DOI: 10.5281/zenodo.10184764

START NEWSLETTER

RECOVER-REFORM-REUSE
for a Sustainable Future

EDITORIAL

Dear members of the START community,

Welcome to the third Biannual Newsletter of the START Project! We are happy to share with you some exciting results and updates from our innovation activities.

It has been 17 months since we started this ambitious project to develop novel thermoelectric materials and devices from mine waste, and we have made significant progress in several areas.

One of the highlights of this issue is a new story board with Starty, our friendly mascot, that tells us something more about the tetrahedrite material and the use of powder technology in the project. You can learn more about the material and the technologies we are using in a fun and engaging way.

Our geology partners have also been busy identifying and characterizing relevant mine waste sites in Germany, so you will have some details on this task. In addition, we have updates on the progress we have made on synthesis, testing and integration of the thermoelectric materials.

Another important event that we want to revisit is the annual meeting that took place at IGME-CSIC in Madrid from May 30 to June 1. This was a great opportunity for all the partners to meet again face-to-face, exchange ideas, discuss challenges and plan future actions. We also had fruitful discussions with Doug Crane, one of our scientific advisory board members, who provided valuable feedback and guidance for our project.

We want to share with you some of the dissemination activities that we have carried out in the past months, such as the LCA (Life Cycle Assessment) workshop given by our partner 3drivers, where we learned about the life cycle assessment methodology and how to apply it to our project. We participated in other dissemination events, such as the EPMA Summer School and Macaronight 2023, and continued our webinars series where we presented our project to a wider audience.

In this issue, we also have a Technical Pill where we address the use of machine-learning techniques to optimize thermoelectric properties in vast composition ranges. This is a very innovative and powerful approach that can help us discover new materials and improve existing ones.

This time we host an interesting interview with Jean-Yves Escabasse, one of the START Scientific Advisory Board members, who shares with us his insights and perspectives on thermoelectricity and its potential applications in various sectors. He also tells us about his experience and thoughts on the European research programmes.

Finally, we invite you to enjoy another leg in our consortium tour, where this time we meet ASGMI, the Association of Iberoamerican Geological and Mining Surveys, and GeniCore, an innovative company with expertise in SPS (Spark Plasma Sintering) technology. They are both key partners in our project and contribute to its success.

We hope you enjoy reading this newsletter and learning more about our project. We invite you to visit our website and follow us on social media for more updates. Thank you for your continued interest and support!

(F. Neves)

Co-funded by the European Union

Project: 101058632 HORIZON-CL4-2021-RESILIENCE-01-07

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

START NEWSLETTER

RECOVER-REFORM-REUSE
for a Sustainable Future

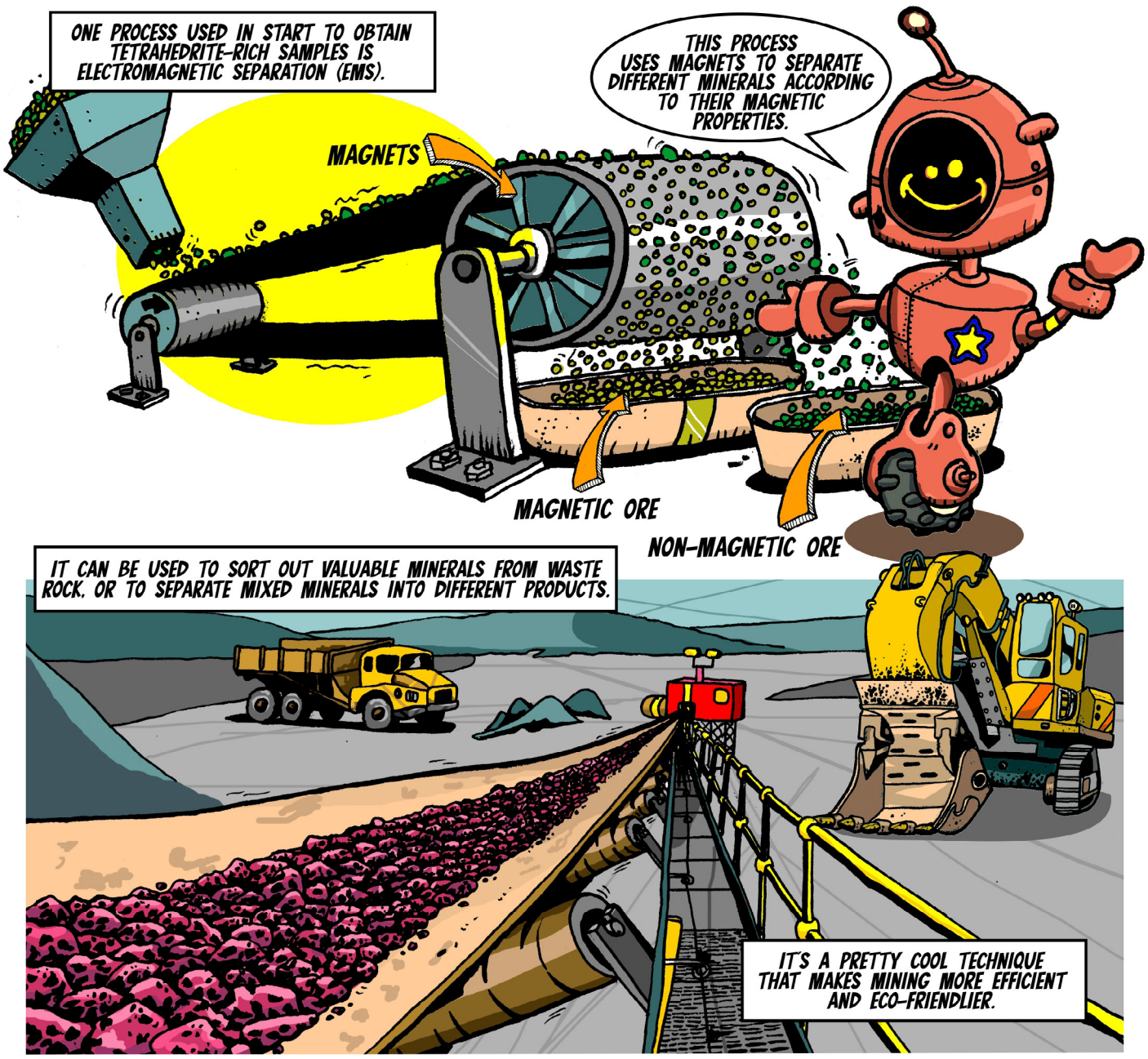
CONTENT

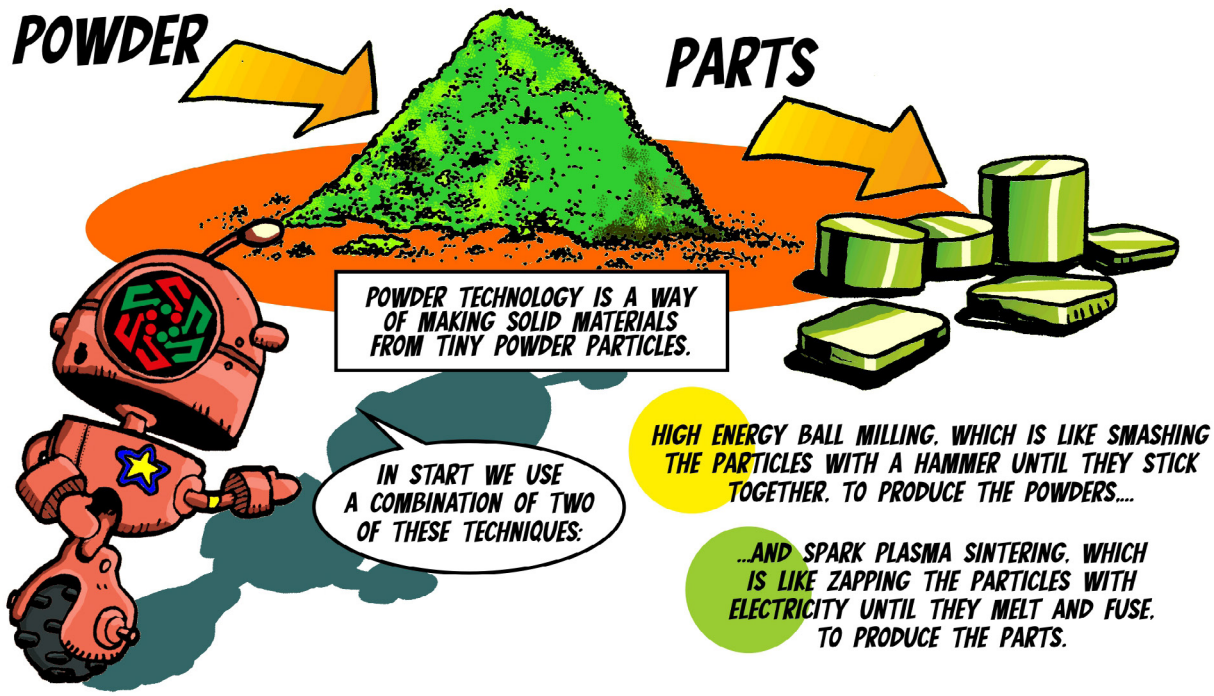
Co-funded by the European Union
Project: 101058632 HORIZON-CL4-2021-RESILIENCE-01-07

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

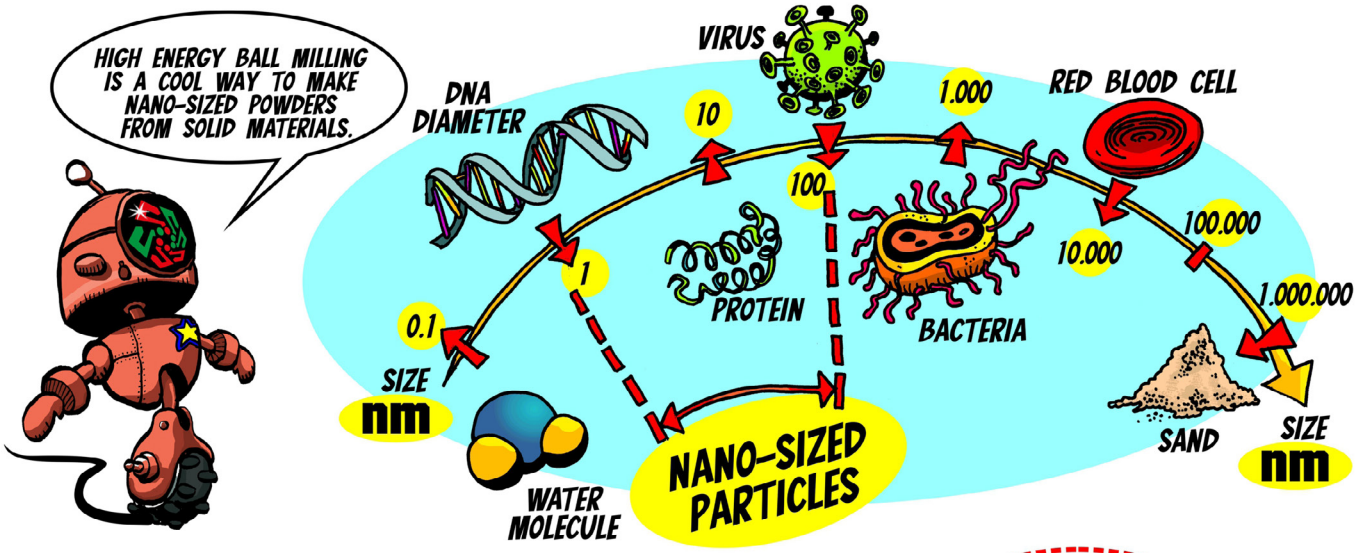
STARTY EXPLAINS START – 3: TETRAHEDRITE – THE MATERIAL

DOI: 10.5281/zenodo.10184764

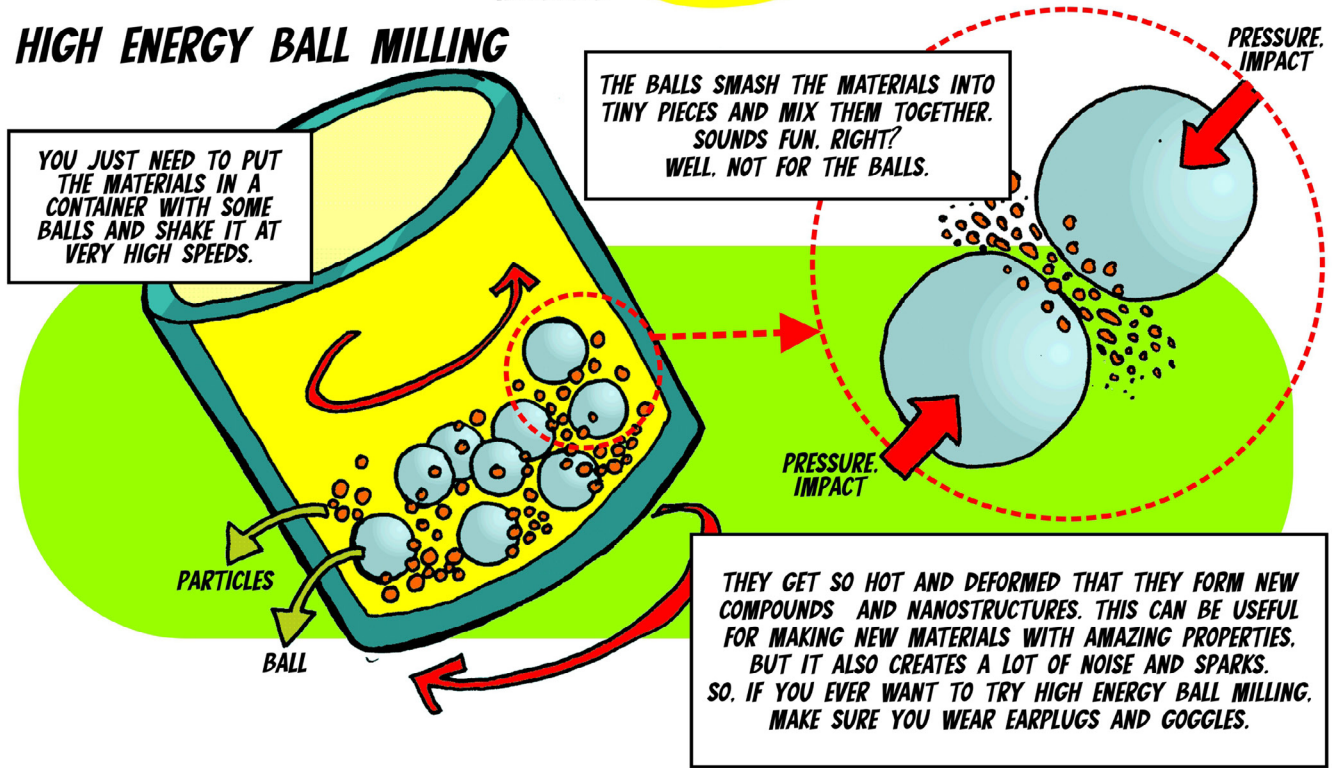




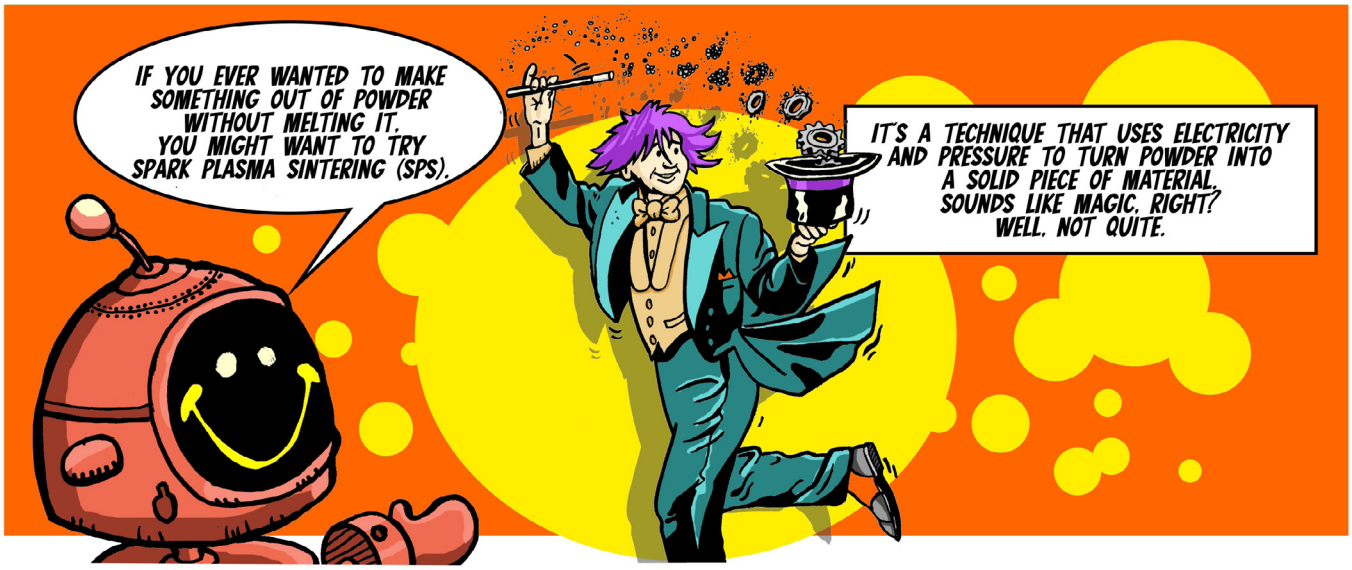
DOI: 10.5281/zenodo.10184764

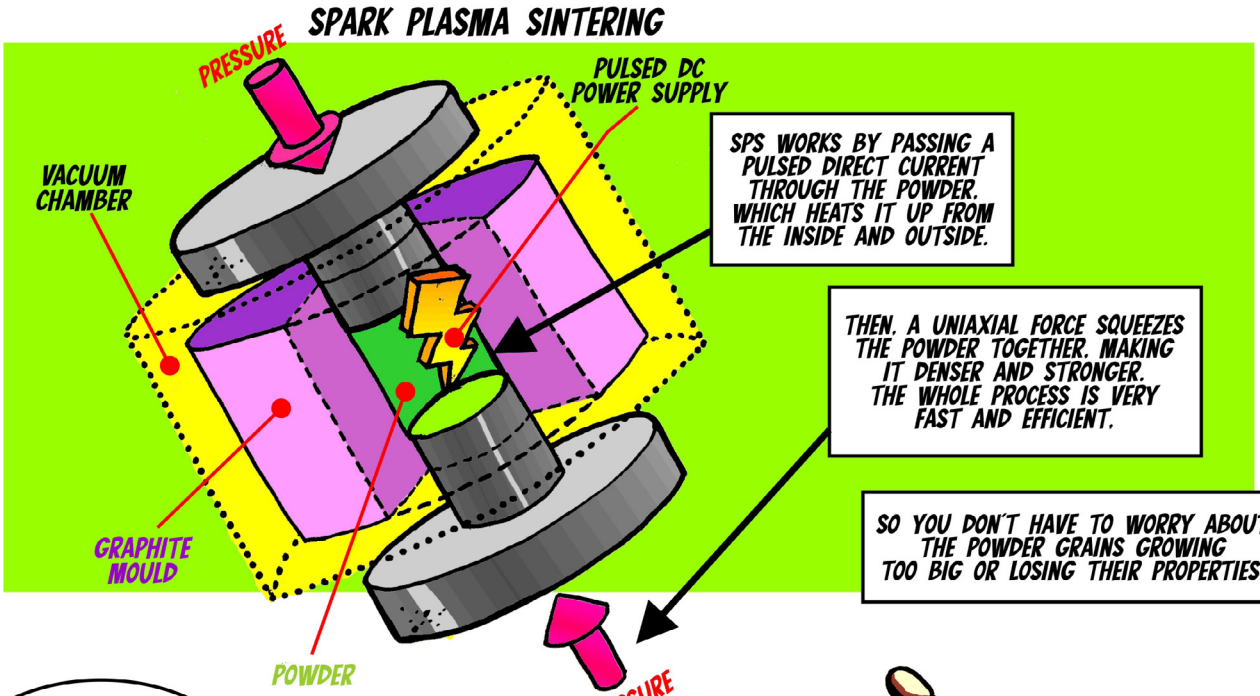


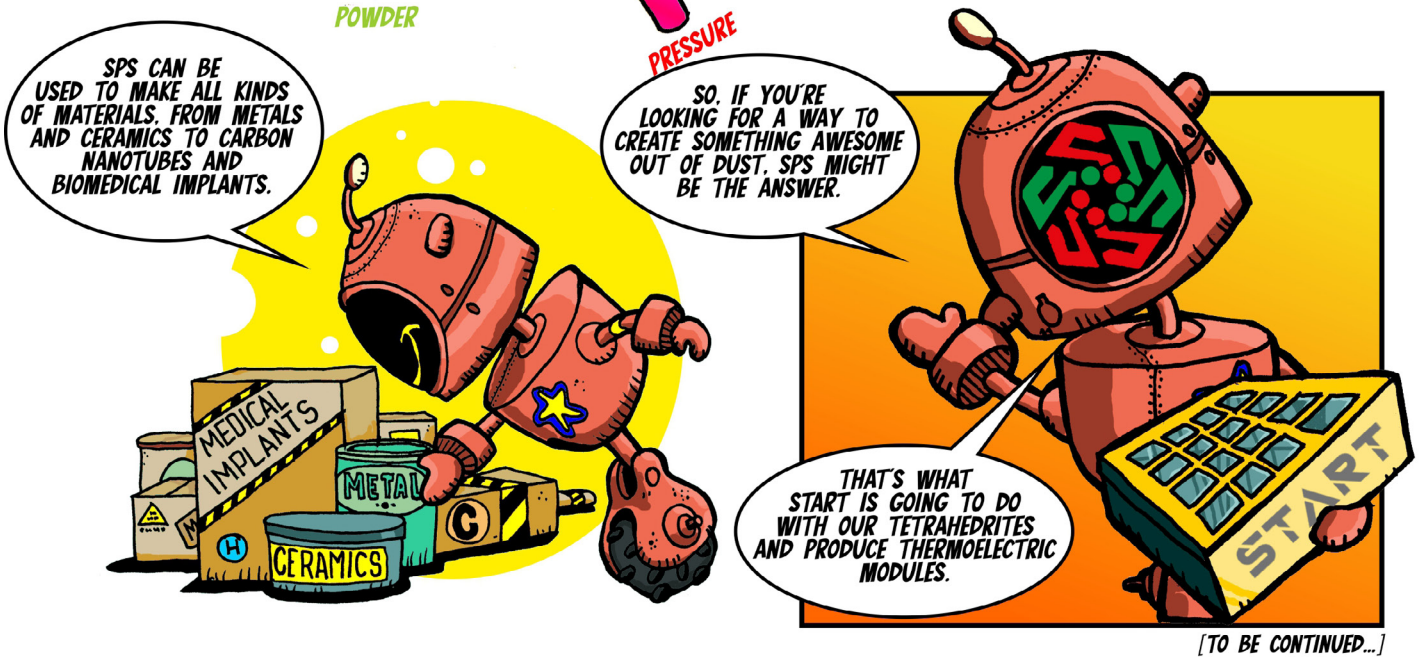
HIGH ENERGY BALL MILLING



DOI: 10.5281/zenodo.10184764







[TO BE CONTINUED...]

DOI: 10.5281/zenodo.10184764

THE EFFORT FOR STARTY IN MANY LANGUAGES

If you read the previous newsletters or followed us on our social media accounts and the website, you already know Starty, that is usually the "frontrobot" of our communication. To make Starty more widely understandable, we made the effort of covering a large part of the EU official languages, and even more. We have made our comics author J. Mascarenhas (LNEG) work hard to deliver new versions of his comic strip involving the robot Starty first in twelve, and then in thirteen different languages!

He received the contribution from many of our consortium partners, with the translation of the original Starty strips (that you have seen in Issues 1 and 2 of our newsletter) into their mother tongues. All in all, we have collected the following localised versions: Catalan, Danish, German, English, Spanish, French, Italian, Dutch, Norwegian, Polish, Portuguese, Slovak, Turkish.

You can find the multilingual editions of "Starty explains START" on our website's Documents page. Soon, also this third edition will be there for you, in your language!

Figure 1 - Starty loves Earth and knows your language too!

DOI: 10.5281/zenodo.10184764

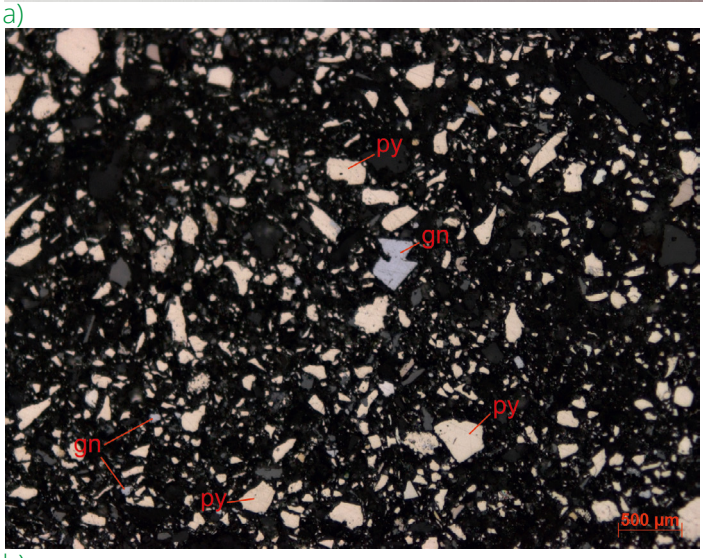
START CHRONICLES: GEOLOGY, THERMOELECTRICS AND MORE

NEWS FROM WORKPACKAGE 2 "SELECTION OF MINE WASTE SITES; PHYSICAL MINERAL SEPARATION AND CONCENTRATION: RELEVANT MINE WASTE SITES IN GERMANY"

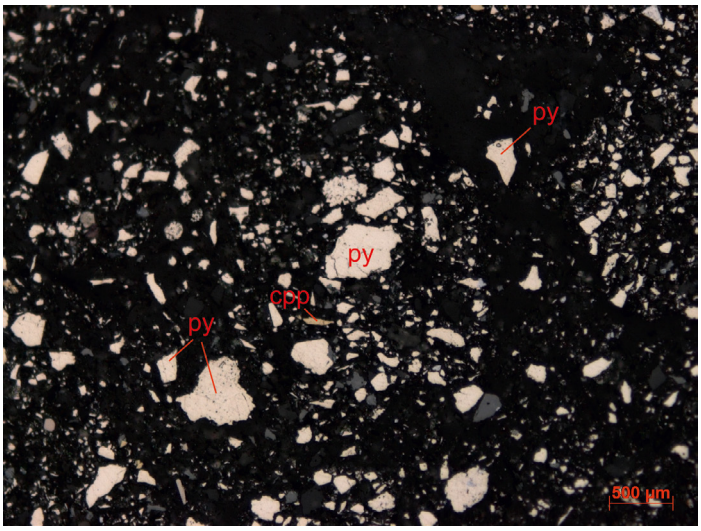
Germany has a long tradition in the extraction and processing of different types of metal raw materials, as is reflected in the mining residues. There are over 2300 different dumps with residues from metal mining in Germany. The dumps include waste rock, processing residues, and slag, and vary in size from < 1000 m^3 to > 1000000 m^3. Most of the dumps are among the smaller ones (< 5000 m^3). The database "Mindat.org" reports 238 mining locations with minerals of the tennantite-tetrahedrite series (the so-called "fahlores", see ***Figure 3a***).

In most of these locations, tetrahedrite is a subordinate mineral. In finding suitable mine waste sites for START, we initially focussed on three relatively large dumps with high contents of sulphide minerals. For these dumps, there could also be an additional environmental benefit in re-using the material, making secondary mining more profitable. The most interesting example would be the tailings dump of the Rammelsberg mine by Goslar (Harz Mountains) with approx. 7 million t tailings of which ca. 20% consists of sulphides (see ***Figure 2***), 25% of barite, and 55% of carbonates and silicates [1,2].

a)



b)

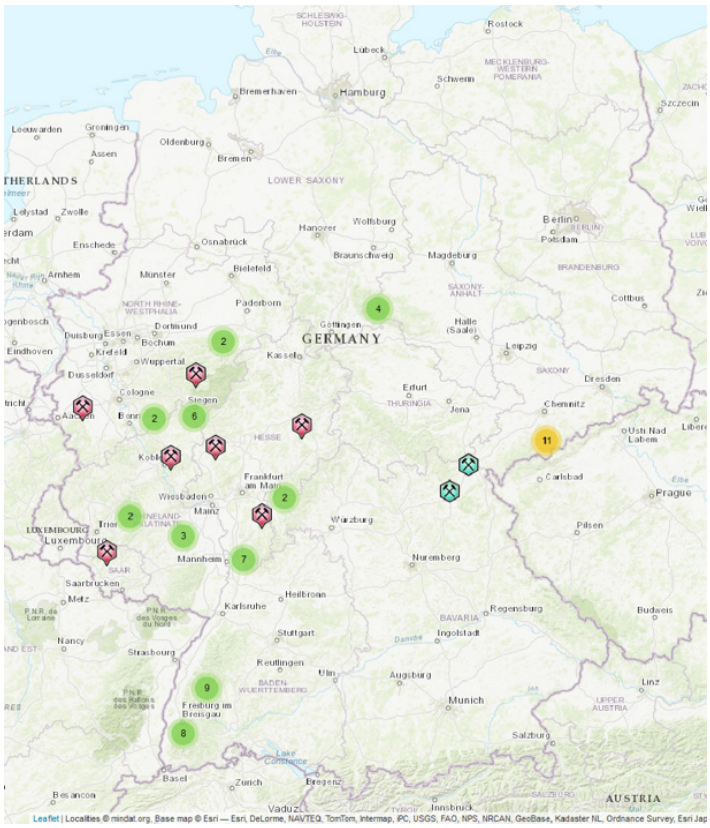


c)

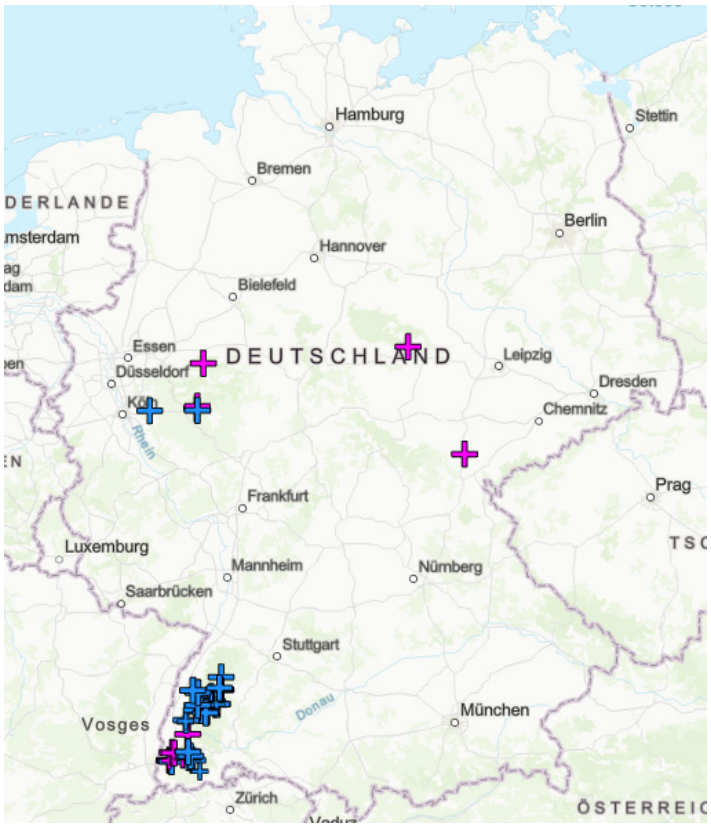
Figure 2 - a) Sulphide-concentrate sample from the Rammelsberg tailings dump that was kindly made available for START by the REMINTA project consortium (https://www.reminta.de), and b) and c) photomicrographs showing the minerals ccp – chalcopyrite, gn – galena, and py – pyrite. XRD (X-Ray Diffraction) analysis revealed that the modal mineralogy of the sulphide concentrate consists mainly of pyrite (49 wt%), barite (10 wt%), muscovite (9 wt%), chlorite (5 wt%), galena (4 wt%), sphalerite (3 wt%), carbonate (10 wt%), feldspars (4 %), and quartz (4%). The common accessory minerals are chalcopyrite, gypsum, and pyrrhotite.

DOI: 10.5281/zenodo.10184764

However, discussions in the project consortium have made clear, that (1) large amounts of iron and lead are unfavourable for the development of suitable thermo-electric elements, and (2) that, in addition to fahlores, other minerals containing copper and antimony are also of interest for START. Therefore, the effort was made to compile a preliminary list of locations with dumps especially enriched in fahlore and/or antimony minerals (see ***Figure 3b***). This work was based on ***Figure 3a***, the data repositories [3, 4, 5, 6, 7, 8], and literature on ore deposits [e.g. 9, 10, 11, 12, for the Schwarzwald mining district]. We have sampled about 25 kg of material from four promising locations (e.g., Schmiedestollenhalde, Wittichen). Gangue minerals showing impregnated sulphide ores of various grain sizes dominate these samples. The samples are currently being analysed in our laboratories, using XRF (X-Ray Fluorescence), ore microscopy, and various SEM (Scanning Electron Microscopy) methods, in order to decide on further processing for use in START.



a)



b)

c)

Figure 3 - a) Mining locations with minerals of the tennantite-tetrahedrite series (so-called "fahlores") in Germany according to mindat.org [4]; b) Possible mine waste locations especially enriched in minerals of the tennantite-tetrahedrite series (blue) and/or antimony (purple); c) Schmiedestollen dump by Wittichen (Schwarzwald Mining District).

DOI: 10.5281/zenodo.10184764

NEWS FROM WORK PACKAGES "NEWS FROM THE LABS (WORK PACKAGES 3, 4, 5)"

Materials modelling and synthesis development has continued in these months on the quest to optimize the composition in terms of nature and amount of transition metal dopants (by DFT - Density Functional Theory[13] modelling), the production process (by Mechanochemical synthesis, MCS) and the sintering conditions (by Spark Plasma Sintering, SPS) for the p- and n-type thermoelectric materials meant to constitute the active core of the thermoelectric (TE) devices.
In order to evaluate the TE properties of MCS tetrahedrite powders with different dopant compositions (p-type material), they first need to be consolidated by SPS. TE properties strongly depend on the sintering parameters, since they contribute to the evolution of the microstructure obtained with the MCS, which in turns affect Seebeck coefficient (S), electrical (σ) and thermal conductivity (κ).
For these reasons, systematic investigation of the SPS parameters was conducted, in particular of the sintering temperature, which led to identifying the conditions to obtain maximum densification (98-99% of the theoretical density). TE properties (Seebeck coefficient, electrical and thermal conductivity) were measured on several compacted samples (***Figure 4***) and this allowed to select both the most promising dopant composition and the optimum sintering conditions.

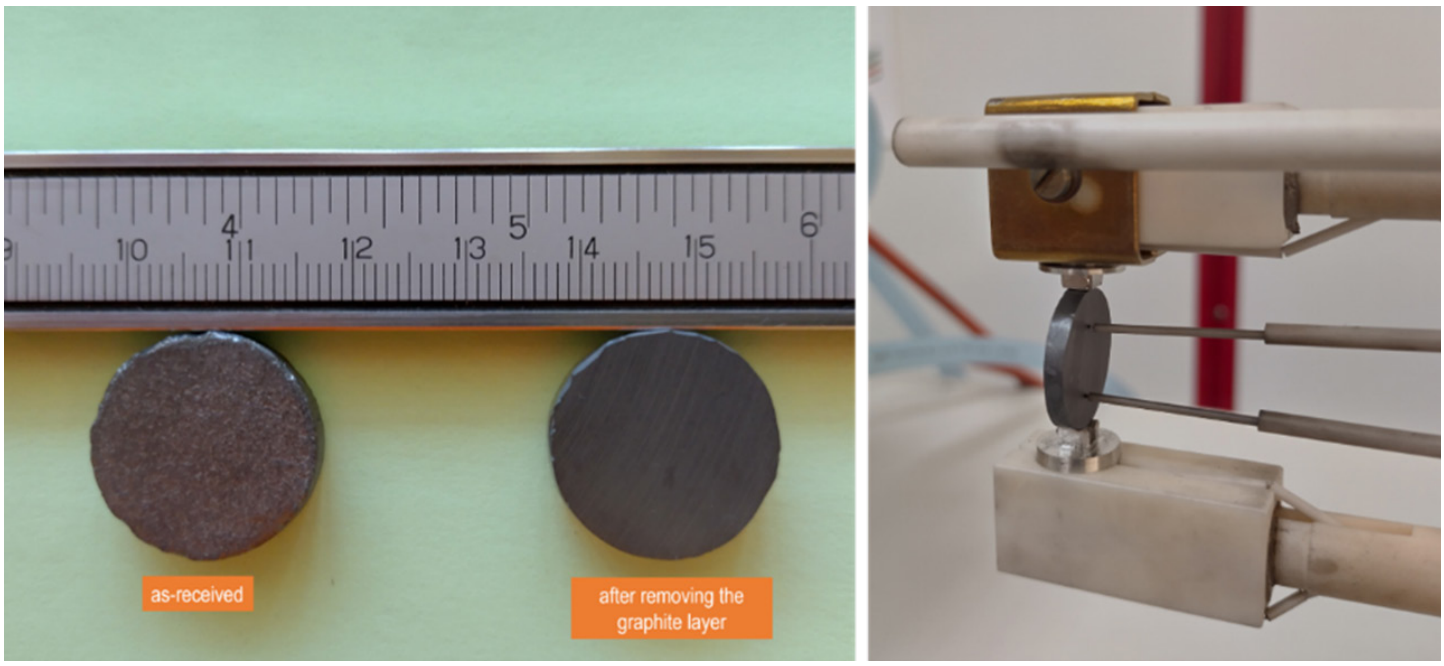


Figure 4 - (left) Tetrahedrite samples after SPS compaction. (right) Assembly of a sample for the Seebeck coefficient and electrical resistivity tests in the LZT-Meter from Linseis.

Larger batches were produced with an optimized composition, and many identical tiles were sintered to assemble the first START TE devices (***Figure 5***).

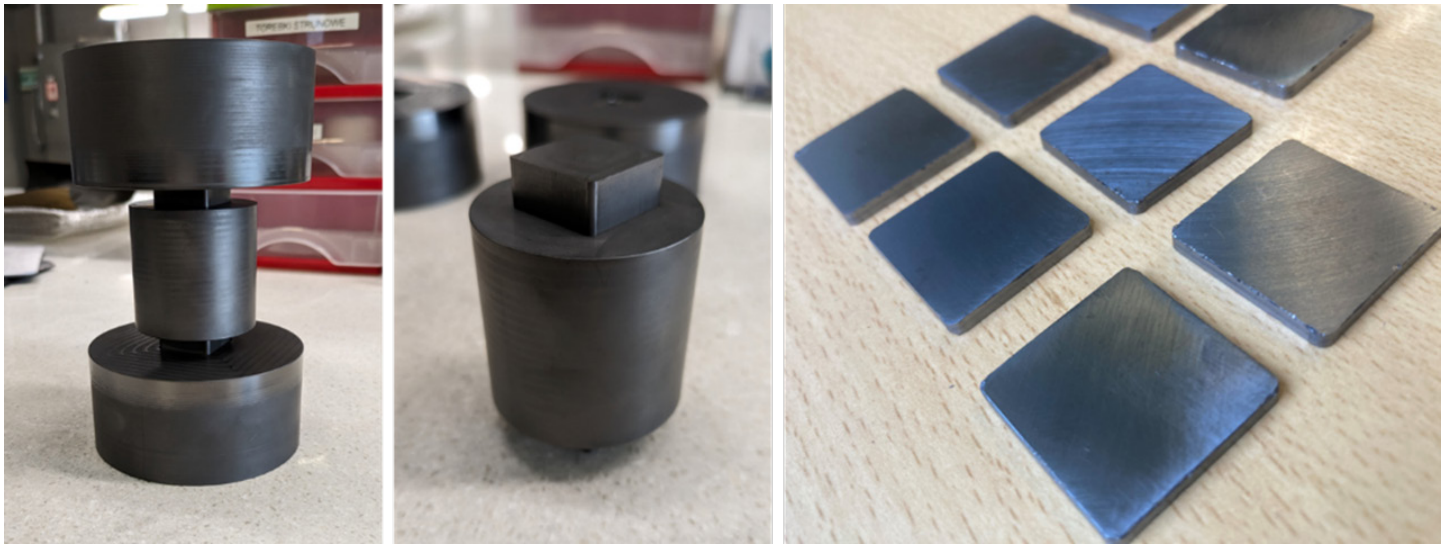


Figure 5 - Photos of the graphite mold and of the sintered tiles of purely synthetic tetrahedrites obtained by SPS, that will be used for the production of the first TE device of the START project. The dimensions of the tiles are 23x23x2.5 mm.

DOI: 10.5281/zenodo.10184764

Having optimized the synthetic tetrahedrite composition, we focused then on the actual goal of the START project, that is to incorporate as much mineral concentrate from mine tailing as possible in the tetrahedrite formulation. First promising results have come also from this front, in particular in the case of samples containing as much as 50% of mineral tetrahedrite a high zT value[14] was measured, close to that of purely synthetic tetrahedrites with optimized composition (0.51 vs 0.49 at 350 °C).
TE devices can only function with both p-type and n-type legs, and, since there is no known n-type tetrahedrites, we have conducted extensive literature research and discussions among the partners to identify a suitable n-type material. The selection has been done considering the compatibility on three main parameters: 1) working temperature, 2) electric properties, and 3) thermal expansion. Eventually, $Mg_{3+\delta}Sb_{2-x}Bi_x$ has been selected since its temperature of peak zT can be tuned to match the range of tetrahedrites' by adjusting the Sb/Bi ratio, the thermal expansion differences can be managed on the device engineering, and it does not contain rare or toxic elements.
The mechanochemical synthesis of this material poses several challenges to be addressed:
(1) Mg has a very low vapour pressure, so part of it could easily evaporate during the consolidation, resulting in a Mg-deficient material;
(2) when x is higher than 0.5, a further Mg-excess is needed to avoid having unalloyed Bi;
(3) it has p-type character if not appropriately doped.
Keeping all this in mind, a first series of MCS powder materials has been produced and it is now on its way to be sintered.

START FIRST ANNUAL MEETING IN MADRID

The START consortium got together from 30th May to 1st of June 2023 for its first Annual Meeting, the second general meeting after the Kick-Off that had happened in Lisbon in June 2022. The event took place in a quite inspiring venue: the Museo Geominero in Madrid, Spain, that was offered by our partner, IGME-CSIC. The meeting was jointly organized by IGME and ASGMI.
Surrounded by an impressively huge collection of rocks, minerals and fossils, the consortium met in the museum's lecture room for three days. Workshops open to the whole consortium were led by the various Work Package leaders; the activities already undertaken, their results, and especially the decisions on how to proceed towards project's objectives were discussed. Some special meetings were dedicated to critical issues, and solutions and strategies were analysed, benefiting of the in-person situation. Doug Crane, one of the members of our Scientific Advisory Board, took a long trip from the US to Spain to join us, and he was also involved as speaker in the hybrid live webinar that was held in the afternoon of the 31st of May (read about that below).
The group also enjoyed conviviality, in the lunch and coffee breaks in the museum's historical rooms, and during a nice consortium dinner in down-town Madrid.
The 2nd Annual Meeting, next year, will be in Italy! Venice awaits us!

Figure 6 - The START consortium partners that were present in Madrid for the first Annual Meeting (only the partner who took the picture is missing!).

DOI: 10.5281/zenodo.10184764

Figure 7 - The main hall of the Museo Geominero of Madrid, that hosted the first Annual Meeting of START.

Figure 8 - Tetrahedrite samples (at the back) are present in the sulphides section of the museum's exhibition.

Figure 9 - Meetings for specific subjects ran in parallel during the Annual Meeting.

START WEBINAR #3

As you may remember, we already have given you information about the two free webinars that we held in February and April 2023. On 31st May 2023, directly from our Annual Meeting in Madrid, we held our third START webinar, that we titled "Sustainable Solutions to Unlock the Potential of Thermoelectrics and Secondary Materials". We gathered there most of the speakers, and held the webinar in hybrid format, with about 30 delegates at the meeting physically in the room, and about the same number connected remotely. Thanks to all who took part! This was the agenda of the 3rd START webinar, 31st May 2023, 14:30-17:00 CEST:

- **14:30** Bruno Vicenzi (European Powder Metallurgy Association) and Filipe Neves (LNEG) – Welcome and introduction
- **14:35** Doug Crane (DTP Thermoelectrics, START Scientific Advisory Board) – "Thermoelectric energy harvesting: principles, challenges and opportunities"
- **15:10** Q&A
- **15:20** Julie Hollis (EuroGeoSurveys, START Scientific Advisory Board) – "The role of EuroGeoSurveys in supporting the EU's ambition to boost domestic critical raw materials supply from secondary resources including mine waste"
- **15:55** Q&A
- **16:05** António José (Bundesanstalt für Geowissenschaften und Rohstoffe) – "Sulphidic mining waste in Germany"
- **16:15** Piotr Lipiarski (GeoSphere Austria) and Thomas Unterweissacher (Unterweissacher) – "Tennantite and tetrahedrite from two Austrian mine waste sites"
- **16:25** Concepción Fernández Leyva (IGME-CSIC) – "Tetrahedrite Deposits in Spain"
- **16:35** Stanislav Šoltés (Štátny geologický ústav Dionýza Štúra) – "Tetrahedrites from Mária Mine, Rožňava, Slovakia"
- **16:45** Q&A
- **17:00** End of webinar

DOI: 10.5281/zenodo.10184764

After the event, we split the long session video into 3 parts, that are D. Crane's, J. Hollis's, and the START speakers, respectively. You can find all these videos in our Multimedia page of the website, where you can also find the previous webinars' footage!

Figure 10 - Doug Crane (DTP Thermoelectrics) presenting in the 3rd START webinar.

START INTERNAL LCA WORKSHOP

In June 2023 the partner 3drivers presented to the Consortium an online workshop dedicated to life cycle assessment (LCA). The session was divided in two parts, the first one with the theoretical introduction to LCA methodology (available for public dissemination[15]), and the second one to perform a LCA practical example in SimaPro software, to gather initial insights of ThermoElectric Generator (TEG) use case and to demonstrate what the LCA work would be for the project (exclusively for the START partners).

The main objectives of the LCA workshop were to:

- Understand what LCA is and how it is conducted;
- Understand the type of data needed;
- Get to know existing tools;
- Define the objective and scope;
- Define the functional unit;
- Develop data inventories for materials and processes;
- Quantify the environmental impacts;
- Interpret the results;
- Understand why it is important to take a whole-life approach to calculate environmental impact;
- Develop LCA with a practical example: ex. what is the stage with the greatest impact and possible mitigation strategies.

Several topics were addressed, including:

1) LCA within Industrial Ecology tools ;
2) Standards;
3) Structure of a process-based LCA model;
4) LCA terminology (ISO 14040:2006);
5) LCA main stages;
6) Principles of LCA;
7) When LCA could be useful;
8) When LCA should not be used;
9) LCA resources;
10) Goal and scope definition;
11) Inventory analysis;
12) Impact assessment;
13) Interpretation of results;

DOI: 10.5281/zenodo.10184764

In the practical session it was possible to get knowledge of TEG complete life cycle stages, from the raw materials extraction, production processes, use stage, to the end-of-life. This was an important preparation for the LCA work to be developed in START context, namely for the definition of the functional unit, and the goal and scope, and also to specify the data required to build the inventory of the inputs from natural resources, the technological sphere (materials, fuels, energy), the outputs (wastes, emissions), and the avoided products (e. g., minerals from recovered tailings, energy produced from waste heat) of the TEG device. The LCA analysis will assess the environmental benefits of START's TEG device in comparison to other synthetic-based devices, in order to demonstrate the sustainability of the product developed from mine tailings.

START LECTURED AT THE 21ST EPMA SUMMER SCHOOL IN DRESDEN, 21ST JULY 2023

The EPMA Powder Metallurgy Summer School[16] is organised by the European Powder Metallurgy Association (EPMA) with support from its members. The PM Summer Schools gives young scientists and engineers advanced teaching of PM's advantages and limitations by some of the leading academic and industrial personnel in Europe. Since 1998, about 1000 young graduates from both industry and academia from all over Europe have attended these summer schools. The 2023 edition, the 21st in the series, was held in Dresden, Germany, from 17th to 21st July. 59 trainees took part.

START was briefly presented by B. Vicenzi (EPMA) during his opening speech on Monday 17th July, as happened in 2022 in the 20th edition in Ciudad Real (Spain). Among the several lectures there were topics that are relevant for START ("Powder Manufacturing and Characterization", "Alternative Methods and Innovative Sintering"), but especially on the project's side on Friday 21st, 13:00 – 13:30, A. Bianchin (MBN) closed the lectures by giving a presentation titled "Thermoelectric Materials and the START Project".

START will feature again in the 22nd edition that will take place in Alessandria (Italy) in July 2024, possibly in a new format, as a lab experience.

Figure 11 - Highlights of the START project presented by B. Vicenzi of EPMA during the opening presentation at the 21st EPMA PM Summer School in Dresden, Germany

Figure 12 - A. Bianchin (MBN) presenting "Thermoelectric Materials and the START Project" at the 21st EPMA PM Summer School in Dresden, Germany.

Figure 13 - A. Bianchin (MBN) presenting "Thermoelectric Materials and the START Project" at the 21st EPMA PM Summer School in Dresden, Germany.

DOI: 10.5281/zenodo.10184764

START LECTURED AT THE 2ND EDITION OF SUMMER SCHOOL "MATERIALS FOR ENERGY TRANSITION" IN PORTO, 7TH SEPTEMBER 2023

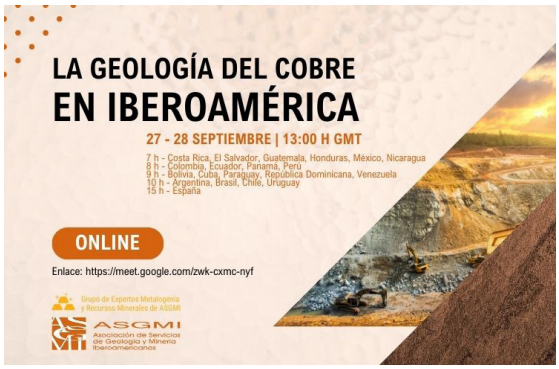
An oral presentation entitled "Projeto START - Utilização de tetraedrites como material termoelétrico" ("START Project – Use of tetrahedrites as thermoelectric material") was given by José Brito Correia to 20 Portuguese PhD and Master's students in the session dedicated to "Advanced Energy Materials" at the 2nd edition of the "Materials for Energy Transition" Summer School. This was a three-day event organised by Sociedade Portuguesa de Materiais (SPM), Ordem dos Engenheiros Região Norte, INL and LNEG. This was an excellent opportunity to publicize the project"s activities among the student community, with a more pedagogical presentation on mechanochemical synthesis, spark plasma sintering and the use of tetrahedrites for thermoelectric applications. At the end of the session Filipe Neves participated in the round table where he had the opportunity to frame the project"s objectives within the current challenges associated with the energy transition and the indispensable contribution of materials.

Figure 14 - Presentation by José Brito Correia (LNEG) at the 2nd edition of the Summer School "Materials For Energy Transition" in Porto, 7th September 2023.

Figure 15 - Round table including Filipe Neves (LNEG) at the 2nd edition of the Summer School "Materials For Energy Transition" in Porto, 7th September 2023.

OTHER START DISSEMINATION EVENTS

ASGMI Webinar "Copper Geology in Latin America", 27th-28th September



The webinar "Copper Geology in Ibero-America", presented by the Ibero-American Geological and Mining Services Association (ASGMI) and organized by its "Expert Group on Metallogeny and Mineral Resources" took place on the 27th and 28th of September at 13:00 (GMT) through Google Meet. The objective of the webinar was to inform about different aspects of the copper mining industry, given the fact that copper is rapidly becoming a very demanded material due to the changes in energy and transportation models.

The webinar featured prestigious speakers from different Ibero-American countries, who talked about topics like copper deposits in different parts of Ibero-America, the geology of said deposits and uses of the mineral.

Ester Boixereu, from the Geological and Mining Institute of Spain (IGME), gave her presentation "Reaprovechamiento de pasivos ambientales de la minería del cobre. El caso del proyecto START" ("Reuse of environmental liabilities from copper mining. The case of the START project"). Her presentation, as well as the rest of the webinar, can be found here: https://youtu.be/PFpbmHLTpDo (in Spanish).

DOI: 10.5281/zenodo.10184764

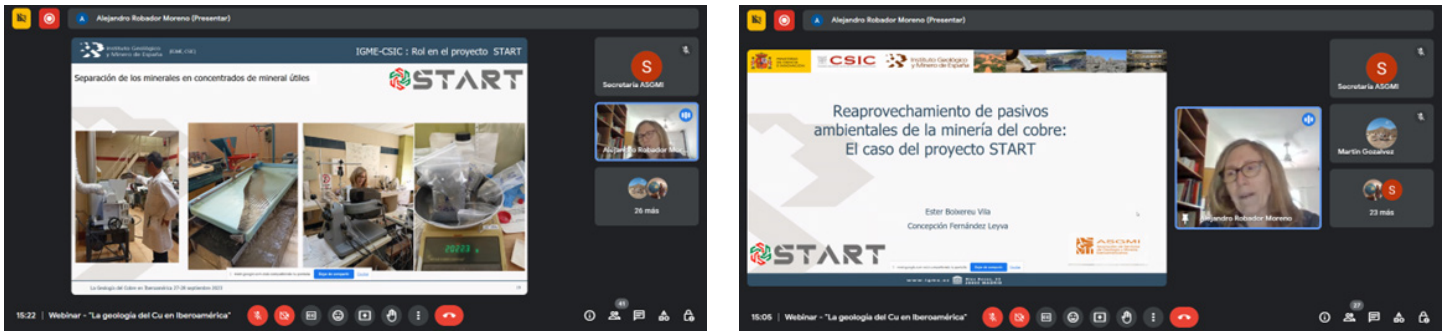


Figure 16 - Two moments from the presentation by Ester Boixereu (IGME) during the ASGMI Webinar "Copper Geology in Latin America".

START in 2023 European Researchers' Night Events

The START project was featured in the MacaroNight 2023 digital EU Corner and the physical EU Corners in Tenerife on the 29th September 2023 and was featured in the Patent's Week (2nd-6th October) in Gran Canaria under the umbrella of the European Researchers Night of the Macaronesia. Copies of Starty's comics were printed by LPRC and distributed. Here are some data of the event:

- Digital EU Corner: 52.800 views
- EU Corner Tenerife : 3.000 participants – 400 comics copies
- Patents Week Gran Canaria: 500 participants – 100 comics copies
- Upcoming social media campaign highlighting the projects November to December

START also took part in the European Researchers Night (also on 29th September) in Lisbon.

Figure 17 - In the "Macaronight", START material was distributed.

Figure 18 - START at the European Researchers Night in Lisbon.

DOI: 10.5281/zenodo.10184764

EURO PM2023 CONGRESS & EXHIBITION

EPMA european powder metallurgy association

1 - 4 October 2023 LISBON

Booth and presentations at Euro PM2023 in Lisbon, Portugal, 01-04 October 2023

The European Powder Metallurgy Association (EPMA) hosted this year its annual European Congress & Exhibition in Lisbon, from 1st to 4th October[17]. About 800 delegates could follow a plenary session, about 70 technical sessions and visit the exhibition with more than 80 exhibitors.

Among the booths, START organised one with informative posters and banners, a collection of exhibits (minerals, powders, an example of thermoelectric generator device) and a screen where the START introductory video and the latest Starty comic strip with explanations about the role of the project in pursuing the objectives of the EU in terms of efficient use of resources were displayed.

Figure 19 - The START booth at the Euro PM2023 Congress & Exhibition in Lisbon.

Figure 20 - The display with samples and the screen with the running Starty comics.

Figure 21 - Demonstration of the START project to students of the Young Engineers programme during Euro PM2023, by J.B. Correia (LNEG)

In the morning of Tuesday 3rd October, four twenty-minute demonstrations of the START project were held by José Brito Correia (LNEG) for international doctoral and master"s students at the project booth. The attendees were participants of the EPMA's Young Engineers programme[18]: 48 students were hosted free of charge in the first 2 days of the congress and were given introductory lectures and a guided tour in the exhibition, including the START booth. These demonstrations featured a general description of the project and the presentation of materials and devices within the scope of thermoelectric materials, arousing great interest on the part of the students.

DOI: 10.5281/zenodo.10184764

On Tuesday afternoon, at 16:30, a 30' oral presentation entitled "Replacement of tellurium in thermoelectric materials" was given by José Brito Correia in Session 44, the Functional Materials Special Interest Seminar – "Sustainability of Critical Raw Materials by PM".

Figure 22 - Presentation of J.B. Correia (LNEG) in Session 44: Functional Materials Special Interest Seminar – "Sustainability of Critical Raw Materials by PM", during the Euro PM2023.

In addition to these specific activities, the two Technical Managers of EPMA B. Vicenzi and K. Boz, gave short introductions to the project during the 6 Sectoral Group meetings (EuroAM, EuroFM, EuroMIM, Euro Press&Sinter, EuroHM, EuroHIP) and a Working Group meeting (EHQS) held in the Congress.

Future events

START is organizing participation in several more events in the next months. At the moment, we are focusing on three upcoming events.

On 30th-31st October, G. Olivenza of ASGMI will give a presentation about START titled "Reusing Secondary Mineral Resources For The Energy Transition: The Project Start Example" at the European Union SuperCluster Lapland Geoconference in Rovaniemi, Finland. It will be a great opportunity for our project to show our approach to similar projects and thus especially for our "clustering" effort for synergies.

In November, ASGMI is expected to hold its in-person workshop on mining environmental liabilities in Brazil. We are currently awaiting official confirmation from the Brazilian Geological Service regarding the event"s dates, and location. Some representatives of START will be present and will likely be able to present our activity there.

Also in November, namely on 13-17 November 2023, the 8th edition of the Raw Materials Week in Brussels will see START participating with some members and dissemination materials (poster, video).

More events will come after these!

If you are from a similar initiative or project and would like to organise something together, please contact us! We have a specific line of activity on "**clustering**" with initiatives that share one or more topics with us, so that would be very welcome.

DOI: 10.5281/zenodo.10184764

TECHNICAL PILLS

DESIGNING OPTIMAL THERMOELECTRIC SULPHIDES

The interdependence of a, σ, and κ has led to design strategies to maximize zT by seeking to decouple the critical connection between electronic and thermal transport:

- **Enhancing $\alpha^2\sigma$**: Solid solutions often show multiband behavior with valleys around the Fermi level, a fingerprint of TE efficiency. Band engineering approaches can move these bands toward their respective edges, leading to reduced energy differences that offer many conducting channels. Methods like band convergence and nestification are usually utilized for increased degeneracy, and extra effective density of states near the band edge regions result also in enhanced Seebeck coefficient. Furthermore, deliberate introduction of ionized impurities, to scatter preferentially low-energy charge carriers (energy filtering), increases $\alpha^2\sigma$ when the reduction in carrier mobility is more than compensated by an increase in Seebeck coefficient.
- **Decreasing κ_{ph}**: In most semiconductors thermal conductivity is dominated by the phonon contribution, so materials with low lattice thermal conductivity are sought. The high polarizability of the sulfide anion leads to significant bonding anisotropy, leading to the adoption of low-dimensional structures, which can reduce the lattice contribution to thermal conductivity as well as enhance the Seebeck coefficient. Solid solutions can also dramatically reduce the lattice thermal conductivity, i.e., disturbance of short-range order tends to scatter phonons, while maintenance of long-range order leaves the charge carrier mobility largely unaffected. Furthermore, the lattice thermal conductivity can be decreased by reducing the crystal size since a substantial fraction of heat is carried by low frequency phonons, and these are prone to scattering at grain boundaries.

The above strategies instigate the systematic exploration of diversified substitutions, but only a minute fraction of sulfide compositions has been scrutinized and through rather conservative and isoelectronic alloying strategies, although more exotic substitutions can lead to high power factors. Stability at the operating temperatures is mandatory in TE applications, and natural substitutions in minerals formed at high temperatures hint at stable configurations. The concept of maximizing configurational entropy to enhance solid-state miscibility inspires the exploration of unfamiliar composition spaces, but most studies focus on metal alloys and oxides and limited work has been carried out on medium- and high-entropy sulfides. In addition to solid solutions at transition metal sites, incorporation of Sn, present in tetrahedrite, as well as partial substitution of S by Se are potentially beneficial.

Charge carrier concentration and phonon vibrational properties can be designed from first principles. The temperature-dependent TE behavior can then be predicted by solving the Boltzmann transport equation. Efficient first-principles techniques based on density functional theory (DFT) are currently employed for high-throughput theoretical studies. The large quantity of data generated by these studies motivates the use of machine-learning techniques to explore TE properties in vast composition spaces.

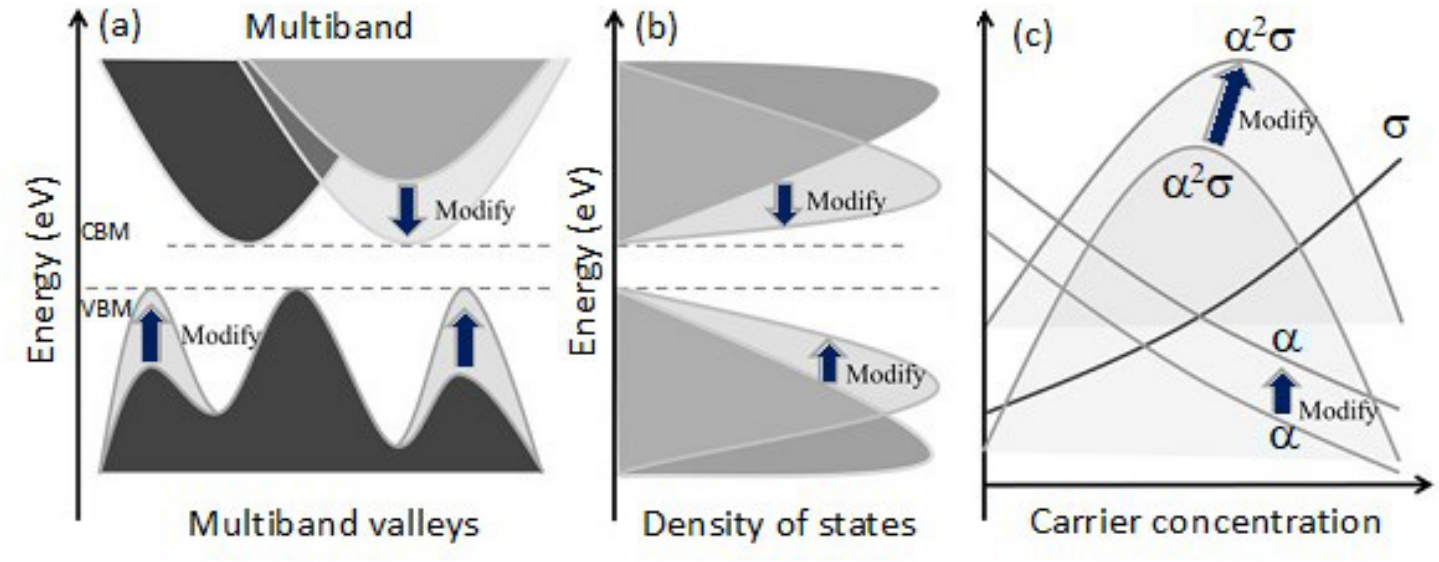


Figure 23 - Modification of (a) band valleys (CBM = Conduction Band Minimum energy, VBM = Valence Band Maximum energy), (b) density of states and (c) corresponding $\alpha^2\sigma$ through electronic band structure engineering (adapted from [19]).

DOI: 10.5281/zenodo.10184764

MEET THE SCIENTIFIC ADVISORY BOARD MEMBERS: JEAN-YVES ESCABASSE

In the last issue we have started to present you the members of our Scientific Advisory Board by short interviews where they highlight their activity and the activity of their institutions and companies.
Today you will read about Jean-Yves Escabasse.

Figure 24 - Jean-Yves Escabasse is a Chemical Engineer and Doctor, with 40 years of experience in R&D and Innovation within several materials industry sectors, with positions held in companies and research institutes, and responsibilities in product and process development, team management, regulatory affairs, IPR issues, sales and marketing, large project management. Coordinator for many multinational projects, in particular "H2020-IND-CE-2016-17/H2020-NMBP-PILOTS-2016 INTEGRAL: Initiative to bring the 2nd generation of ThermoElectric Generators into industrial ReALity (GA 720878, 2016-2019).

Jean-Yves, we understand that since the beginning of your career you have always been involved in R&D and specifically in European research programmes. How would you rate the quality of EU support to its research, development, and innovation entities and to companies' efforts in the field?

Yes, I've been working in Research and Technical Organisations (RTOs) for more than 30 years. EU support through various instruments, in particular Horizon Europe, is essential to foster innovation in Europe. European funding programmes are looked at with much envy across the World. This is emphasised by the long list of third countries requesting to be associated to Horizon Europe. I won't comment much on basic research, which by nature can almost only be funded publicly, or, as seen in a few countries, by patronage. What disturbs me with such private sponsoring is the research agenda being set by individuals whose (high) merit is to be wealthy. It's most honourable from them to invest their fortune in public interest causes, but the development of the knowledge base of humanity should belong to public authorities and not rely on charity. Regarding applied research, i.e., medium-to-high TRL activities, experience and reason tell me that its funding must be founded on three equal-value pillars. As this R&D work is meant to be transferred to and exploited by industry, industry itself must pay part of it, either in-kind or in-cash; the second pillar is made of public-funded projects, e.g., Horizon Europe. These two sources of funding for RTOs are essential and must be acquired by intensive commercial activities. Both are extremely and rightly competitive, as it is fair that only the best projects must be selected. However, this does not suffice. RTOs cannot be 100% funded by public or private contracts and a fair share of public, basic, automatic funding is necessary, e.g., as a government grant. This is the financial model of large RTOs such as CEA, Fraunhofer and VTT, in particular. Ideally each pillar should represent one third, but unfortunately government funding is lower than that and this is one of the reasons why Europe does not invest the intended 3% of GDP in R&D and innovation. The other reason is the chronic under-investment of industry in own R&D activities.

Is Horizon Europe achieving its declared objectives, according to you? What would be your suggestions for improvements for the next framework?

This is a difficult question. Horizon Europe is undeniably very ambitious and has noble goals. There is an old saying to the effect that you should not bite more than you can chew. An unwanted effect could be to spread its aid too thinly. This is probably the result of a complex and lengthy elaboration and approval process of Framework Programmes by the triangular loop Commission/Member-States Council/Parliament. In effect, lobbyists and budgetary or political considerations take precedence, maybe in opposition to real needs of the Research and Innovation community. I noted that the Commission has now for several years developed Public Private Partnerships under several collaboration models: co-funded, co-programmed or joint undertakings. The last two largely involve industry participation, both in financial commitment and technical inputs. To me, this is a very strong point for the relevance of work programmes and project topics, at least in Pillar 2 of Horizon Europe.

DOI: 10.5281/zenodo.10184764

Europe is facing a growing challenge in securing the supply of critical raw materials (CRMs) that are essential for its green and digital transitions. In your opinion what are the potential impacts of the CRM supply challenge on the achievement of the EU"s climate and energy goals?

Climate change is a tremendous challenge for the whole mankind. If you look at it, the use of fossil energies is a major cause. Other greenhouse gases than CO_2 are also strong contributors and should be dealt with, e.g., methane emissions by cattle or fluorinated compounds in various applications, but this is not the topic here. Take it or leave it, we must urgently cut our CO_2 emissions worldwide, lest our planet becomes unliveable. Now what does it mean? One third of CO_2 emissions in the most advanced countries (Western World + BRICS + a couple of others) is caused by the transport sector, where an obvious solution to replacing fossil fuels is electrification. Another third is caused by heating and cooling. Unlike what some activists try to impose, I don't believe that humans will forgo the benefits of technical progress and are prepared to go back to pre-industrial conditions of life. Therefore, it's unrealistic to think that energy demand can be drastically reduced. Most advanced countries must indeed save energy, but developing countries have a legitimate claim to using more energy. In this context, global energy demand cannot and will not decrease. This means that more, but cleaner energy must be produced, and it must be used more sustainably.

Regarding production, CO_2 emission-free energy is either nuclear (by fission, until fusion becomes reality) or renewable (solar, wind, hydraulic...). Most renewable energies are intermittent, so to dispose of continuous power supply, pilotable sources are unavoidable. If you want to avoid coal, gas or fuel, this means nuclear. All these need critical metals: uranides as nuclear fuels, rare earths for magnets in power generators (windmills and others), e-motors (vehicles, robotics and machinery in industry), lithium and graphite in batteries, ultra-pure silicon and silver in solar panels, platinum group metals in fuel cells and electrolysers, nickel and cobalt everywhere to quote only the main ones.

The digital transition has the same consequence: more computers, more chips in cars, in manufacturing equipment, in domotics, everywhere, mean more silicon and doping materials of high purity.

So, if we really want to achieve the EU"s climate and energy goals, we must massively electrify transport, industry and domestic usage. This means that we all need critical metals in high amounts, while Europe cannot fulfil its needs easily. Market demands are here, mines and conversion are elsewhere. We have the following options:

- **Forego**: I don't believe that we can altogether forego transport, lighting, domestic comfort, but we must in any case dramatically reduce energy consumption in all domains. This belongs to individual and collective behaviour, worldwide.
- **Reduce**: Naturally, industry offers electrified products with highest performance, for example driving range for e-cars, based on high-capacity batteries and high-efficiency e-motors. But do we really need a 3-tonne SUV with 500 km range to drive most of the time in town and go to work or shopping? Lower performance means dramatically reduced needs for Critical Raw Materials (CRMs). Modesty can perhaps avoid us complete forbearance. Here again a matter of behaviour. Reducing the market demand means frugality. You can also reduce the technical demand by a better use of the same materials: this belongs to science. Material research can provide technologies where a reduced amount of CRMs can achieve the same performance, e.g., grain boundary diffusion of dysprosium in RE magnets. There's still a high potential in this field.
- **Substitute**: again, this is a matter of scientific research. For instance, Nd or Pr can be replaced by La or Ce with almost the same performance. These are indeed CRMs, but far more abundant and cheaper than Nd or Pr. So, substitution + modesty (accept a slightly reduced performance) can be a solution. In addition, research can discover new materials to complement those already known and needed for the transition, but this will take time, a lot of time.
- **Recycle**: obviously, what you get from end-of-life products needn't be supplied from primary sources, e.g., mining. However, considering the tremendous rise in demand, this will help but not suffice. Primary materials will always be needed, so recycling alone can't be the solution.

To conclude, yes, the access to CRMs is instrumental in Europe's achievements. To be frank, I have doubts that we can make it in time, unless we do a lot of "foregoing".

Since 2016 you are with CEA in Grenoble, France, and when you joined you have been involved in a H2020 project named INTEGRAL, whose subject was actually thermoelectricity. Can you tell us more about it?

INTEGRAL was about upscaling second-generation of improved thermoelectric materials, mainly based on silicides and half-Heuslers: affordable and mostly based on earth-abundant elements and eco-friendly materials, in order to address mass-market needs (automotive, heavy-duty trucks, autonomous temperature control and industry waste heat recovery). INTEGRAL would allow the industry to step up towards advanced manufacturing and commercialisation of systems integrating multifunctional TE materials, through material customisation, in particular using a nano-based approach, latest techniques for characterization and process control as well as up-scaled pilot-line demonstrations. Ambitious goals had been set for performance, production scale and costs. Technically, things went well, and we were indeed able to carry out successfully most foreseen demonstrations in relevant or even industrial environment, especially in industrial waste heat harvesting.

DOI: 10.5281/zenodo.10184764

However, in the automotive (petrol engine, passenger vehicle) and transport (long haul diesel truck) sectors, we were faced with too low temperature difference and thermal transfer on the hot side, leading to disappointing efficiencies. As a matter of fact, Internal Combustion Engines (ICEs) have become so efficient that the temperature of exhaust gases is too low to operate TEGs efficiently. To make it short, considering the price of fuel at the time and the cost of the TEGs compared with the harvested power, it wasn't worth it. What killed the game was the diesel-gate crisis in 2015, where Original Equipment Manufacturers (OEMs, car makers) took it seriously and suddenly turned their interest towards electric vehicles. Nowadays, all investments by OEMs go in this direction and they have no interest in TEGs in ICE vehicles. So, I don't see any future there.

How do you see thermoelectric devices in the rush towards energy efficiency and cleaner production? Do you foresee good opportunities in some sectors in the near future?

In addition to what I concluded about INTEGRAL, above, I think that any process that requires high temperatures or involves very hot sources may benefit from energy harvesting: metal industries, glass, cement, ceramic industries, and also domestic heating at small-home, family-home or collective-home levels. When in winter, everyone wants to be warm and comfortable at home, they push either their boiler (whether with oil, gas, or wood) or their heat pumps, or both. Any kWh that's produced at home with a TEG coupled with the boiler can be fed directly to the heat pump or sold to the grid. Combined heat-and-power, though conceptualised many years ago, just makes sense!

Now, there are challenges, which need to be tackled to make TEGs reliable and efficient. As I earlier mentioned, thermal transfer is essential, and this is true for both hot and cold sides. Not only you need good heat exchangers, but also good conductivity at the interfaces. Architecture of devices and systems is pivotal, and there's a lot of work to do in this field. Next, TEGs are by essence working under thermal gradients and if you want a good thermodynamic yield, you need a high temperature difference. This causes important thermomechanical constraints on materials with different coefficients of thermal expansion. Not the least of the challenges is cycling. Most of the time, TEGs will be used intermittently, meaning that the hot side will alternatively become very hot and back to cold while the cold side will not change that much. This means fatigue on the materials (TE materials are generally brittle) and on the interfaces. Looking into the literature and on what's presented in TE conferences, a lot of research is made on materials to increase zT, which indeed makes sense, but I have the feeling that researchers tend to neglect challenges of assembling those materials into modules, devices and systems.

You have seen what START is trying to do in the field of thermoelectricity, mine waste recovery and waste heat recovery. What are, in your view, the strongest features of our project?

Mankind has lived in abundance for centuries, but now this is over. Cheap oil, coal, gas and mineral-rich ores led us to pick only the best and most accessible resources and through away the rest, like torching gas in oil wells and extracting only the most valuable ores in mines, while throwing away tailings rich with other elements. The current change of paradigm leads us to think better. Extracting tetrahedrites for mine waste is one good example, and I like the idea of coupling it with another tapping in wasted resources, namely heat. Static conversion such as TEGs have this benefit of easily producing electricity from heat that would otherwise be thrown away. In that sense, START is a very good idea. However, in order to make thermoelectricity work, don't forget that many other technical challenges must be solved.

Thanks Jean-Yves!

Figure 25 -The INTEGRAL Horizon 2020 project ("INitiative to bring the 2nd generation of ThermoElectric Generators into industrial ReALity"[20]) was led by CEA (France) and carried out between December 2016 and November 2019.

DOI: 10.5281/zenodo.10184764

CONSORTIUM TOUR

We continue our tour of consortium members: in this issue, meet ASGMI (Spain) and GeniCore (Poland).

ASGMI - ASSOCIATION OF IBEROAMERICAN GEOLOGICAL AND MINING SURVEYS

ASGMI, the Association of Iberoamerican Geological and Mining Surveys is a non-profit organization founded on 1993 which represents twenty-two National Geological Surveys in Latin-America, Portugal and Spain. It has its own legal entity since 2012, and it is currently formed by twelve groups of experts dedicated to different areas of Geoscientific knowledge. The main mission of ASGMI is:

To generate and disseminate geoscientific knowledge to contribute to the socioeconomic development of society by horizontal, bilateral and multilateral cooperation between the associated members.

- To provide international, scientific and technical cooperation focused on development, but considering society's growing concerns about natural disasters, management of mineral, hydric and energetic resources, pollution and climate change effects.

- The institutional strengthening of the associated Geological and Mining Services.

The main activities of ASGMI consist of monthly meetings of expert groups that collaborate on tasks related to projects funded by the European Union in which ASGMI participates or ASGMI projects that include initiatives such as the development of the recently published "Geochemical Sampling Manual" or the "Critical Minerals Map of Latin America" currently being developed by the Mineral Resources Expert Group. In addition to ASGMI's annual in-person General Assembly, the organization hosts thematic workshops, both in-person and virtual, open to the entire scientific community.

Inside START, ASGMI cooperates in different parts of the project. Through its Group of Experts in Mining Environmental Liabilities, ASGMI participates in the selection of mine waste sites and physical separation and concentration of minerals. (WP2).

ASGMI also participates in the Communication and Dissemination work package (WP6) of the project, collaborating in the management of information on SlideShare and in the communication and dissemination of technical and scientific information related to the project at various events and initiatives in which ASGMI is involved. ASGMI leads the clustering task, with objective is to identify similar projects to establish synergies and carry out joint communication efforts. Additionally, ASGMI is responsible for organizing a training workshop open to Bbachelor's and Mmaster's degree students, where they can interact with researchers, ask questions, and learn more about the project.

(https://asgmi.org)

DOI: 10.5281/zenodo.10184764

GENICORE

GeniCore
Genius at the Core

What is GeniCore and U-FAST?

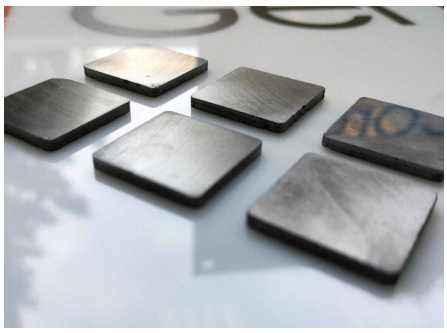
GeniCore is a pioneering company in the field of material engineering, specializing in the manufacturing of Spark Plasma Sintering (SPS) machines. These machines are designed for sintering a broad range of innovative powder materials and applications. One of GeniCore's standout products is the U-FAST system. This system is engineered to generate current pulses with the shortest rise time available in the market. The U-FAST system can sinter materials either without grain growth or with limited grain growth, thanks to its unique design that optimizes the connection between the power supply and the stamps. This not only enhances the machine's performance but also significantly reduces power consumption.

What is Pulse Plasma Compaction (PPC)?

Pulse Plasma Compaction (PPC) is an advanced form of the conventional Spark Plasma Sintering (SPS) process. PPC employs high voltage and short electrical pulses to achieve full densification of materials at lower temperatures. This is particularly useful for sintering sulphide-based powders. The technology offers several advantages over traditional SPS, including faster heating rates, more accurate control of sintering energy, and higher levels of safety and reliability. PPC is a modification of the conventional SPS process, where energy stored in a capacitor bank is delivered to the powder in short pulses. This field-enhanced diffusivity enables full densification at lower temperature setpoints than in conventional SPS.

How is GeniCore Contributing to the START Project?

GeniCore's innovative PPC and U-FAST technologies are playing a crucial role in the START project. These technologies are expected to bring about significant improvements in material density and stability. This is particularly beneficial for the performance of thermoelectric (TE) materials used in the project. The START project aims to leverage these technologies to prevent thermally induced solid-state reactions in TE materials, thereby enhancing their overall performance. The production of square samples in place of traditional cylindrical compacts will also be assessed, representing a cost-effective solution and a huge step forward in the consolidation of parallelepiped thermoelements required for device assembly.



DOI: 10.5281/zenodo.10184764

BIBLIOGRAPHY

[1]Römer, F. and Goldmann, D. 2019, Wiederaufbereitung eines bergbaulichen Abfalls im Harz – Wie aus Altlasten in Zukunft vielleicht Lagerstätten werden., CHEMKON 2019, 26, 66. DOI: 10.1002/ckon.201800080

[2]Schirmer, T., Römer, F., Elwert, T., Goldmann, D., Characterization of tailings of the Rammelsberg ore deposit for a potential reprocessing. Proceedings of the 9th European Metallurgical conference, EMC 2017, 25-28 June 2017, www.scopus.com

[3]German mine waste cadastre for metal raw materials (under development, BGR, Hannover, stand 01.09.2023);

[4]The online database http://www.mindat.org and references therein, accessed in May 2023

[5]The online database www.mineralienatlas.de and references therein

[6]The online database de.wikipedia.org/wiki/Liste_von_stillgelegten_Bergwerken_in_Deutschland and references therein

[7]Google Maps, maps.google.com

[8]Fritsche, R. and Schmidtz, J., 1996, Bestandsaufnahme von Rückstandshalden aus Bergbau und Erzaufbereitung in Baden-Württemberg; Forschungszentrum Karlsruhe, Technik und Umwelt, Band II: Mittlerer Teil., FZKA 5769B, https://publikationen.bibliothek.kit.edu/270040565/3813594

[9]Metz, R., 1988, Historischer Atlas von Baden-Württemberg XI, 10. https://www.leo-bw.de/media/kgl_atlas/current/delivered/pdf/HABW_11_10.pdf

[10]Metz, R., Richter, M., Schürenberg, H., 1957. Die Blei-Zink-Erzgänge des Schwarzwaldes. Beiheft Geol. Jahrb. 29, 277

[11]Walter, B.F., Mathias Burisch, Tobias Fusswinkel, Michael A.W. Marks, Matthew Steele-MacInnis, Markus Wälle, Olga B. Apukhtina, Gregor Markl, 2018, Multi-reservoir fluid mixing processes in rift-related hydrothermal veins, Schwarzwald, SW-Germany, Journal of Geochemical Exploration, 186, 158-186, https://doi.org/10.1016/j.gexplo.2017.12.004

[12]Werner, W. and Dennert, V., 2004, Lagerstätten und Bergbau im Schwarzwald, LGRB, Freiburg, ISBN 2-00-014636-9

[13]https://en.wikipedia.org/wiki/Density_functional_theory

[14]The maximum efficiency of the energy conversion process (for both power generation and cooling) at a given temperature point in the material is determined by the thermoelectric materials figure of merit z T, given by [Équation], where σ is the electrical conductivity, κ the thermal conductivity, S is the Seebeck coefficient, all functions of absolute temperature T.

[15]Available in https://www.start-heproject.com/multimedia/

[16]https://summerschool.epma.com/

[17] https://europm2023.com/

[18] https://www.youngengineers.epma.com/

[19] N. Wang, M. Li, H. Xiao, Z. Gao, Z. Liu, X. Zu, S. Li, L. Qiao, npj Comput Mater 7 (2021) 18

[20] https://cordis.europa.eu/project/id/720878

CONTACTS

START regularly updates its website and social media with news about its activities, but also with more general documents and info on the topics of relevance for the project. Thermoelectricity, waste heat recovery, mine waste remining, sustainability, raw materials and critical raw materials, energy efficiency, and many others.

If you are interested in receiving this newsletter and other special news from the project directly in your mailbox, consider subscribing our mailing list on the website ("Contacts" page, "subscribe" section)! Clicking on the "Subscribe" button, you will fill a form generated by SendinBlue, our mailing system, and will subsequently receive an E-Mail to confirm your address. Your data will be treated and stored in accordance with the EU GDPR Regulation. And do not forget to follow all our social media accounts! Here is the list of the important links to click to reach our news:

Website: https://www.start-heproject.com/

Twitter: https://twitter.com/START_HEproject

LinkedIn: https://www.linkedin.com/company/86266991/

Twitch: https://www.twitch.tv/start_he_project

YouTube: https://www.youtube.com/channel/UCHVjEhpVz9uaEgzICj2InPA

SlideShare: https://es.slideshare.net/StartProject/

If you have special queries, you can contact us at the following addresses: contact@start-heproject.com

Filipe Neves, LNEG (coordinator) filipe.neves@lneg.pt

Bruno Vicenzi, EPMA (dissemination manager) bv@epma.com

DOI: 10.5281/zenodo.10184764