrated.

The LIBS spectra showed a strong matrix dependence, which is why independent calibration models had to be created for the predominantly copper oxide and the predominantly copper sulphide samples as well as for the iron ore samples. For ME-XRT and LIBS a validation of the respective calibration model was carried out with an independent test set of the respective ore group. Due to the limited radiolucency with X-rays, the realistic grain sizes are in the range of a few centimeters. Depending on the composition, i.e. especially the density and atomic number of the elements involved, the thickness that could still be easily radiated using 160 kV spectra was between approx. 30 mm for the iron ores with iron content > 60 % and correspondingly high density, and approx. 50 mm for the copper ores.

In the evaluation of the prediction of the copper content, the coefficient of determination R2 was used as a comparative variable. For the LIBS measurements, values between 85 % and 99 % were achieved for the copper ore samples, while R2 values between 36 % and 74 % were shown here for the ME-XRT measurements. LIBS achieves a higher accuracy in prediction, but is subject to statistical fluctuations with inhomogeneous samples and few measuring points on the surface, while ME-XRT does not achieve this local accuracy, but includes the entire volume of the sample and allows higher throughputs in sorting.

Three different deep neural network architectures were designed for concentration evaluation and prediction, combined with three different preprocessing steps. In each case, the data from the sensor technologies were examined individually, as well as the fusion of the data. The fusion of the two sensor modalities showed an increase compared to the individual data evaluated with the same methods. However, the accuracy of prediction using ML methods is lower than for conventional data evaluation. Presumably, this is due to the small amount of training data available for machine learning methods in this project.

In addition, High-resolution analysis of 11 rock types using LIBS and ME-XRT with reference analysis using conventional scanning electron microsopy (EDS-based chemical imaging), was conducted. Results show that LIBS provides a similar data quality and density regarding chemical analysis on a micro-scale as the conventional SEM analysis. ME-XRT provides data at a lower resolution and is not able to distinguish each chemical element. However, the analysis gives a projection of a 3D representation of the rock volume, whereas LIBS and SEM are 2D (surface) analytical tools. Our results show that there is an application potential for the LIBS and ME-XRT for geological characterization of rocks for e.g. mining and exploration purposes that include, but are not limited to mineralogy, mineral chemistry, texture, structure, as well as alteration and mineralization patterns.

On the other hand, studies on the impact of implementing such ore-sorting processes on water and energy reduction at large and medium size mining companies were carried out. Firstly, such relative reduction of these resources can only be accounted when they are referred to the flow rate of valuable material being processed. Secondly, such reduction is approx. 30% for both resources. The high throughput usually observed at large scale in copper beneficiation plants is still a major challenge for these technologies. The current state of the art though could fit very well the needs of the medium size mining companies.

SUPERMET

SUPERMET PROJECT

Green and disruptive process for the recycling of precious metals avoiding high temperatures and the generation of large volumes of toxic effluents to be treated:

The SUPERMET project aims at recycling the precious metals palladium (Pd) and platinum (Pt) contained in spent catalysts. Precious metals are widely used in applications such as catalysis, in petrochemistry and fine chemistry but also mainly in the automotive field (catalytic converters). The scarcity of these metals constitutes a risk for European countries, which do not have this primary resource. Thus, palladium and platinum are not only precious metals but also critical raw materials for European industries. The techniques currently used to recycle these metals from urban mines, by pyrometallurgy and/or hydrometallurgy, are energy-intensive (high temperatures > 1400 °C for pyrometallurgy) and/or generate large volumes of toxic effluents (acidic aqueous effluents in the case of hydrometallurgy). The objective of the recycling process proposed in SUPERMET is to develop "all-in-one" extraction agents to be used in an extraction process using supercritical CO_2 as a green solvent to recover the precious metals present in the spent catalysts. (catalysts supported on ceramic matrices).

Design of polymer additives for the extraction of precious metals from spent catalysts by supercritical CO_2 extraction:

Supercritical CO_2 extraction technology, industrialized nearly 60 years ago, allows for the extractions of valuable or undesirable components from raw materials such as coffee, hops, perfume, and aromatic plants without using solvents that are harmful to the environment. So far, little work has explored the extraction of precious metals using the supercritical CO_2 process. Indeed, CO_2 on its own does not have the capacity to dissolve and therefore extract metals. To perform this operation, it is necessary to add one or more extraction agents which can both bind to metals and interact with CO_2. These "all-in-one" extractants are not currently available on the market. The "all-in-one" extractants proposed in the SUPERMET project are called complexing polymers. Due to the adjustable solvent properties of supercritical CO_2, the dissolved polymer-metal complex can be isolated from CO_2 by simple depressurization. These processes can be carried out at low temperature (<100 ° C), are not destructive and do not generate toxic effluents. In addition, ideally, the polymer and CO_2 can ultimately be recycled back into the process after recovery of the metals.

Main results:

20 supported catalysts were characterized, 82 polymers were synthesized (fluorinated, silicon-based, hydrocarbon-based) and 240 extractions by supercritical CO_2 were carried out. The SUPERMET project made it possible to develop polymers capable of complexing the precious metals (Pd, Pt) present in supported industrial catalysts and to determine the operating conditions of CO_2 (e.g.: 250 bars / 40 ° C) allowing the extraction of metals: extraction rate up to 73%. This technology could be extended to other types of metals and waste to be recycled, such as lithium-ion batteries (critical metals cobalt and lithium) and fuel cells (Pt). Assessment (LCA) done on SUPERMET process along with the economical evaluation enable to underline the main parameters to work on for an eco-design of the process at industrial scale. https://supermetproject.eu/

Scientific production:

3 articles: A. Ruiu *et al.*, *Journal of CO2 Utilization* **2020**, *41*, 101232. https://doi.org/10.1016/j.jcou.2020.101232. M. Senila *et al.*, *Materials* **2020**, *13(22)*, 5136. https://doi.org/10.3390/ma13225136. A. Ruiu *et al.*, *Molecules* **2021**, *26*, 684. https://doi.org/10.3390/molecules26030684. 1 international fair, 13 congresses and 6 workshops (11 international oral communications, 9 posters).

Illustration:

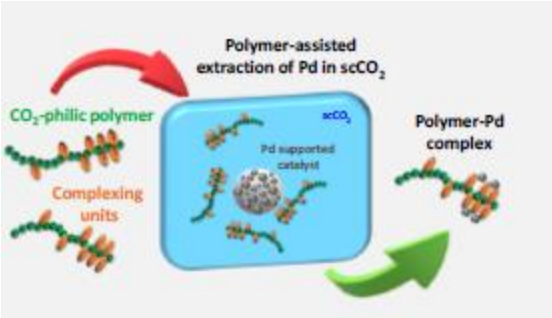


Figure: Polymer-assisted extraction of palladium from supported catalysts in supercritical carbon dioxide.

Factual information:
The SUPERMET project is an exploratory research project coordinated by Patrick LACROIX-DESMAZES (ICGM, University of Montpellier, CNRS, ENSCM) in France. It associated National Institute for Research and Development of Optoelectronics Bucharest, Research Institute for Analytical Instrumentation (Romania), as well as the Fraunhofer Institute for Chemical Technology ICT (Germany) laboratories, Heraeus Deutschland GmbH & Co. KG company (Germany), and Innovation Fluides Supercritiques association (France). The project started on 1st of May 2018 and lasted 42 months. ANR grant amounted to 221 011€, UEFISCDI grant amounted to 137 000€, BMBF/JUELICH grant amounted to 573 782€ and ADEME grant amounted to 78 400€ for a total budget of 1 497 211€.