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START NEWSLETTER

RECOVER-REFORM-REUSE
for a Sustainable Future

EDITORIAL

Dear members of the START community,

We are almost halfway through the project activities and what a journey this has been! The advances we have made together are nothing short of remarkable. This edition of our Newsletter is a testament to our collective dedication and the exciting progress we've achieved. The completion of our first Periodic Report marks a significant milestone, and the advancements in tetrahedrite mineral-based thermoelectric materials are not just promising—they're a leap towards a sustainable future.

We're excited to share updates on our ongoing activities, our synergistic collaborations with the EHRASE cluster and THERMOS project, and insightful technical information on thermoelectric generators. But that's not all, join us on the Consortium Tour, where this time SGUDS and IGME-CSIC take centre stage. Plus, don't miss the insightful interview with Doug Crane from our Scientific Advisory Board, whose expertise enriches our understanding of thermoelectrics.

This edition also features the fascinating adventures of Starty, exploring the practical uses of thermoelectric devices in a narrative that's both educational and engaging.

Looking ahead, we eagerly anticipate your visit to the START booth at the upcoming 40th International and 20th European Thermoelectric Conference, ICT/ECT 2024, in Krakow.

We hope this Newsletter serves not only as a source of information but also as an inspiration for continued excellence. Stay connected with us for more exciting updates from START on our website and social media channels.

(F. Neves)

CONTENT

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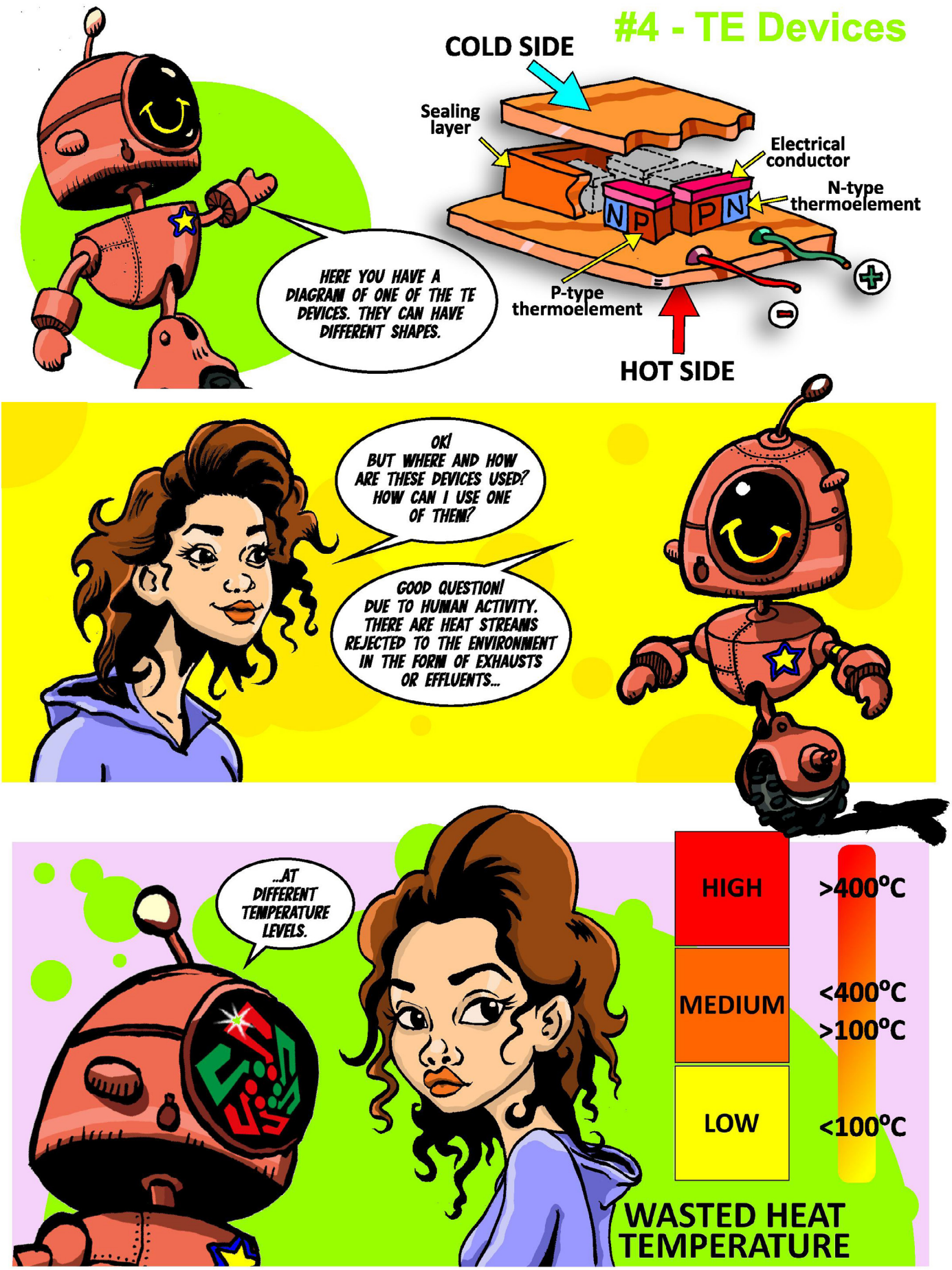
STARTY – 4: TE DEVICES



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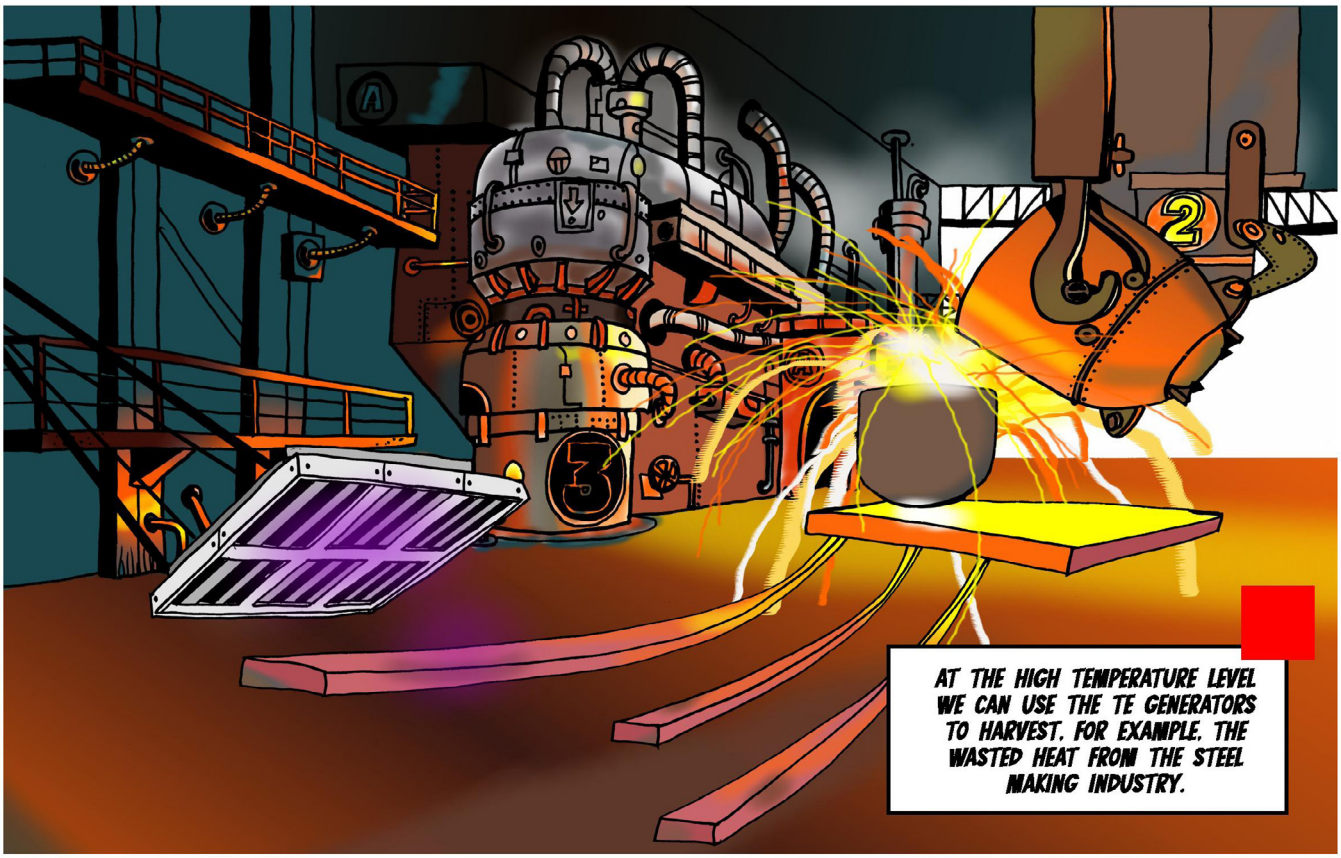

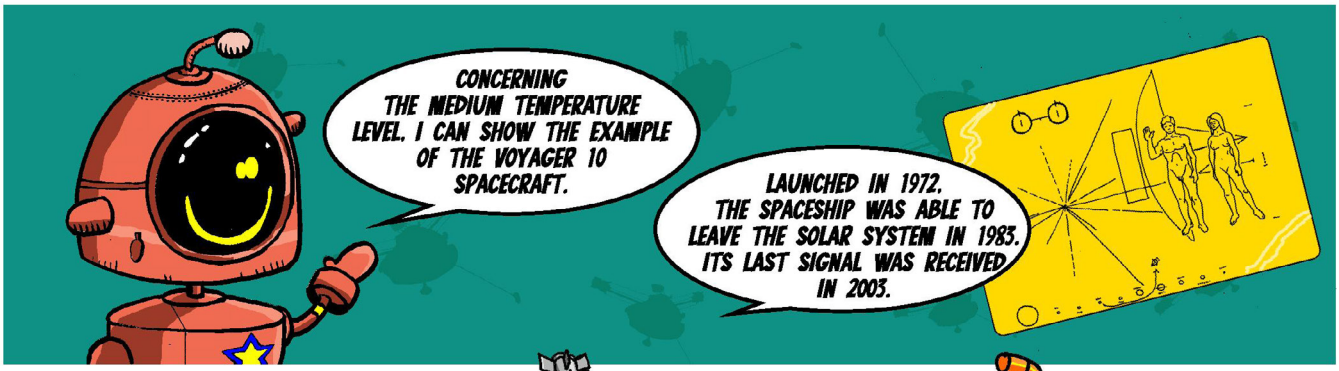

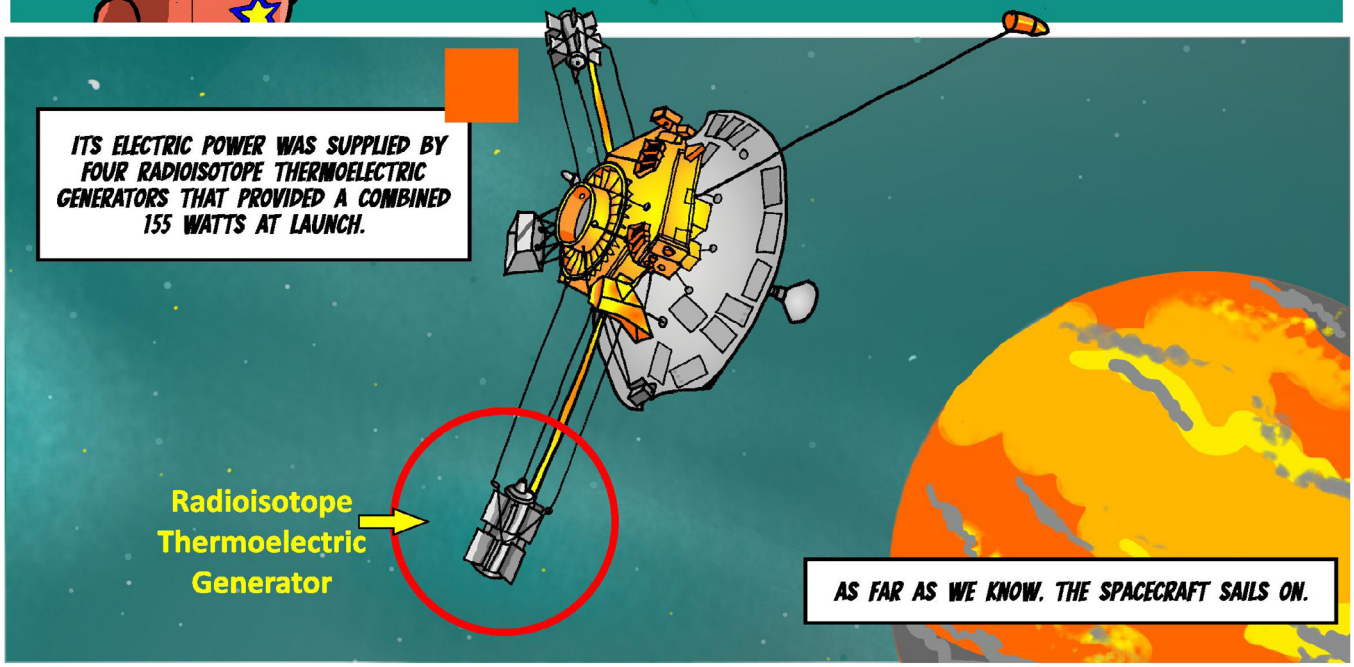

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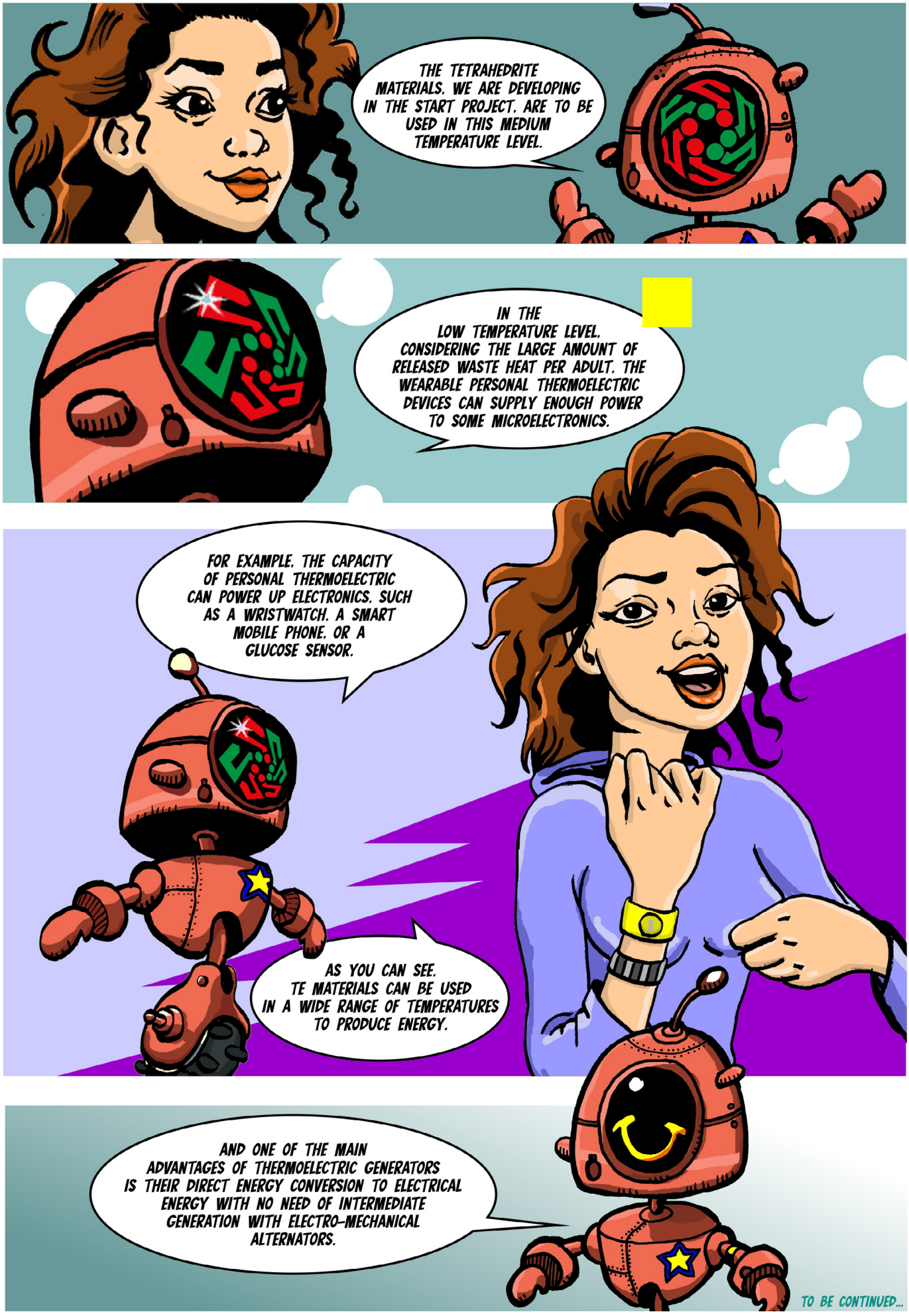

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START CHRONICLES: GEOLOGY, THERMOELECTRICS AND MORE

NEWS FROM WORKPACKAGES

NEWS FROM WORK PACKAGE 3 "Development of tetrahedrite mineral-based thermoelectric materials"

WP3 partners have synthesized (by High Energy Ball Milling, HEBM) and sintered (by Spark Plasma Sintering, SPS) more tetrahedrites samples at varying mineral/synthetic ratios, with the aim of incorporating the highest amount of mineral concentrate from mine tailings in the formulation of the TE compositions, but without compromising too much on the thermoelectric properties. The main results obtained with these samples have been summarized in the radar graph in Figure 1: thermoelectric (TE) properties (measured at 350 °C) are shown for samples prepared in the START project, and for a reference tetrahedrite sample[1], which has the highest reported ZT value among tetrahedrites made via the same synthesis process employed in the project (HEBM + SPS).

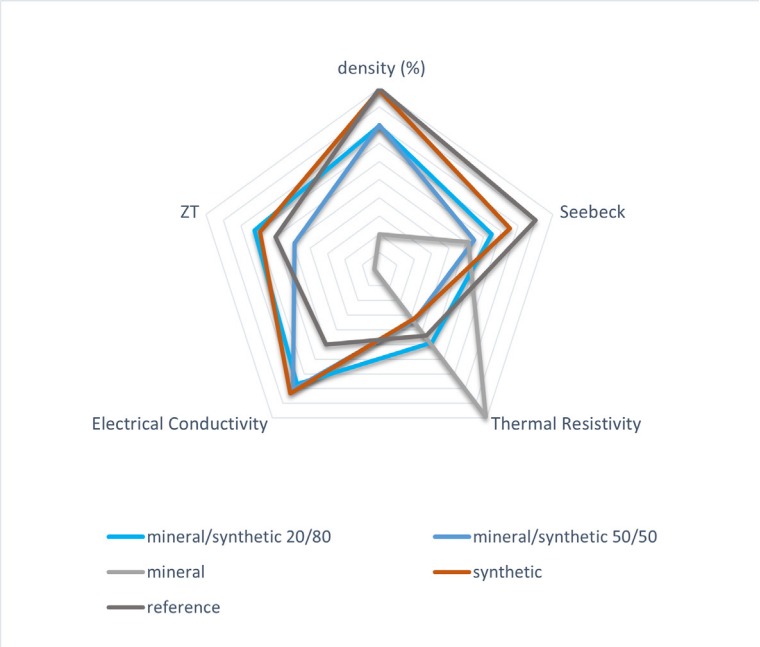

Figure 1 - Radar graph summarizing the TE properties of some representative START samples, measured at 350 °C. To help visualization, each axis goes from zero or from the value of minimum acceptability to the maximum value measured for each property, for this class of materials. Density (%) is the density of the sintered pellet with respect to the density of the powder material. Axes spans: (density (%): 80-100; Seebeck: 100- 250 ($\mu V \cdot K^{-1}$); Thermal resistivity: 0.5-3 ($m \cdot K \cdot W^{-1}$); Electrical conductivity: 0-20 ($mS \cdot m^{-1}$); ZT: 0-1. In general, a bigger area identifies a better performing TE material.

As can be observed from the graph:

i. the synthetic tetrahedrite with optimized composition developed in the START project has higher ZT compared to the maximum value reported for HEBM+SPS samples (0.69 vs 0.61)

ii. the TE properties of the pure mineral are clearly inferior (possibly related to incomplete sintering)

iii. incorporating 20% of mineral concentrate in the tetrahedrite formulation yields a material with figure of merit comparable to the synthetic one (ZT = 0.72)

iv. incorporating 50% of mineral concentrate results in slightly decreased ZT (0.49).

While in the initial phase of the START project, the performance of a tetrahedrite sample was assessed solely based on the maximum ZT/PF reached at 350 °C (target range of working temperatures identified for the TEG devices is RT-350 °C), at this stage of the project, the thermal stability over time has been included as additional criterion to further refine the p-type materials composition. This evaluation is very important to obtain a material that can withstand the operational environment in which the final TEG will operate. For these experiments, the TE properties S (thermopower) and ρ (electrical resistivity) were measured at constant intervals over the course of four days, while the sample was kept at 350 °C in helium atmosphere. Thermal conductivity was measured at the beginning and at the end of the thermal treatment. Preliminary results evidenced a promising retention of TE properties over the investigated time period, confirming their suitability for the integration in the first implementation of a START-Thermoelectric Generator.

Next steps will be the evaluation of the effect of repeated thermal cycles on the thermoelectric properties, as the materials will be subject to multiple heating and cooling cycles at the working conditions. These effects will not only be assessed by measuring the TE properties, but also by performing temperature dependent XRD measurements and TEM microstructure analysis.

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Since tetrahedrites are known to be sensitive to degradation if heated in a non-inert atmosphere (oxidation and sulphur loss at T > 450 °C), we are testing the use of protective coatings to "encapsulate" the p-type thermoelectric legs, and thus to overcome the thermal degradation of the device during actual operating conditions (see WP4). The first sintered and coated legs are almost ready now for the integration tests and assembly of the first START TE device. Updates on this in the next Newsletter, stay tuned!

NEWS FROM WORK PACKAGE 4 "Assessment of thermoelectric materials"

The characterization of mineral and synthetic materials continues as a background activity of the whole project. New key results include the use of mass spectrometry to detect the formation of SO_2 gas in the materials during annealing, which is responsible for generation of porosity and loss of sulphur during device service (Figure 2). In addition, density functional theory provided a fundamental understanding of the role of iron in closing the band gap of tetrahedrite (Figure 3).

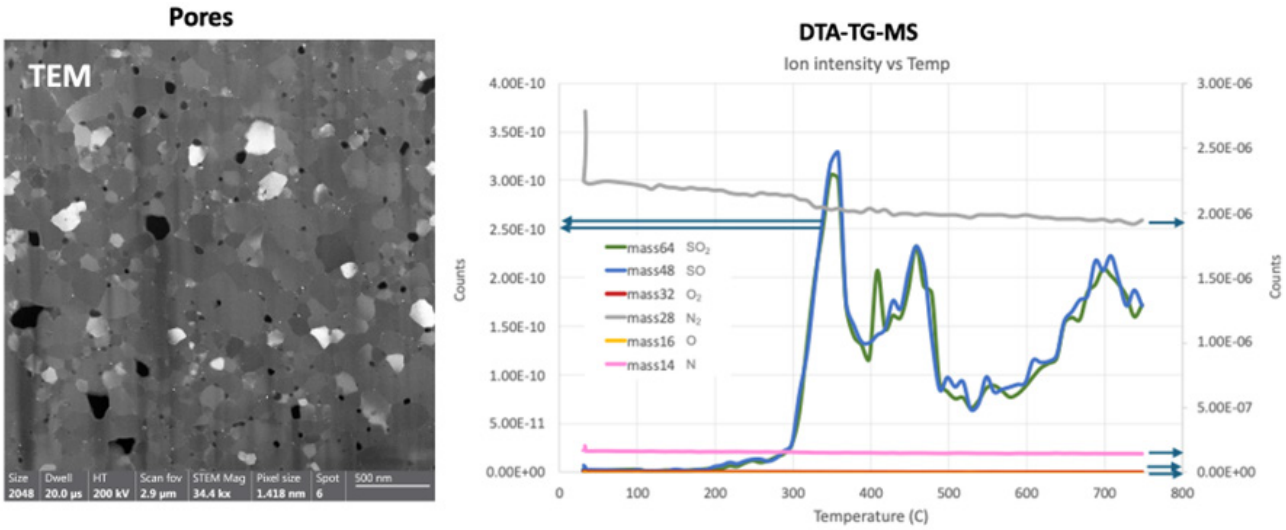

Figure 2 - SO_2 gas forms above 300 °C in the material produced by mechanical synthesis.

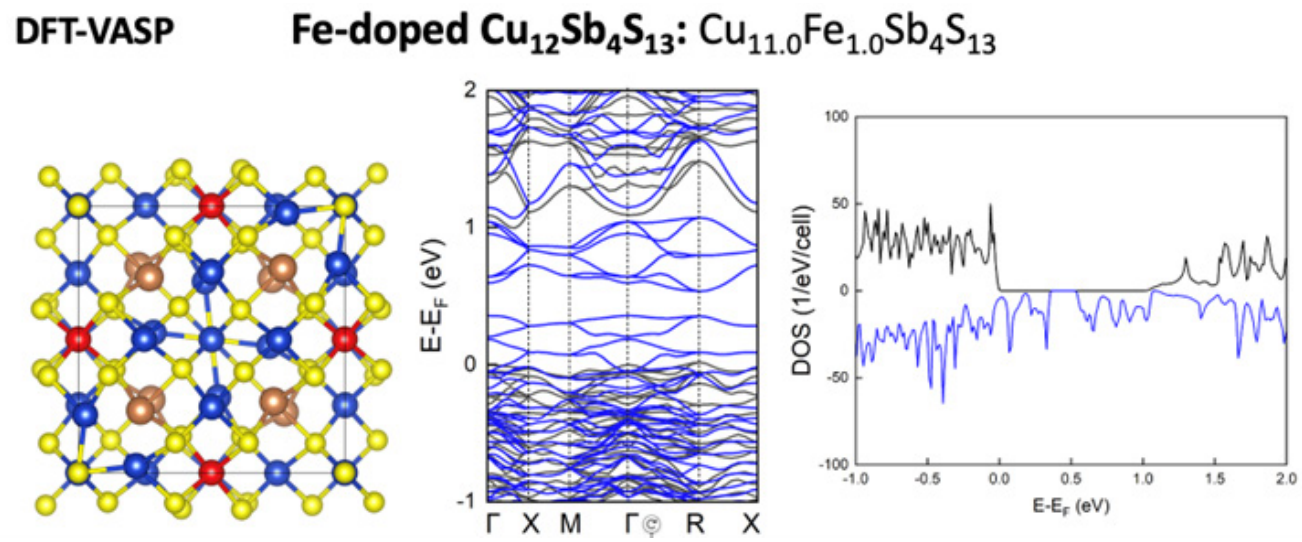

Figure 3 - Iron introduces new electronic states in the band gap of tetrahedrite. Relaxed atomic structure, electronic band structure, and density of states of $Cu_{11.0}Fe_{1.0}Sb_4S_{13}$. The blue, yellow, orange, and red spheres correspond to Cu, S, Sb and Fe atoms, respectively.

NEWS FROM WORK PACKAGE 5

Model for the START TE module

In WP 5, RGS and SINTEF initiated the development of a comprehensive COMSOL model for the START module. This endeavour commenced with establishing a coupled thermal and electrical effect, initially utilizing temperature-dependent data for P-type tetrahedrite and N-type magnesium antimonide materials. To optimize the efficiency of these materials, the hot side temperature was set at 350 ºC, while the cold side remained at 50 ºC. As material data became available from LNEG in WP 3 for synthetically produced tetrahedrite materials, they were seamlessly integrated into the model (example modelled scenario shown in Figure 4 (left, right)). Over the subsequent 6 months of modelling activities, the incorporation of n-type material data and the inclusion of heat interface (convection heat transfer on the hot and cold sides) will be prioritized to fine-tune the thermoelectric generator architecture, including fill factor and leg dimensions, to maximize power production from incoming heat flux density. Additionally, mechanical properties will be accounted for to assess the expected thermomechanical stresses in the module due to the varying coefficient of thermal expansion (CTE) of the different materials.

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Regarding the choice of materials for the general stack and required layers, a suitable candidate for the diffusion barrier layer for both tetrahedrite and magnesium antimonide has been selected. For bonding/brazing purposes, two nano/micro-structured silver sinter pastes have been procured. Initial tests were conducted to explore process optimization for sintering these silver pastes, using thin metal foils. Various parameters such as applied pressure, sintering atmosphere (argon/air), sintering temperature and time were tested. Successful bonds were achieved with both silver pastes, demonstrating electrical resistances down to 6 milliohms and minimal porosity (see Figure 5 (left)). Currently, shear testing of the optimized bonds is being carried out to get detailed images of the fracture surface and a value for the shear strength for these bonds.

Furthermore, initial designs for ceramic substrates with copper pads plated with silver have been developed (Figure 5 (right)), and a manufacturing partner has been identified for production. Over the next 6-9 months, TEG active material sintered discs from WP 3 will be coated with the diffusion barrier layer and subsequently sliced into pellets of tuned dimensions based on modelling outcomes before being bonded to these ceramic substrates for the first TEG module prototype.

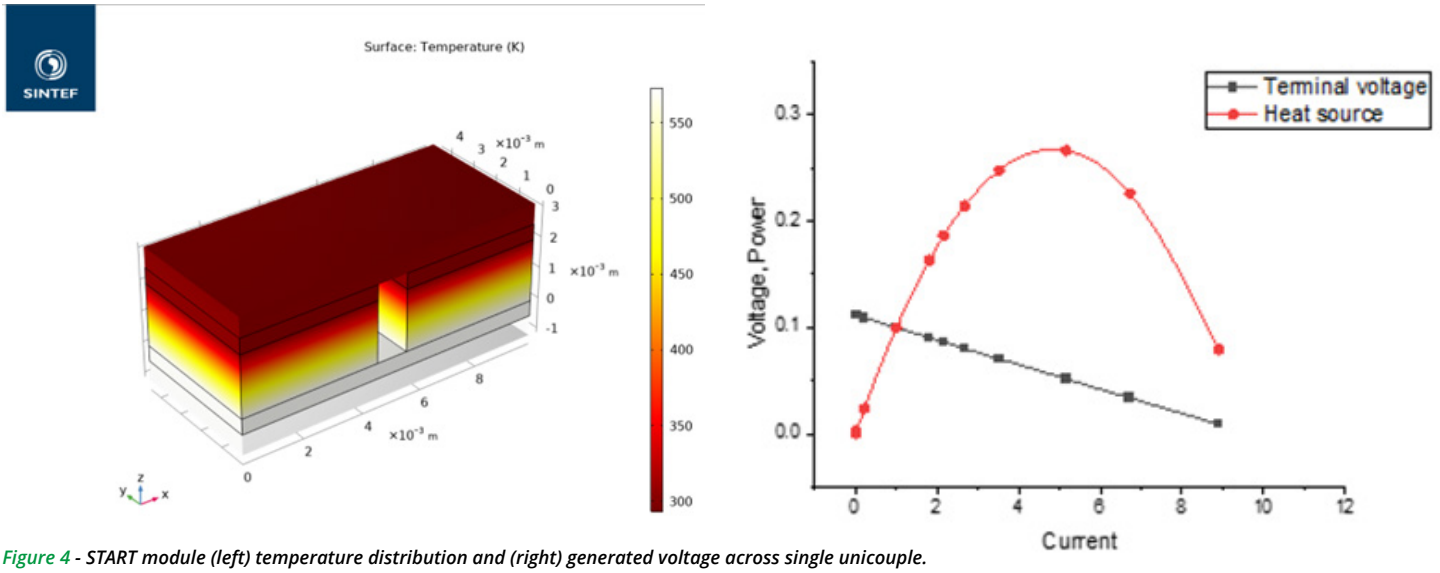

Figure 4 - START module (left) temperature distribution and (right) generated voltage across single unicouple.

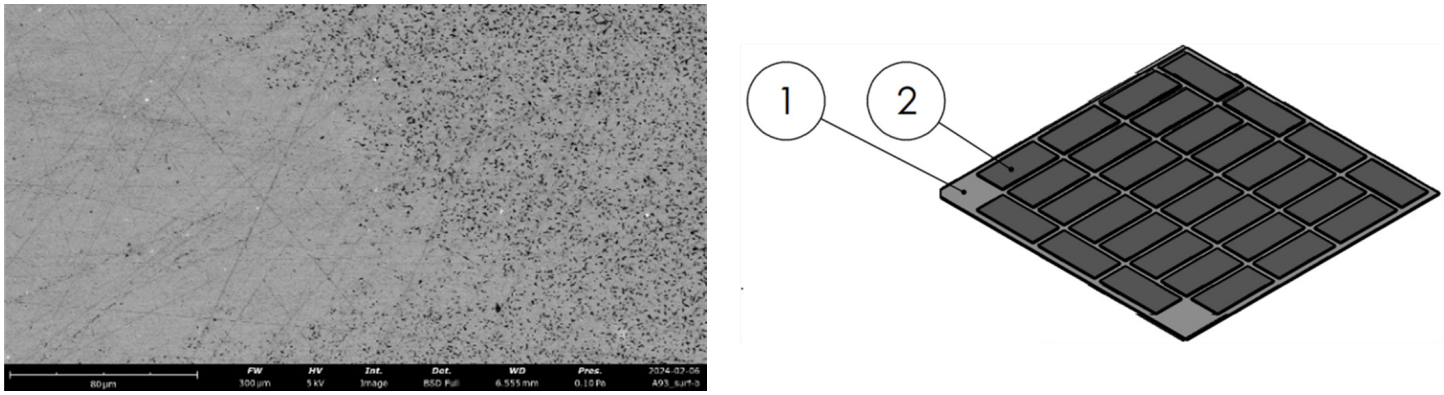

Figure 5 - (Left) Silver bonding microstructure; (Right) Ceramic substrates for START modules including electrode designs.

START LCA and LCC models

The work done so far within the scope of WP5 – Device production, validation and demonstration, accompanied by literature review and benchmark analysis, allowed the definition of the Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) models considerations that should be applied to the TEG to be developed in START project.

The preliminary goal & scope definition considers:

i. The comparison between the TEG device developed in the project and conventional ones based in BiTe and PbTe for low and medium/high temperature applications, respectively;

ii. The analysis will be referred to a TEG module (n-type and p-type legs, interconnect, ceramic plate);

iii. The environmental impact and costs analysis will be performed to scenarios with/without waste heat recovery and to tailings recovered semiconductor materials versus synthetic based ones;

iv. The proposed functional unit will be 1 kWh of generated electricity.

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With the implementation of the methodology specific for the LCA inventory development, resulted as a preliminary evaluation, the following items for collection of data regarding the TEG life cycle inputs and outputs:

Inputs (materials):
- Sulphides tetrahedrite for p-type formulation (kg)
- Cleaning products, other reagents and consumables (kg)
- n-type component base material (kg)
- TEG components (alumina plates, cooper interconnectors, others) (kg)
- Cleaning fluids, adhesives, solder, other consumables (kg)
- Water consumption (kg or m^3)
- Diesel consumption (kg or m^3)

Inputs (energy consumption):
- Mining activities (extraction, concentration, purification) (kWh, MJ)
- p-type production (powder technology, rapid solidification, layer deposition, others) (kWh, MJ)
- n-type production (kWh, MJ)
- TEG assembly production (kWh, MJ)
- End-of-Life technology (kWh, MJ)

Outputs:
- Electricity produced by the TEG (kWh)
- Wastes, leachates (kg or m^3)
- Air emissions (kg)

A combined analysis of LCA and LCC will focus on the determination of the best environmental strategies and the most cost-effective options. The expected lifetime of the TEG device is a very important indicator in the study. The LCC model will include capital, facility & management (operation and productivity) and disposal costs, and consider no maintenance costs for the TEG use stage, since this type of device has no moving parts.

NEWS FROM WORK PACKAGE 7 "Preparing for the future"

Focus Groups and the Delphi method have been used to collect views and opinions from experts and stakeholders on the future of thermoelectricity in general, and of the START project in particular. These methods counted with the participation of internal and external experts from several areas of importance to START including thermoelectricity, renewable energies, powder metallurgy, geosciences and commercialization. While the Focus Groups were created to bring together experts and used to collect data through group interaction, the Delphi method was used to gather information from the experience and knowledge of the participants, driving their knowledge towards a consensus.

Three Focus Groups were held physically and online. Ten questions were posed to the participants:

1. What are the big uncertainties of Thermoelectrics (TE) and materials for TE value chains? What could happen that changes the value chain?
2. What kind of applications do you see as potential and promising based on TE materials? By which year do you think such application could reach the market?
3. Do you know of any ongoing research or new results related to TE? Do you know of any new trends in TE?
4. Do you believe that the future of TE could be based on tetrahedrites?
5. Would you be willing to pay more for a sustainable TE device? How much more?
6. Do you miss any elements from the START planned activities/focus?
7. What are your main doubts for the START approach?
8. What are the benefits that you expect that you could gain/use from the START project? Any commercial ones?
9. Who (companies, research groups, field of expertise, etc.) could be interested in the START technological approach?
10. Would the appearance of a new, more efficient material, hinder START from becoming commercialised? If yes, what could we plan/do for avoiding that?

The Delphi method was held online, where a series of statements and questions were introduced to participants. Based on experts' opinions and views, qualitative and quantitative data is collected. An example of a statement used, and the respective statistics are shown in Figure 6.

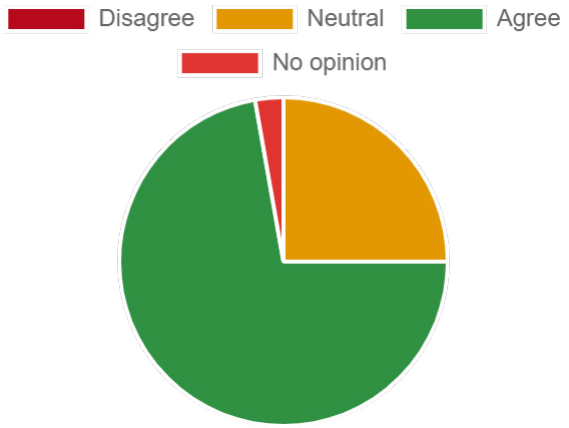

Figure 6 - Experts' views and opinions to the statement: "The application of thermoelectric devices to transform waste heat into energy is the future of renewable energy and circular economy".

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The responses highlight several perspectives on the role of thermoelectric (TE) devices in the future of renewable energy. Some believe TE will have a place in the family of renewable energies, with a focus on thermal energy harvesting for industrial digitalization. Suggested application areas include the combined use of waste heat for electric power and domestic heating, with low-grade heat harvesting using TE seen as a priority, aligned with EU targets for sustainable heavy industry. Concerns on the application of TE are about cost efficiency, sustainable manufacturing, and heat-to-electricity efficiency. TE devices are acknowledged as one option for converting waste heat into electricity, though their role is perceived as limited to specific niche applications. Overall, the potential contribution of TE to the energetic green transition is recognized, but there is an acknowledgement of the existence of other renewable energy technologies with higher efficiency rates, that might be more interesting than TE. The importance of utilizing waste heat, especially in the current context of substantial waste heat generation, is emphasized for clean energy and energy circularity.

Both the Focus Groups and Delphi method interactions showed that experts see the START approach as having great potential for current and future application, which can contribute to generate green energy.
It also shows that is very important to define value chains, applications, commercialization strategies, better performance of TE devices and to having prototypes developed and tested in end-user applications.
These physical and online exercises allowed the team to collect data that will prove essential in designing and implementing a commercialization and sustainability pathway for the START technology-based value chain. The next steps include developing an innovation, sustainability and commercialization strategy that can help the START project activities to reach the market with unique, sustainable thermoelectric devices.

START FIRST REPORTING PERIOD POSITIVELY ASSESSED

The START consortium ended its first formal Reporting Period towards the EU at the end of August 2023, covering the first 15 months of the project. For those not too familiar with Horizon Europe and in general with European projects, a Reporting Period is a period at the end of which, in addition to all reports (deliverables) that have to be given at the respective deadlines along the duration of the project, the partners have to put together a summary Periodic Report containing both the assessment of the technical work done and the costs incurred in that period. The experts nominated by the Commission check the quality of the work done, the correspondence with the expected objectives within the time frame, and the coherence of the costs declared with what had been priorly budgeted. The process takes some months, first to write the reports on the consortium side, and then on EU side to check the reports. A Project Review Meeting is also undertaken, where the experts and the EU Project Officer give their opinions on what they have received and discuss with the consortium about issues or improvements for the future.

Finally, we are happy to say that apart from some minor observations and clarifications requested, the first Periodic Report was accepted towards the end of last year, and the consortium already received the relevant part of the grant from Horizon Europe. Well done, START!

START WEBINAR #4: “POWDER TECHNOLOGY FOR TETRAHEDRITE P-TYPE SEMICONDUCTORS"

As you may remember, in 2023 we organised three free webinars, that took place in the first part of the year. There you could learn especially about our approach to the geology part of the activity, i.e. where to find tetrahedrite minerals, and how to collect and assess them.

In 2024 we planned to continue, and another free webinar, the fourth of the series, has been organised for the 14th of March, 15:00-16:50 CET. We titled it “Powder technology for tetrahedrite p-type semiconductors”, and we invited three of our consortium members to report on what is being done to transform the tetrahedrite mineral into a suitable thermoelectric material, using the magic of powder metallurgy. This was the programme of the event:

14:45 - Participants admission

15:00 - Bruno Vicenzi (European Powder Metallurgy Association) and Filipe Neves (LNEG) – Welcome and introduction

15:05 - Serena Busatto (MBN Nanomaterialia Spa) – “Mechano-chemical synthesis of thermoelectrically-optimized tetrahedrites from mine tailing” + Q&A

15:40 - Damian Karpowicz (GeniCore Sp. Z. o.o.) – “U-FAST – devices for SPS technology” + Q&A

16:15 - Patricia Almeida Carvalho (Sintef AS) – “Assessing the stability of novel tetrahedrites produced by powder metallurgy” + Q&A

16:50 - End of webinar

The event was well attended, with 64 registered (and many added to our project mailing list) and 38 attending. The full footage of the webinar is available on START’s YouTube channel[2].

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START WEBINAR #5 - "Thermoelectric devices and applications"

To continue with the free webinar series, the next event will be again, like last year (webinar #3), organised in conjunction to our project Annual Assembly, that will take place in Oslo, at the SINTEF premises. This hybrid format allows the consortium to take part in person, and other participants, including consortium members that cannot be with us in Oslo, to take part remotely.

The webinar, titled "Thermoelectric devices and applications", will take place on Friday 7th June 11:00-12:45 CEST and this is the provisional programme:

11:00 - Welcome and introduction Bruno Vicenzi (EPMA)

11:00 - Maarten den Heijer (RGS Developments) – "Thermoelectric Power Generation applications for Heavy industries and Combined Heat and Power"

11:30 - Hao Yin (TEGnology) – "100% Green Power for IoT sensors and industrial applications from low-grade excessive heat"

12:00 - Jean-Yves Escabasse (START's Scientific Advisory Board member) – "Adding value to TEG design by Additive Manufacturing: illustration in STARTREC, a new HORIZON project"

12:30 - Q&A with all speakers

12:45 - End of webinar

Soon you will have more information on the event if you follow our website and our social media (LinkedIn and X , find all links in the Contacts section at the end of this newsletter). As always, the webinar will be totally free, but registration will be strictly required. Join us if you want to know more about thermoelectric devices and their applications!

START JOINS THE ERHASE CLUSTER

Clustering with similar projects and initiatives is one of the activities that START is taking seriously, to improve both dissemination and communication, and to have better chances for the future exploitation and better impact. When clustering is effective it is beneficial for all parties!

During the initial stages of the clustering activity, we came across an already existing cluster of EU projects, named ERHASE[3] . ERHASE stands for **EneRgy HArvesting for a Sustainable future** and the aim of the cluster is to address the technical scope areas within the context of energy harvesting and storage technologies. The ERHASE cluster was formed by 3 projects: FAST-SMART, SYMPHONY and InComEss.

The SYMPHONY project[4] presents a novel energy harvesting platform designed to power wireless sensor nodes deployed in remote or challenging environments. This system utilizes a fully printed energy supply comprised of recyclable and non-toxic materials. These materials include the ferroelectric polymer P(VDF-TrFE), printable silicon-based rectifiers, redox polymer batteries, and cellulose-based supercapacitors.

The project focuses on developing cost-effective and scalable methods for printing these materials onto flexible films, subsequently integrating them with energy-efficient electronics and sensor technologies, and offers the potential to significantly reduce CO_2 emissions across various applications by, for instance:

- Extending the operational lifespan of wind turbines.
- Optimizing heating and cooling systems through enhanced presence and motion detection using smart floors.
- Minimizing energy consumption in e-bikes via remote monitoring of tire pressure.

The printability of the technology facilitates cost-effective integration into stretchable and flexible devices. This unlocks vast potential for implementation in a wide range of future Internet of Things (IoT) applications.

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The "PLUG AND FORGET" philosophy serves as the driving force behind FAST-SMART[5]. This initiative brings together leading universities, research centres, and industry experts specializing in materials science, solar panels, and transportation systems. The project's core objective is to significantly enhance the efficiency of harvesting ambient energy sources, such as light, heat, and mechanical vibrations. This captured energy can then be converted and utilized to power various devices, including sensors and solar panels. This process is known as energy harvesting, achieved through the implementation of specialized devices called energy harvesters, and offers significant environmental benefits by utilizing readily available natural energy sources that would otherwise be wasted. A critical challenge in current energy harvesting technology lies in the reliance on toxic materials, such as Lead, and strategically important materials classified as Critical Raw Materials (CRMs), like Titanium. These CRMs are often limited in European supply chains, creating vulnerabilities and dependence on external sources. The FAST-SMART project addresses this challenge by developing innovative energy harvesters that utilize novel materials. These materials will be free from harmful elements and readily available within Europe's mining portfolio. The project focuses on two key categories of energy harvesters: piezoelectric and thermoelectric. These devices will be rigorously tested in three application fields – railway track vibration detection sensors, solar panels, and hybrid engines. The project's scope extends beyond material innovation. It also aims to revolutionize the assembly process by implementing more efficient, low-energy consumption synthesis techniques coupled with faster assembly methods.

InComEss

The InComEss[6] project focused on developing efficient smart materials that combine energy harvesting and storage capabilities in a cost-efficient manner for the widespread implementation of the Internet of Things (IoT). These materials are based on advanced polymer composites and are designed to harvest electrical energy from readily available ambient sources. By demonstrating applicability in key sectors like structural health and vehicle monitoring across various industries such as aeronautics, automotive and building scenarios. InComEss aimed to unlock significant market potential. The project proposed a single/multi-source concept that can harvest ambient sources, such as mechanical energy and waste heat, and produce electricity with the aim of powering wireless sensor nodes (WSN) according to the use-case requirements. This concept realized the demonstration of Piezoelectric and Thermoelectric Energy Harvesting Systems (EHSs) for powering various sensors, including Fiber Optic Sensors (FOS, in aeronautics and building), and Micro-Electro-Mechanical Systems sensors (in vehicles) and sensors monitoring through an IoT platform. InComEss prioritized the development of sustainable Energy Harvesting prototypes free of lead and rare-earth elements, and based on polymers for enhanced recyclability. The avoidance of hazardous materials and the implementation of low-cost processing routs will help to reduce the Green House Gas (GHG) emissions.

The goals of the ERHASE cluster are the usual objectives of clustering:

- Define a knowledge sharing framework around common goals.
- Increase the outreach of each project's activities and enhance the visibility of EU efforts towards energy harvesting and storage technologies.
- Enhance and rationalize communication and dissemination, and stakeholders engagement activities.
- Strengthen the relationship between EU-funded projects guidelines.

Having acknowledged the relevance of the cluster and the affinity to the objectives of our project, START decided to join this cluster and is now listed in the 4 present members.

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The connection already led to a common activity: on the occasion of the Final Workshop of the project InComEss[7], that was held online, free for registered users, on 31st January 2024 (the project ended on 29th February), START was invited to join a special ERHASE session, where START, and also FAST-SMART and SYMPHONY, presented their state-of-the-art. The programme of the session, that came after a morning dedicated to the results of InComEss, was the following:

14:05 - SYMPHONY Project, P(VDF-TrFE) based piezoelectric nanogenerators for energy autonomous sensor systems - Dr. Jonas Groten, Joanneum Research Forschungsgesellschaft mbH, SYMPHONY Project Coordinator

14:20 - FAST-SMART Project, FAST and Nano-Enabled SMART Materials, Structures and Systems for Energy Harvesting - Prof. Yi Qin University of Strathclyde, FAST-SMART Project Coordinator, M. Rostagno, GAE Engineering, Dissemination and Exploitation Manager

14:35 - START Project, Conversion of secondary mineral resources into value-added products for energy harvesting systems - Dr. Filipe Neves, LNEG – National Laboratory of Energy and Geology, START Project Coordinator

14:50 - End of the event

The event attracted 58 participants. The full InComEss Workshop, including the ERHASE session, is available on YouTube[8].

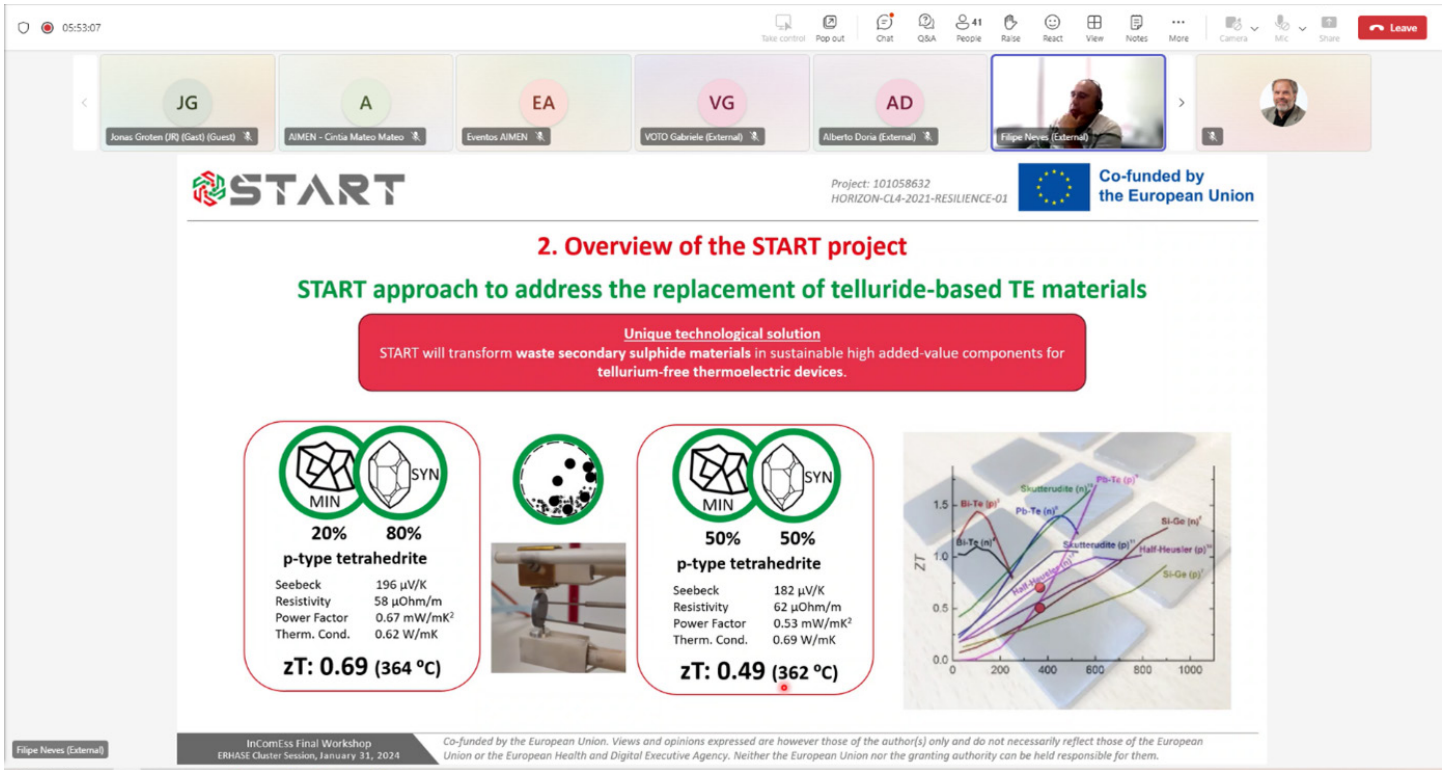

Figure 7 - A moment of F. Neves presentation during the ERHASE session of the InComEss Final Workshop, 31st January 2024.

START COLLABORATES WITH THERMOS

Another recent clustering team-up pursued by START is the connection with the project THERMOS. This is the acronym for "Tellurium-Free Thermoelectric Modules by Interface Engineering", and as you can easily see the objectives quite converge with those of START. THERMOS is a 36-month project that began on 1st May 2022 (like START) and is coordinated by prof. Kornelius Nielsch of Leibniz Institute for Solid State and Materials Research Dresden. It was funded by the M-era.Net framework for a total grant of about 1.2 M€.

THERMOS targets the development of highly efficient thermoelectric (TE) modules based on nanograined Zintl-phase materials for solid-state cooling and conversion from heat to electricity. The complete process chain in THERMOS uses scalable processing techniques from the synthesis of nanopowders by high energy ball-milling, compaction, to the assembly of TE devices. In contrast to commercial Bi_2Te_3 modules, the project consortium will develop modules free of the scarce element tellurium with higher performance. The n-type $Mg_3(Sb,Bi)_2$ and p-type MgAgSb semiconductors that contain abundant elements were selected for the THERMOS device. The targets are a greatly enhanced heat-to-power conversion efficiency (η) of 8-9% in comparison to Bi_2Te_3 from 20 to 300 °C, and a TE cooling (ΔT) of ~60 to 70 °C that is competitive against Bi_2Te_3-based modules. The moderate price, abundance and non-toxicity of the elements constituting the Mg-based Zintl-phases materials in THERMOS make them ideal candidates to substitute the highly toxic and scarce Bi_2Te_3 and to boost their commercialization.

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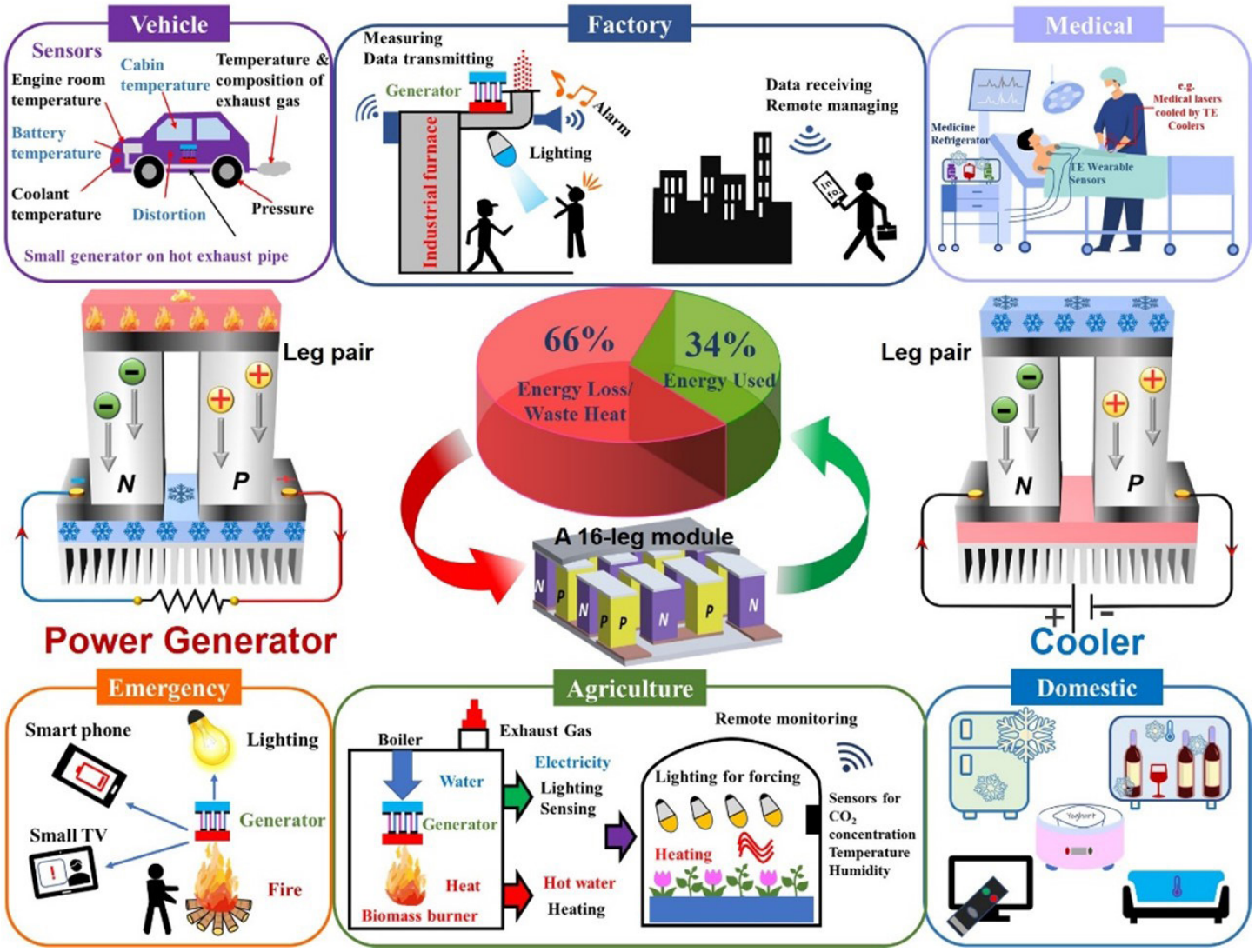

Figure 8 - Potential applications of TE modules in various fields[9].

THERMOS innovation objectives are:

(1) To develop high-performance Te-free TE materials through interface engineering by particle atomic layer deposition (pALD).

(2) To assemble TE modules based on novel materials to improve η and cooling ΔT and to enhance the module robustness by ALD encapsulation.

(3) To fabricate nanograined TE materials in scale towards the production of larger-area modules with a high number of legs (n=16 to 64).

(4) To test the modules in real applications and to evaluate their whole life cycle in terms of production, operation in an application and recycling.

THERMOS envisioned results are:

(1) Realize ***a)*** a η~8-9% and ***b)*** a cooling ΔT > *60°C* with Te-free TE modules through interface engineering.

(2) Robust modules to survive >5000 heat cycles while maintaining >95% relative efficiency in argon and in air with ALD protected layers.

(3) Establish routines to fabricate high-quality Te-free TE powders on a ~kg scale per batch, and to assemble modules with 48 to 96 legs.

(4) Test TE modules in real environments. Evaluate life cycle of modules in terms of production, operation in an application and recycling.

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THERMOS will address several application needs. Solid-state TE devices have no moving parts and can be operated for decades without maintenance. In the past, they have been used in noise-free solid-state refrigerators, military and space applications. Since 2000 the TE research has focused on waste-heat recovery from combustion engines, powering wireless sensors, mobile and medical applications, and on-spot cooling (Figure 8). The markets for TE devices are growing annually by 7%, especially in the areas of telecommunication and the Internet of Things (IoT). These applications require modules made of non-toxic elements with low costs and stable performance at high temperatures with zero maintenance (Figure 9).

The THERMOS project will have wide impact and several potential benefits. It will develop modules with an improved η to 9% and a notable cooling ΔT ~ 60 °C that will outperform and replace conventional Bi2Te3 modules to enable new market opportunities upon the usage of sustainable materials. It will lay the foundations for patent application and production of a new generation of TE modules in Europe. The THERMOS concepts for the material synthesis, like interface engineering and the module encapsulation by ALD, are also critical for developing TE modules from other emerging materials like Heusler alloys. THERMOS will support the SME company TEGnology to enhance their portfolio of TE modules for a larger temperature range.

THERMOS started at **Technology Readiness Level** TRL 2 with material synthesis and will reach TRL 6 with industrial involvement. TRL 3 had already been demonstrated by IFW for module development based on Zintl-phase materials.

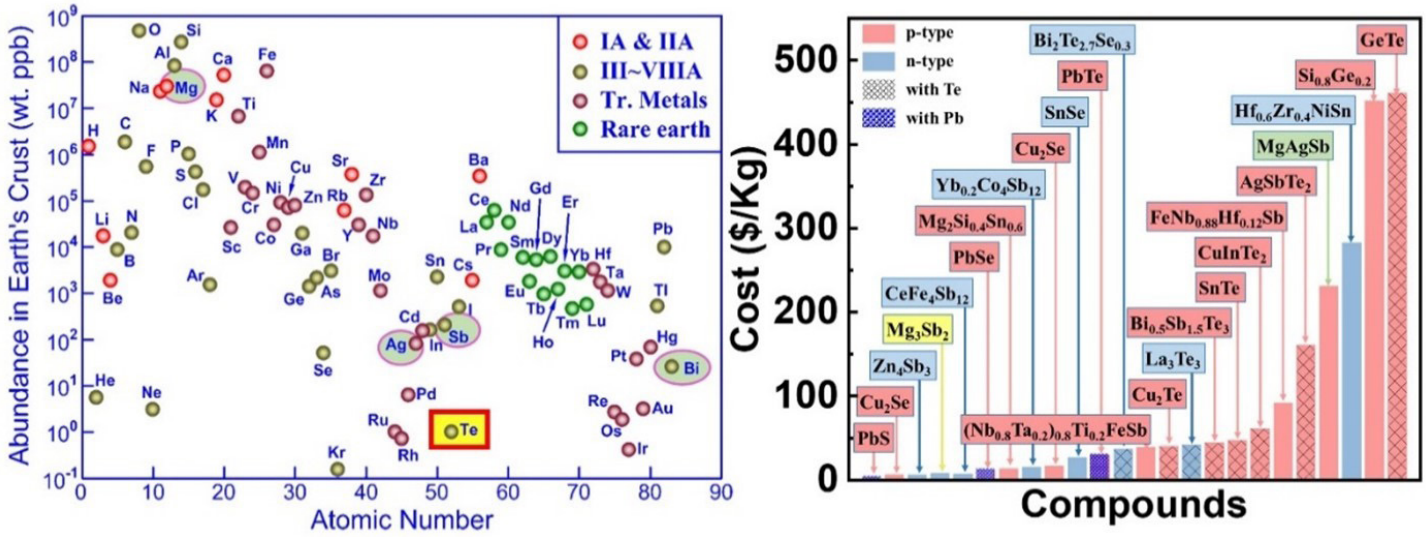
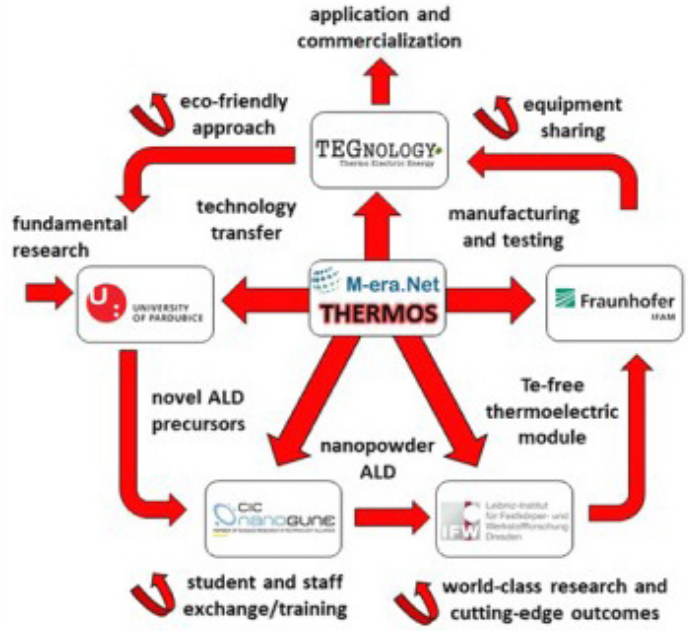


Figure 9 - (left) Abundance (atom fraction) of the chemical elements in Earth's upper continental crust as a function of atomic number[10]. (right) Cost ($ /kg) of raw materials for the typical n- and p-type TE materials[11].



The THERMOS consortium is based on a high synergy between five partners from four countries. Starting on the left side in Figure 10, the anticipated workflow and collaboration frame is based on the design and synthesis of novel Se, Bi and Sb precursors for ALD (WP2). The BUReS group@UPce (Czech Republic) has ample experience with such fundamental organometallic research. The quality and effectiveness of the prepared precursors will be tested by the group of M. Knez@NanoGUNE (Spain). Initially in a static ALD reactor and, upon optimization, the process will be transferred to a fluidized bed ALD reactor to enable coating of powders (WP2 and WP3). NanoGUNE is highly active in thin film coatings, ALD and nano technologies and is fully competent to complete these tasks. The team of K. Nielsch@IFW (Germany) is crucial for the synthesis and investigation of thermoelectric powders (WP1) modified on the surface by ALD@NanoGUNE (WP3).

Figure 10 - Cooperation, workflow and benefits within the THERMOS consortium.

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The overall strategy of the IFW-Dresden is bringing fundamental material research into applications in the areas of thermoelectric materials, superconductors and magnetic materials. Upon assembly and protective encapsulation of the developed TE modules (WP4 and WP5), their fabrication will be upscaled (WP6) with the aid of V. Pacheco@IFAM (Germany).
IFAM conducts fundamental and applied research for solution-oriented material and technology development with thermoelectric materials and modules as the most important research topics.
IFAM will be also responsible for the life-cycle analysis (LCA) and recycling of TE modules (WP8).
The team of H. Yin@TEGnology (Denmark) is essential for demonstrating the functionality of TE modules in a real environment and commercialization of the project outcomes, (WP7). TEGnology is one of the few companies in the EU that is dedicated to the design and manufacturing of thermoelectric generators with environmentally friendly and sustainable materials (and also a partner of START!).

In addition to the particular benefits of each partner (see above), the following four benefits are the most important for the consortium as a whole: (i) highly collaborative and world-class research to be performed with cutting-edge outcomes; (ii) mutual student and staff training; (iii) sharing equipment and expertise; (iv) environmentally friendly approach by replacing toxic commercially used materials.

Thus, at START and THERMOS we really believe that fruitful collaboration can be achieved, and meetings are planned between the relevant partners in the two projects, so that synergies can be made at any level, including the organisation of joint activities for dissemination. On 11th April, a delegation of START met some of the THERMOS main partners in IFW Dresden, the THERMOS coordinator's premises (Figure 11). The discussion was very fruitful and is leading to practical collaboration in the very near future, increasing the chances for both projects of achieving the respective objectives, and overall, that thermoelectric solutions can be more universally accepted as viable routes for waste heat recovery in Europe. We will keep you informed of the outcome of our discussions!

Figure 11 - The THERMOS-START meeting on 11/04/2023 set the basis for joint initiatives.

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START ARTICLE ON INNOVATION NEWS NETWORK

START has prepared an article that describes the project and its first results in the initial year and a half: the text, titled "The START project: Transforming mining waste into waste heat recovery materials" has been published by the website Innovation News Network[12], and will be also included in the next issue 18 of their magazine "The Innovation Platform", due on 3rd June. A banner about the project is also visible on the same website, with a link to the START website.

The START project: Transforming mining waste into waste heat recovery materials

Critical Raw Materials | 12th March 2024

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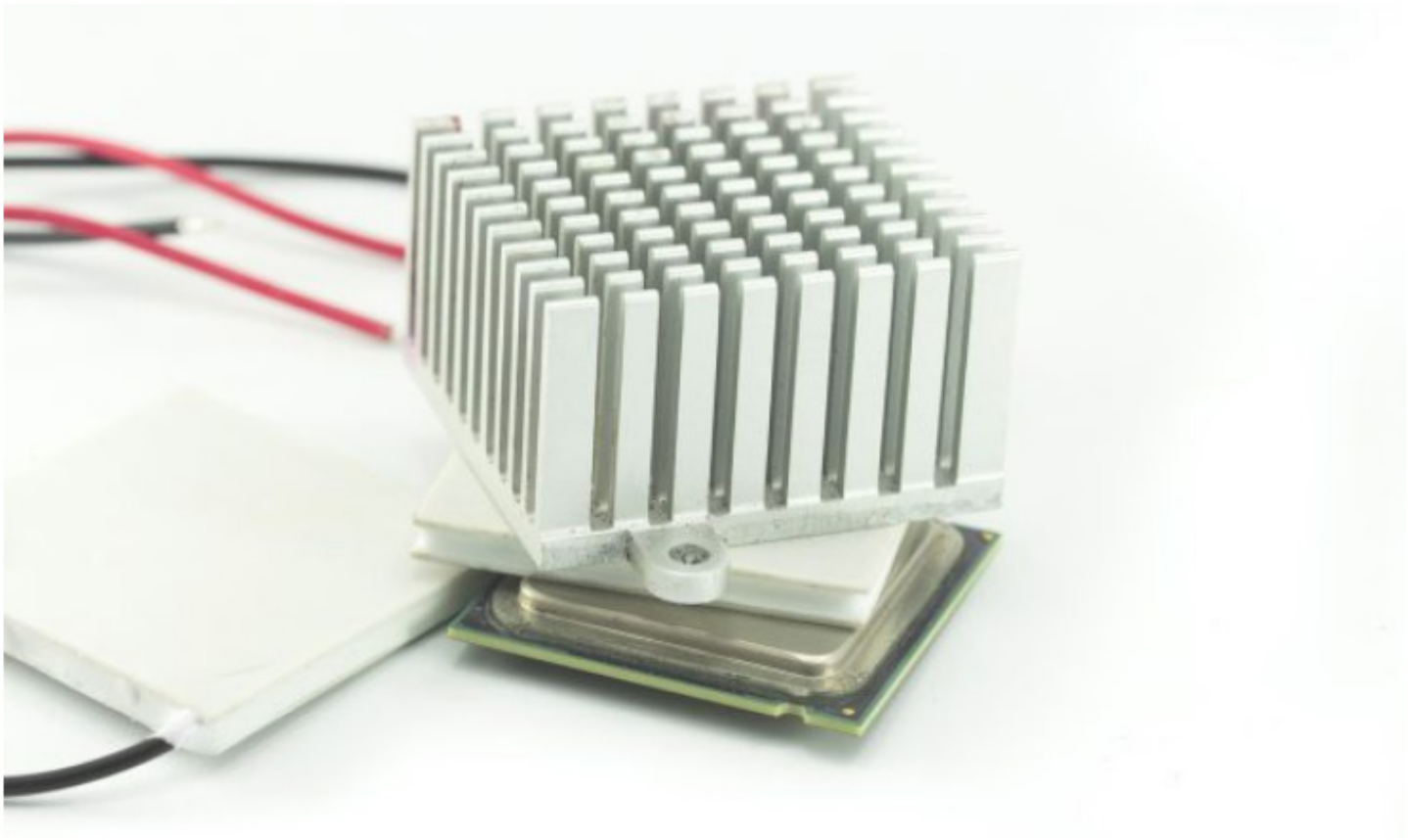

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Figure 12 - Heading of the article published on Innovation News Network.

We believe that by this communication effort on such a platform the awareness about our project will spread well beyond the boundaries of our scientific and industrial communities (mainly in the mining, geology and powder metallurgy sectors). In fact, the INN website reaches a wide audience (the latest statistics available on the platform show about 1M total page views in the last 6 months, for instance).

We are also planning another publication in late 2025, with more focus on the results achieved by then.

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START DISSEMINATION EVENTS

EU SuperCluster Lapland Conference in Rovaniemi (Finland)

On October 30th and 31st, 2023, G. Olivenza from ASGMI gave 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. In this conference, she talked about the objectives of START, its benefits for the environment and contribution to the sustainable development goals. More than 140 participants attended the event, in which more than 20 EU projects related to innovation in the exploration and acquisition of mineral resources were presented. Discussions about sustainability, the environment and social acceptance took place in the same event.

START at the EU Raw Materials Week in Brussels

Like last year, we also showcased during the EU Raw Materials Week 2023, a yearly event gathering a wide range of stakeholders discussing policies and initiatives in the field of raw materials, providing an overview of ongoing EU activities in the sector.

We showed our introductory video, with the addition of the Starty comic (issue #2), and also a poster. Participants could thus watch and learn more about the project's objectives and actions.

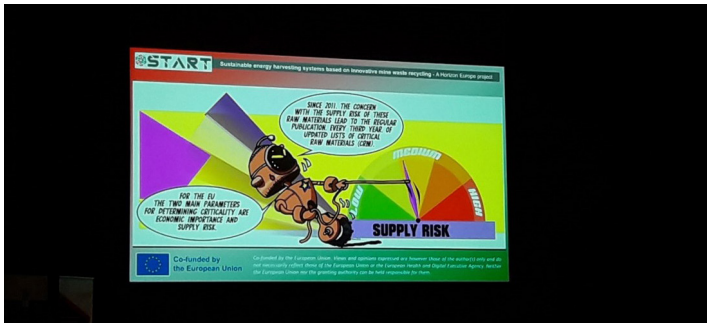

Figure 13 - START video displayed during the Raw Materials Week 2023.

Environmental liabilities workshop in Criciúma (Santa Catarina, Brazil)

An ASGMI passive liabilities workshop was held in the Brazilian city of Criciúma from November 28th to December 1st, 2023. The workshop consisted of three days of conferences[13] about different topics related to mining environmental liabilities and their remediation in Ibero-America, and one day of field trip in which a mine was visited, as well as different points around the city of Criciúma where the effects of environmental liabilities could be seen. Furthermore, there were some points in the trip where these liabilities had been remediated using different methods.

The conferences treated topics such as the management of environmental liabilities in different Ibero-American countries; the extraction of mineral resources from tailings; the use of those tailings to make construction materials; the geochemical and mineralogical characterization of tailings; and proposals for risks evaluation methodologies.

Between the many conferences of the workshop, Dr. Fredy Guzmán (Mexican Geological Survey) and Dr. Cátia Prazeres (Laboratório Nacional de Energia e Geologia) spoke about the START project and the contributions of the Mining Environmental Liabilities Expert Group of ASGMI to the Work Package 2 during their presentations.

Figure 14 - Attendees at the Mining Environmental Liabilities workshop held in Criciúma, Santa Catarina, (Brazil)

"Latin America – Europe: Cooperation opportunities for a more sustainable raw materials industry. The EU-AlSiCal project case" workshop in Brasilia (Brazil)

The workshop "Latin America – Europe: Cooperation opportunities for a more sustainable raw materials industry. The EU-AlSiCal project case", held from 30th January to 1st February 2024 in Brasilia, was organized with the aim of discussing the main challenges faced by the Aluminium and other metallurgical industry throughout its value chain, from extraction to the production of final products. This event was arranged by ASGMI in order to promote the AlSiCal project in which ASGMI participates.

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The workshop had the objective of establishing a dialogue among different social actors (industry, research, governance, and communities) to obtain answers to meet the growing demand for aluminium as a result of the energy transition, in a way that is sustainable while maintaining the industry's competitiveness and profitability, as well as social acceptance.

Between the many conferences that spoke about topics such as the status of raw materials in Ibero-America and Europe, the innovations in industry regarding raw materials and the use of modelling tools in innovation, Fredy Guzmán, from the Mexican Geological Survey (SGM) gave a talk in which he mentioned the START project and the innovations it represents.

Figure 15 - Fredy Guzmán, Head of Environmental Projects at the Mexican Geological Survey (SGM) and Chair of the Mine Environmental Liabilities Group of ASGMI giving his talk "Identification, characterization, and recovery of mining environmental liabilities" during the EU-AlSiCal workshop in Brasilia (Brazil).

Figure 16 - Attendees at the EU-AlSiCal workshop in Brasilia (Brazil).

START at the Prospectors & Developers Association of Canada (PDAC) Convention in Toronto, Canada, 3 - 6 March 2024

The World's Premier Mineral Exploration & Mining Convention[14] is the event of choice for the world's mineral industry and this year it had almost 27000 participants. Led by the European Health and Digital Executive Agency (HaDEA), and under the motto "European Union for a sustainable future" (Figure 17), the European Union (EU) booth accommodated and promoted EU research and innovation projects under the Horizon 2020 and Horizon Europe programmes, among many other activities. START was one of the 13 projects (Semacret, Multiminer, Nexgen-Sims, Rotate, Digiecoquarry, m4mining, EIS, GREENPEG, S34I, MineI0, Vector, and Hephaestus) selected to join the EU booth at PDAC 2024 (Figure 18). Filipe Neves (LNEG) was the representative of the START project and during the first day of the convention it was possible to briefly present the project to Ms Marina Zanchi, Director of the HaDEA and Ms Katleen Engelbosch, Head of Department (Digital, Industry, and Space) at HaDEA (Figure 19). For the START project, the 4 days of PDAC2024 resulted in an excellent opportunity for networking and promoting START activities within the mineral exploration and mining community.

Figure 17 - EU booth at PDAC 2024.

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Figure 18 - Projection of the START video in the Horizon Europe area of the EU booth.

Figure 18.b - START leaflets end booklets with all Starty comics were available at the EU booth.

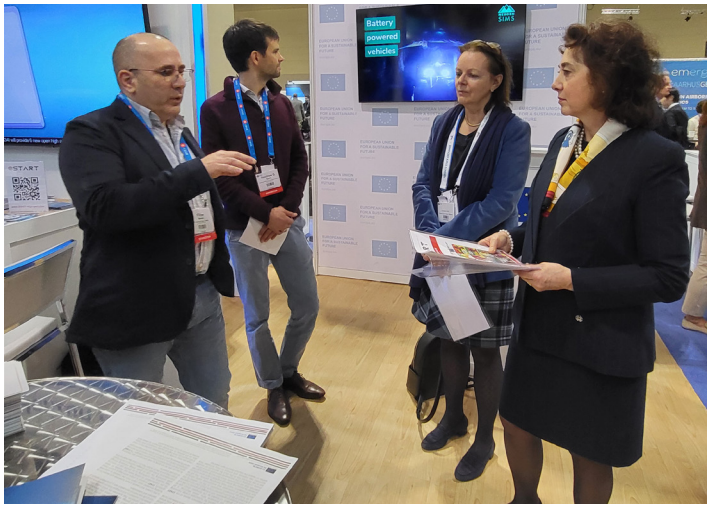
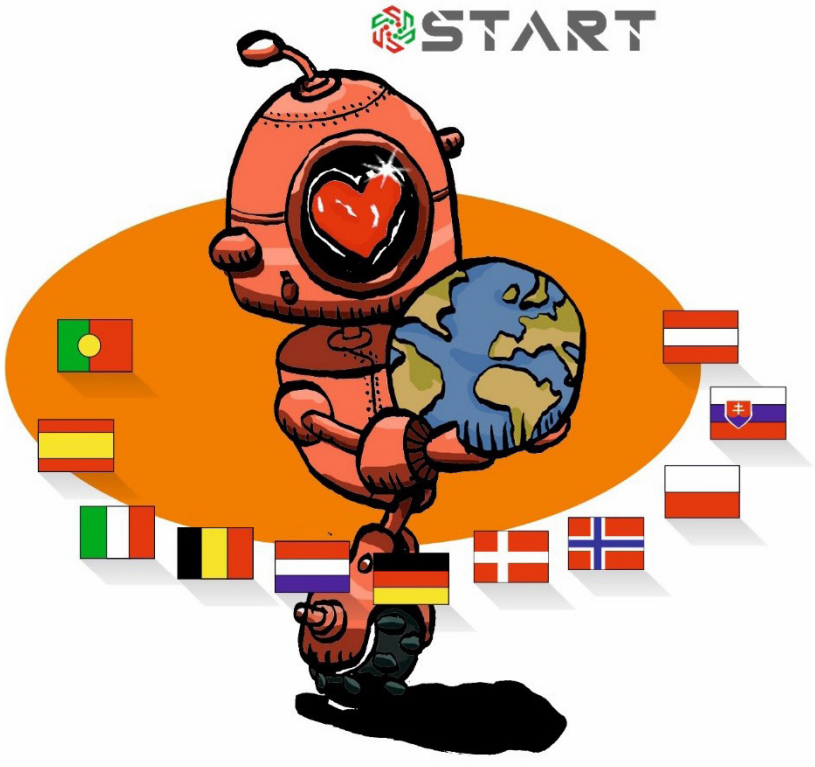


Figure 19 - (Left), Filipe Neves (START project coordinator) with Ms. Marina Zanchi, Director of HaDEA (on the right), and Ms. Katleen Engelbosch, Head of Department (Digital, Industry and Space) at HaDEA (center). (Right), Group photo of representatives of the H2020 and HE projects with Ms. Marina Zanchi, Director of HaDEA, Ms. Katleen Engelbosch, Head of Department (Digital, Industry and Space) of HaDEA, and Marko Cacanoski, START Project Officer.



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ASGMI General Assembly, 8-12 April 2024

From 8th-12th April 2024, the ASGMI General Assembly was held in the city of Pachuca de Soto, Mexico. The activity of the different ASGMI groups of experts was overviewed and discussed, and information about the status of the START project was given in the presentation about the annual activities of the ASGMI expert groups.

FUTURE EVENTS

START is organizing participation in several more events in the next months.

In the afternoon of 16th May, during the EPMA General Assembly, that takes pace in a hybrid format and gathers many members of the association, a presentation of Serena Busatto (MBN Nanomaterialia SpA) will be given, titled "START approach to powder metallurgy: Advanced materials for energy harvesting".

We are also planning to organise a specific event later in the summer, linked to our clustering activities and in the framework of our exploitation efforts, but we will have to come back to you via our website and social media, just be aware of that!

This year, START will be present with a project booth at some events.

In June, we will take part in the 40th International and 20th European Thermoelectric Conference, ICT/ECT 2024, that will take place in Krakow, Poland, from 30th June to 4th July 2024. This is the main international event for thermoelectrics, and in addition to our booth there will also be presentations in several sessions, more info will be given on the website and social media in advance of the event. Meet us there if you are taking part as well!

The IGME team working on the START project will present an oral communication in the "Congreso Geológico de España 2024"[15], which is held every four years. This year the host city is Avila and it will take place from the 2nd to 6th July. The title of the communication will be "Transformación de pasivos mineros en activos energéticos; El caso del proyecto START" ("Transforming mining liabilities into energy assets. The case of the START project"). The work introduces the project and deals with the specific activities carried out in Spain and the tetrahedrites sampled.

In the Euro PM2024 European Powder Metallurgy Congress & Exhibition, organised as usual by EPMA and taking place this year in Malmö (Sweden) from 29th September to 2nd October, a START booth will be present, with all materials about the project available for the visitors of the large PM community.

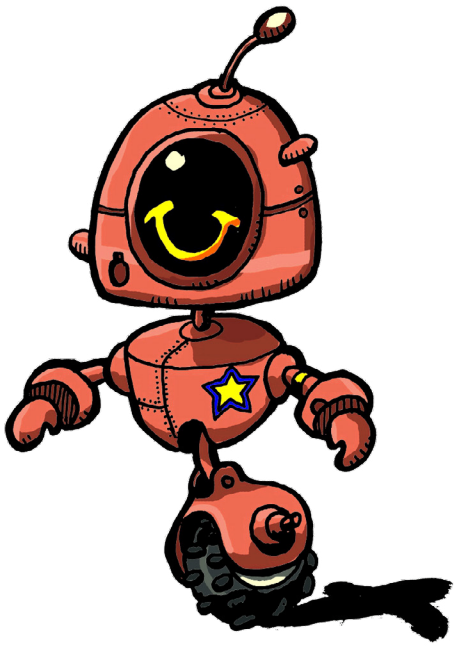
Other events are directly linked to our training activities.

In the yearly edition of the EPMA powder Metallurgy Summer School, that will be hosted in Alessandria (Italy) from 15th to 19th July, the trainees will be shown a small demonstration about thermoelectric devices. The demo will be brought to the School by TEGnology, one of the partners in the project, and Hao Yin will explain how these devices can be used for waste heat harvesting and other applications. In addition to this, B. Vicenzi of EPMA will, as usual, give some basic info about the project in the initial speech of the school.

Moreover, in September 2024, a training course for Master students interested in the topic will be run as part of the START communication and dissemination work. The objective of this training is to give the START project and the work that is being carried out a greater visibility within a community of students. Different experts from geological surveys involved in project and universities will participate in it. The workshop will last approximately 10 hours divided in 5 days and will be celebrated in English. The organization of this event is currently underway; therefore, the exact dates are yet to be defined.

More events might see START participating in addition to these, and we will inform you in due time.

If you are from a similar initiative or project and would like to organise something together, please contact us!



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TECHNICAL PILLS

Some useful information that covers topics that are linked to our project! In this issue, we deal with the applications of thermoelectric generators.

APPLICATIONS OF THERMOELECTRIC GENERATORS (TEG)

Applications in heavy industry

The combined recovery of power and steam in European heavy industry aims to significantly reduce energy consumption and CO_2 emissions through the implementation of innovative technologies. Recent estimates reveal that industrial processes account for 26% of European primary energy usage (3196 TWh) and 48% of final CO_2 emissions. Additionally, about 29% of this energy is lost through effluents or exhausts, totalling around 920 TWh, with only approximately 304 TWh/year deemed recoverable. The START initiative focuses on high-temperature applications, targeting industrial clients that have high-temperature waste heat (>500 °C), particularly in energy-intensive sectors like primary and secondary steel and metals, glass, chemical, and cement industries. Notably, Iron and Steel (I&S) and Non-metallic Minerals (NMM) industries possess the highest share of such waste heat sources, offering a total usable heat reservoir of 123 TWh. RGS development has significant expertise in integrating TEG devices within these industries, as depicted in Figure 20. Beyond the electricity advantages, these applications also allow end-users to utilize concentrated heat as hot water in other areas of the facility, particularly valuable given the current surge in gas prices affecting industries.

Figure 20 - RGS Thermagy integrated in (Left) glass industry and (Right) in a typical steel plant.

Applications in μCHP

Heating and cooling needs for residential, commercial, and industrial sectors constitute roughly half of the EU's energy consumption. Residential heating, comprising 16% of the total Primary Energy Supply (PES) at 17875 TWh, is currently supplied through collective infrastructures like gas or district heating grids, or via solid/liquid fuels such as biomass, which require no dedicated infrastructure for transport. Since 1990, biomass has seen a doubling in its role as an individual residential heating source, increasing primary energy supply from 265 TWh to 570 TWh, also reflected in final heat consumption. Given these widespread demands across Europe, the biomass-boiler market is experiencing significant growth, with increasing demands for enhanced performance and reliability. RGS holds a distinctive position in this global market as the sole industrial supplier of SiGe TEGs, with the technical expertise to integrate them into commercial boilers using innovative system designs, as illustrated in Figure 21.

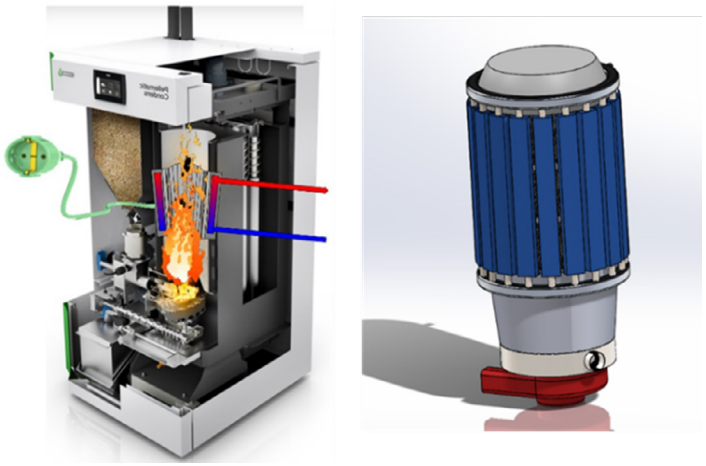

Figure 21 -(Left) TEG systems integrated into commercial boilers for CHP systems; (Right) Cylindrical TEG systems.

Applications in low-grade industrial waste heat.

Waste/excessive heat from industrial manufacturing exceeds the amount of all renewable energy sources in total (Figure 22, top). While some part of the heat is reused for pre-heating or converted to power through Rankine Cycles, it is economically unprofitable to reuse this energy in other ways, due to the lower power density. It is especially difficult when the grade of the heat is low (temperature is below 250 °C or lower).

A thermoelectric generator is known to be robust, as there are no moving parts or chemical reactions. And in this temperature range, the instability of the thermoelectric materials and stress on the TEG modules are low moderate. It makes large-scale energy harvesting from waste heat profitable, providing the TEGs themselves can be produced and implemented in very affordable prices. However, due to the limited efficiency in this temperature range, the output power is also moderate. It requires a thorough and holistic redesign of the material and module production.

Scale is the key for profitability. The Return of Investment of such applications has put stringent request on the selection of materials to be used. But in return, the big space and continuous heat availability might compensate for the low unit output. The inexpensive tetrahedrite materials from the START and a flexible module design (Flex-TEG, Figure 22, bottom) from TEGnology pave a new way of making large-scale thermal energy harvesting profitable.

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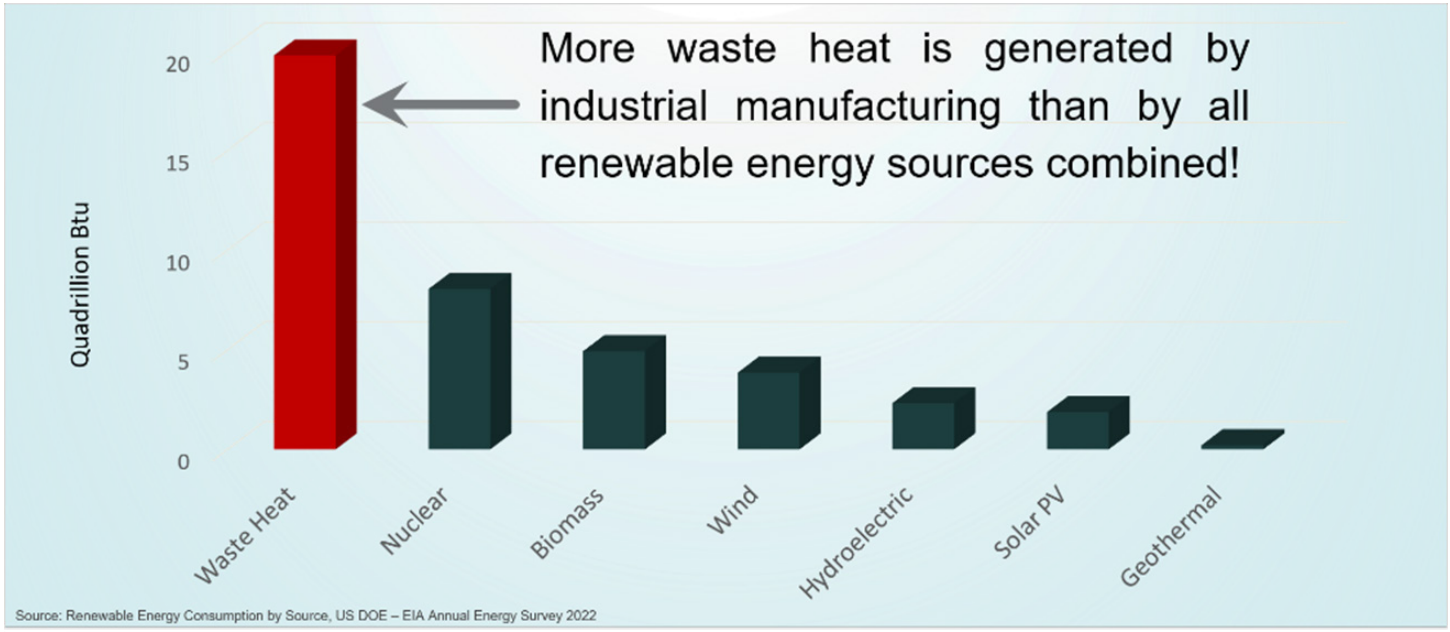

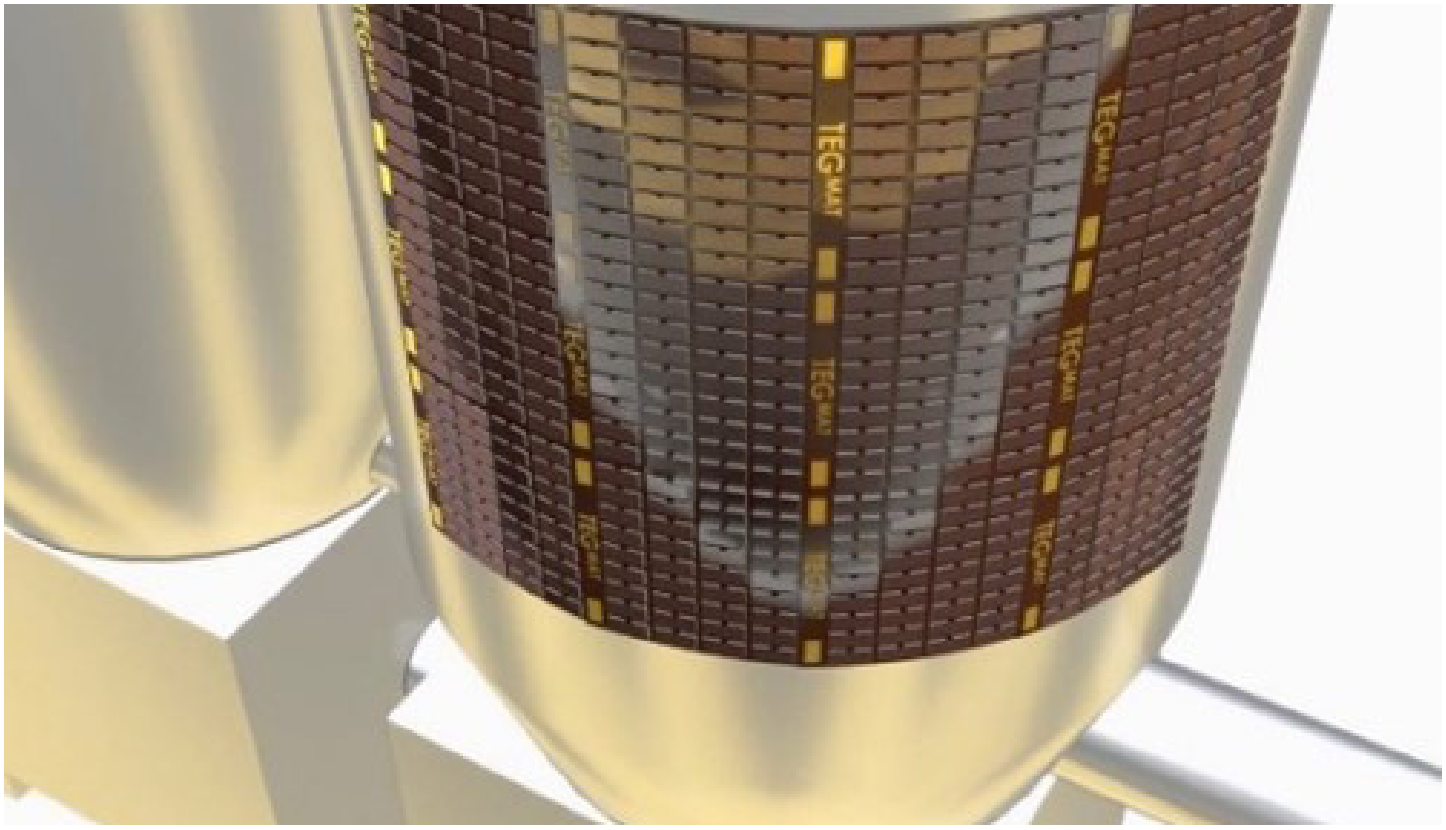

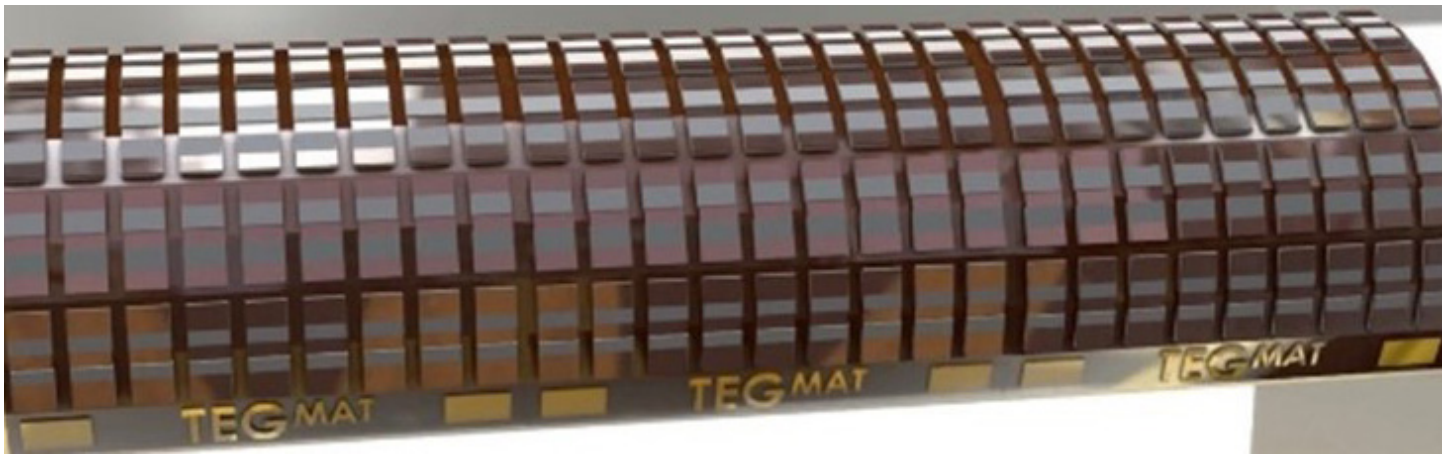

Figure 22 - (Top) Amount of industrial excessive heating in compared to other renewable sources; (Bottom left) Applying Flex-TEG on large, curved surfaces; (Bottom right) Attaching Flex-TEG on pipes.

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MEET THE SCIENTIFIC ADVISORY BOARD MEMBERS: DOUG CRANE

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 Doug Crane, who has been working for many years now in the industrial side of thermoelectrics in the US.

DTP THERMOELECTRICS

Figure 23 - Doug Crane works on thermoelectric technology development and the innovation and optimization of thermoelectric heat-to-power and thermal management. He is the Chief Technology Officer (CTO) of DTP Thermoelectrics. He served previously as Director of Thermoelectric Engineering at Alphabet Energy, Inc. and as Principal Engineer of Thermoelectric Systems/Development at Gentherm, Inc. (formerly Amerigon, Inc. and BSST LLC). He has over 25 patents and patent applications and has authored several book chapters and dozens of peer-reviewed papers and conference proceedings in the field of thermoelectrics. Doug was also the Principal Investigator for the U.S. Department of Energy's Automotive Waste Heat Recovery program at Gentherm, where he led a project team that included BMW, Ford and Tenneco. He holds a Bachelor of science in Mechanical Engineering from the University of California, Berkeley, and a Master of Science and Doctorate in Mechanical Engineering from the University of Maryland at College Park, where he studied the simulation of thermoelectric waste heat recovery from an automotive cooling system.

Doug, what raised your interest in thermoelectricity and what is your perception of the changes in the awareness of this technology outside the TE community along your career?

I first became aware of thermoelectrics in choosing a dissertation topic in graduate school. My dissertation was on thermoelectric waste heat recovery from an automotive cooling system. Unfortunately, I do not feel that there is much further knowledge of thermoelectrics now outside of the community.
Thermoelectrics does not have the general visibility of photovoltaics. I worked at Gentherm for 10 years. Gentherm's climate control seats provide heating and cooling to occupants and are in over 50 production vehicle models today. That said, I don't think that the general public really understands the technology behind the seats and these seats still tend to be in higher end models.

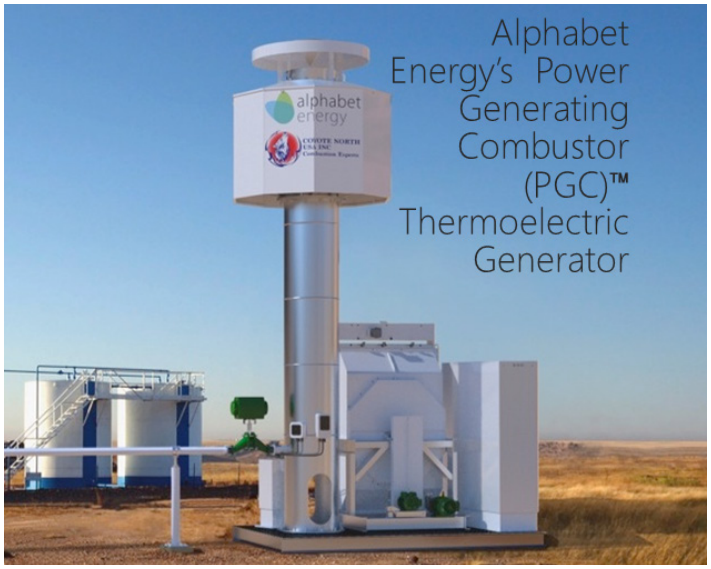

Figure 24 - A large TE generator by Alphabet Energy.

What achievements would you list as groundbreaking in the last decades, and what do you think would be the most needed breakthrough for a wider use of TE devices?

Considerable attention came to thermoelectrics in the early 2000s as a result of work from Rama, Harman, and Dresselhaus that showed the potential for higher ZT materials with higher potential conversion efficiencies. At Gentherm, our TEG design received recognition as one of the most promising technologies of the year in Car and Driver. Work by Poudel, Chen, and Ren at Boston College, MIT, and GMZ brought further attention to potentia performance gains. Alphabet Energy and Phononic have raised significant funding and created considerable media attention. Higher efficiencies and effectiveness, lower cost, and improved manufacturing for higher cost effectiveness is still what is needed most in order to reach more markets as has been seen in photovoltaics.

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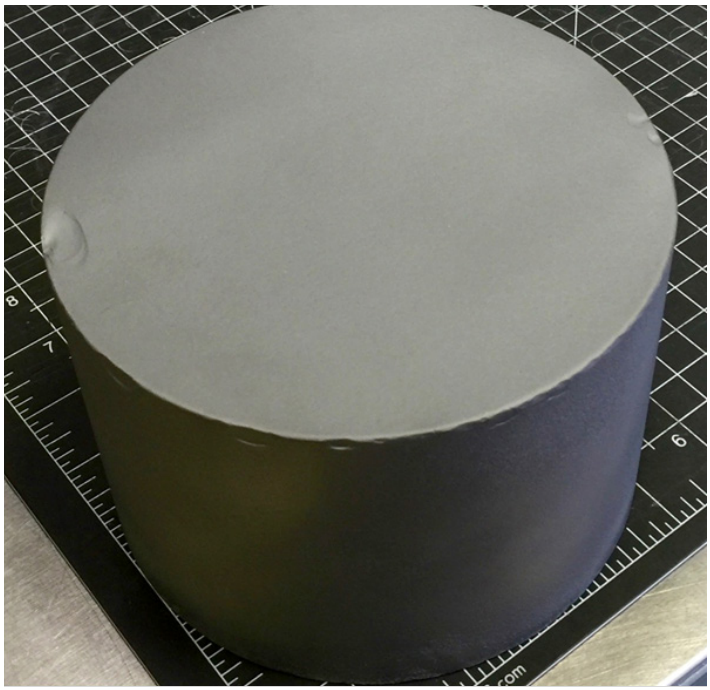

Tetrahedrite (10.2 kg):
156 mm diameter
105 mm thick

Figure 25 - Large ingot of tetrahedrite thermoelectric material made by Alphabet Energy.

You have been working in programmes funded by the US Department of Energy: have you had the chance of understanding the main difference, and similarities, in the way innovation projects are funded in the US and in Europe? What regulations and incentives foster or hinder these projects?

Government funding in the US for thermoelectrics was more prevalent 10 – 15 years ago. Many of the program managers who championed such projects in the US are no longer in the same positions. It is very important to have government stakeholders with an interest in the technology to receive funding. In the past, emissions regulations and incentives relating to emissions reductions have been great motivators for the automotive companies to consider thermoelectric waste heat recovery and as such spurred interest in government funding. With further focus on electric vehicles with less opportunity for higher temperature waste heat recovery and previous difficulties reaching cost effectiveness goals, interest from the automotive sector has lessened.

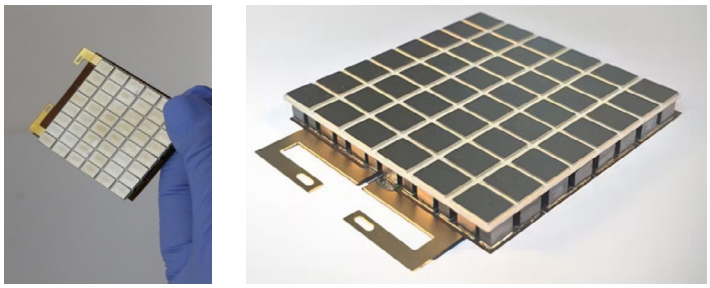

Figure 26 - Alphabet Energy's power card and power card-y.

A question we already asked Jean-Yves in the previous newsletter:
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?

I believe that thermoelectrics will have a role in energy efficiency, cleaner production, and refrigerant-free thermal management.
The benefits of solid-state heat to electricity energy conversion can be unique in many applications. Until cost effectiveness increases, applications will remain niche.

You discover a working time machine and decide to jump to 2035. Are thermoelectric devices widely used by industry and society?

I believe that it is possible, especially with work such as that being done by START.

How do you see the development and implementation of START's thermoelectric devices based on tetrahedrites?

I see START's thermoelectric devices being implemented initially in niche applications for waste heat recovery where the cost effectiveness of the natural tetrahedrite recycled from mine waste can provide benefit on multiple fronts. I believe that START's devices can reach further applications as manufacturing continues to ramp up and cost effectiveness increases.

What led you to accept being in our Scientific Advisory Board? What are, in your view, START's strength and weaknesses?

I believe in tetrahedrite materials after having worked at Alphabet Energy.
I also was intrigued at the idea of using natural tetrahedrite from mine waste and the benefit of using waste materials to create waste heat recovery devices. The team is strong and diverse. The team might be strengthened further by eventually having an end-user member that really pulls the technology to a particular starting application.

Thanks Doug!

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CONSORTIUM TOUR

We continue our tour of consortium members: in this issue, meet SGUDS (Slovakia) and IGME-CSIC (Spain).

STATNY GEOLOGICKY USTAV DIONYZA STURA (SGUDS)

State Geological Institute of Dionýz Štúr, subordinated to the Ministry of Environment SR is a contributory organization which provides geological research and exploration at the territory of the Slovak Republic, creation of information system in geology as a component of the nation-wide information system, registration and evidence activities related to geological works performance, collecting, evidence and making available the geological works results carried out at the territory of the Slovak Republic, Central Geological Library performance, issuing and purchase of maps and professional geological publications.

The State Geological Institute is named after prominent geologist of the Slovak origin Dionýz Štúr. A proposal to establish an independent geological research institute in Slovakia was submitted in November 1938. The act on the State Geological Institute was approved by the Assembly on May 15, 1940, and on June, 12 of the same year the respective Governmental Directive was issued.

Figure 27 - Headquarters of the State Geological Institute of Dionýz Štúr in Mlynská dolina in Bratislava.

SGUDS role in the START project is to collect, identify and provide the required mineral materials for project partners for further research.

Figure 28 - First samples of tetrahedrite concentrate from Rožňava mine.

https://www.geology.sk/

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AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS (CSIC)

The Spanish National Research Council (CSIC) is the largest public research institution in Spain and one of the most renowned institutions in the European Research Area (ERA). It is affiliated to the Ministry of Science and Innovation through the Secretary General for Research. IGME is the Spanish Geological and Mining institute, with 175 years of history. Since 2021, it is an institute embedded into CSIC.

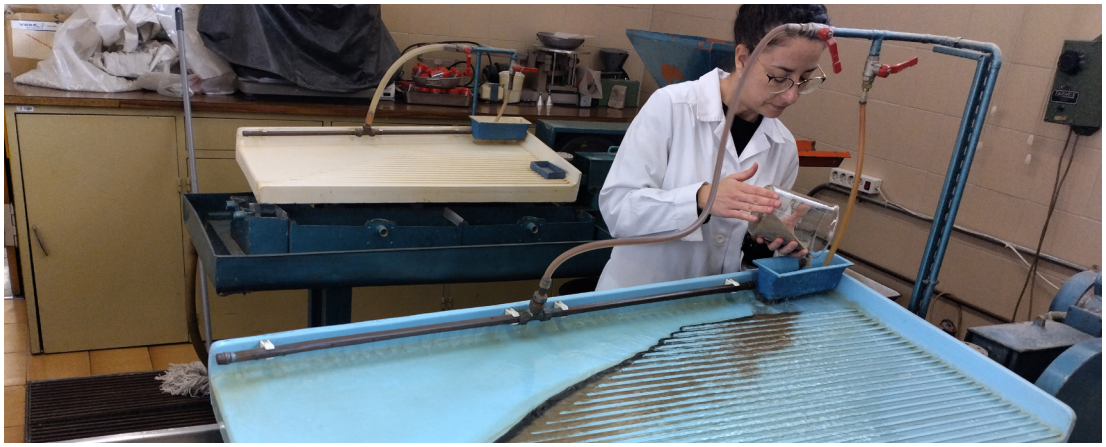
The main mission of IGME is to provide the Public Administration, the Autonomous Regions Administrations and the general society, with precise knowledge and information regarding the Earth Sciences and related technologies for any development on the Spanish territory. The functions of IGME are: Studies, analysis and research in the field of Earth Sciences and Technologies, generation of basic scientific knowledge, technical-scientific assistance and advice to public administrations, economic agents and society in general, concerning geology, hydrogeology, geoenvironmental sciences, geological resources and minerals. The IGME develops interdisciplinary relations with other areas of knowledge, contributing to the best understanding of the territory and of the processes that form and modify it, to the sustainable use of its resources and the conservation of the geological and hydrogeological heritage.

MINISTERIO DE CIENCIA E INNOVACIÓN

Instituto Geológico y Minero de España

CSIC

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS



The IGME team in START project is formed by Ester Boixereu (PI) Concepción Fernandez- Leyva, Ramón Jiménez, Paula Adánez and Jesús Reyes, who are part of the Department of Geological Resources for an Ecological Transition. The role of this team in the project is broad, as we participate in 5 of the 7 WPs of the project, although the activity has focused so far mainly on obtaining the tetrahedrite concentrates, contemplated in WP 2. Within the different packages the role of the IGME team is:

WP1: Coordination and management. In this work package, our main contribution has been the organisation, together with ASGMI, of the project meeting in Madrid, in May 2023.

WP2 Mine waste site selection, physical separation of minerals and concentration. To date, we have focused our activity on this work package, which is now close to completion. Firstly, we have been able to select 21 sites, a priori, with high tetrahedrite potential from our IGME Mineral Resources database. Following criteria such as % tetrahedrite, grain size and volume of mine waste facilities, this number was reduced. Sites have been selected from all over Spain in whose mine wastes there is a higher potential to find tetrahedrites. A total of 7 sites have been sampled, El Coriellu and Delfina Mines (Asturias), Peña Negra (León); Santísima Trinidad (Teruel), Santa Filomena (Cuenca), Lanteira (Granada) and Sierrecilla (Huelva). Mineral separation and concentration tests have been carried out on the samples in order to assess the best methods to obtain the purest tetrahedrite.

WP 4: Characterisation of materials. Work regarding this WP has just started. SEM analyses are being carried out and microprobe analyses are scheduled in the short term.

WP 6. Dissemination and communication. We have given several conferences and webinars to spread and disseminate the project learnings to date. These are: XV Congreso Internacional de Energía y Recursos Minerales (León, Spain, 22-24 November 2023), Science Week, Cu-AGSMI, XI Congreso Geológico de España (Ávila, Spain, 1-6 July 2024).

WP7: Innovation and exploitation strategy. We are making contacts with Spanish industries and companies.

https://www.csic.es/

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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 Brevo, 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/

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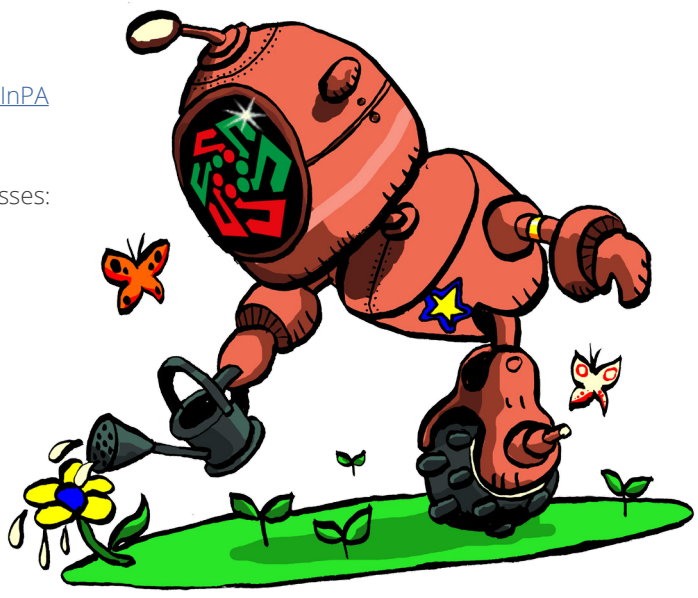

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