EU-Latin America Partnership on Raw Materials

Funded by the European Union

Project START: From WASTE to HIGH-TECH

Daniel de Oliveira (Ph.D.)

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www.START-HEproject.com

START

LNEG

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

Co-funded by the European Union

START

SUSTAINABLE ENERGY HARVESTING SYSTEMS BASED ON INNOVATIVE MINE WASTE RECYCLING

Horizon Europe Programme

Pillar II – Global Challenges and European Industrial Competitiveness

Cluster 4

Digital, Industry and Space

Destination

Increased Autonomy in Key Strategic Value Chains for Resilient Industry

Call HORIZON-CL4-2021-RESILIENCE-01

A digitised, resource-efficient and resilient industry 2021

Topic HORIZON-CL4-2021-RESILIENCE-01-07

Building innovative value chains from raw materials to sustainable products

Innovation Action

Challenge: to develop innovative and sustainable technology and business solutions for new high value added and sustainable products with enhanced functional properties based on the EU produced raw materials.

Focus: on raw materials necessary for the renewable energy ecosystems.

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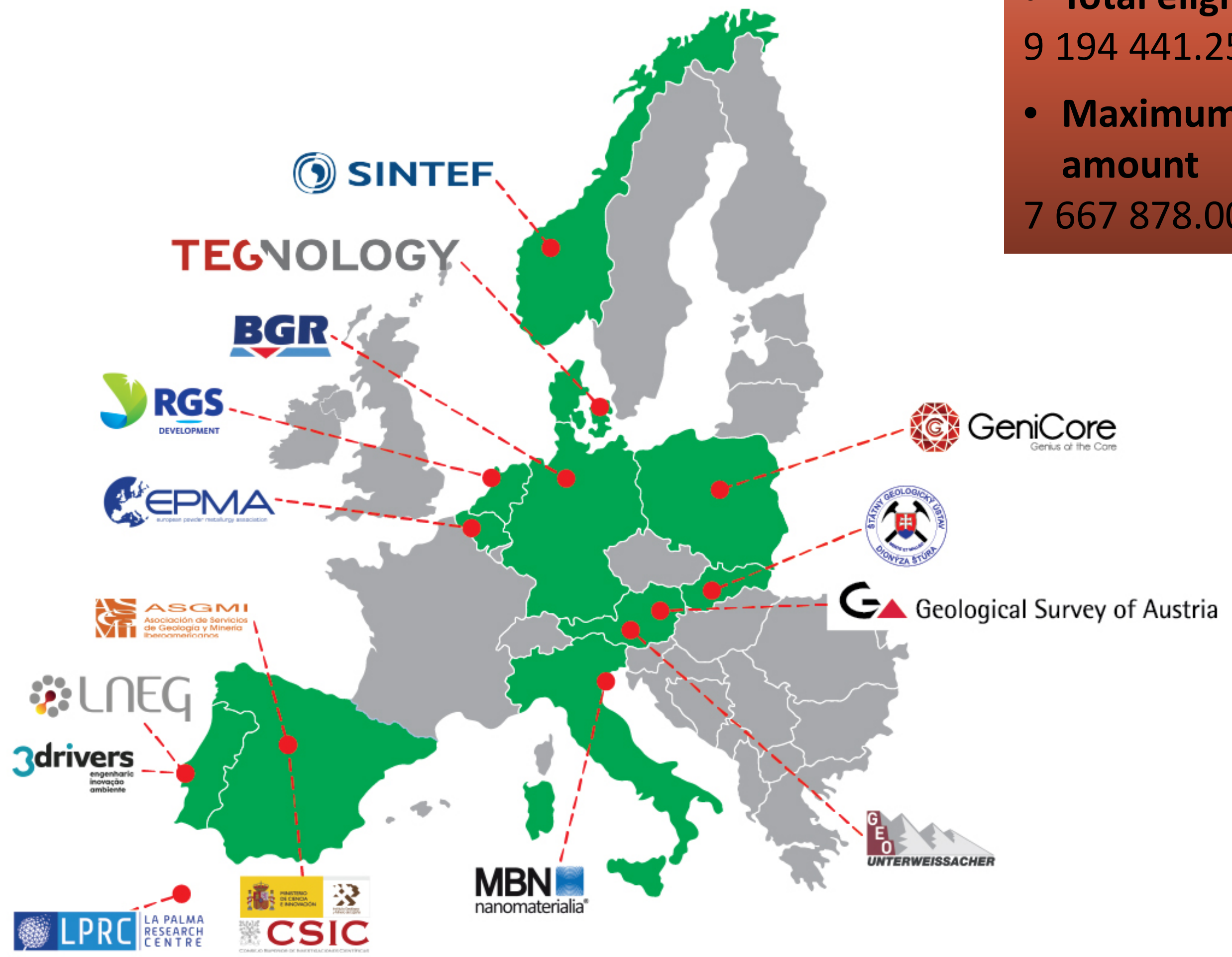
- **Duration**
48 months
(1/6/2022 – 31/5/2022)
- **Total eligible costs**
9 194 441.25 €
- **Maximum grant amount**
7 667 878.00 €

Main objective

Build an **innovation ecosystem in the EU related to the development of sustainable and economically viable tellurium-free thermoelectric (*TE) waste heat harvesting systems**

How to achieve

By producing advanced sulphide p-type thermoelements that incorporates discarded waste secondary sulphides, mainly tetrahedrite to replace the current commercial tellurium-based p-type thermoelements (expensive and rare element, which is predominantly sourced in China).



(*) thermoelectric device creates voltage when there is a different temperature on each side

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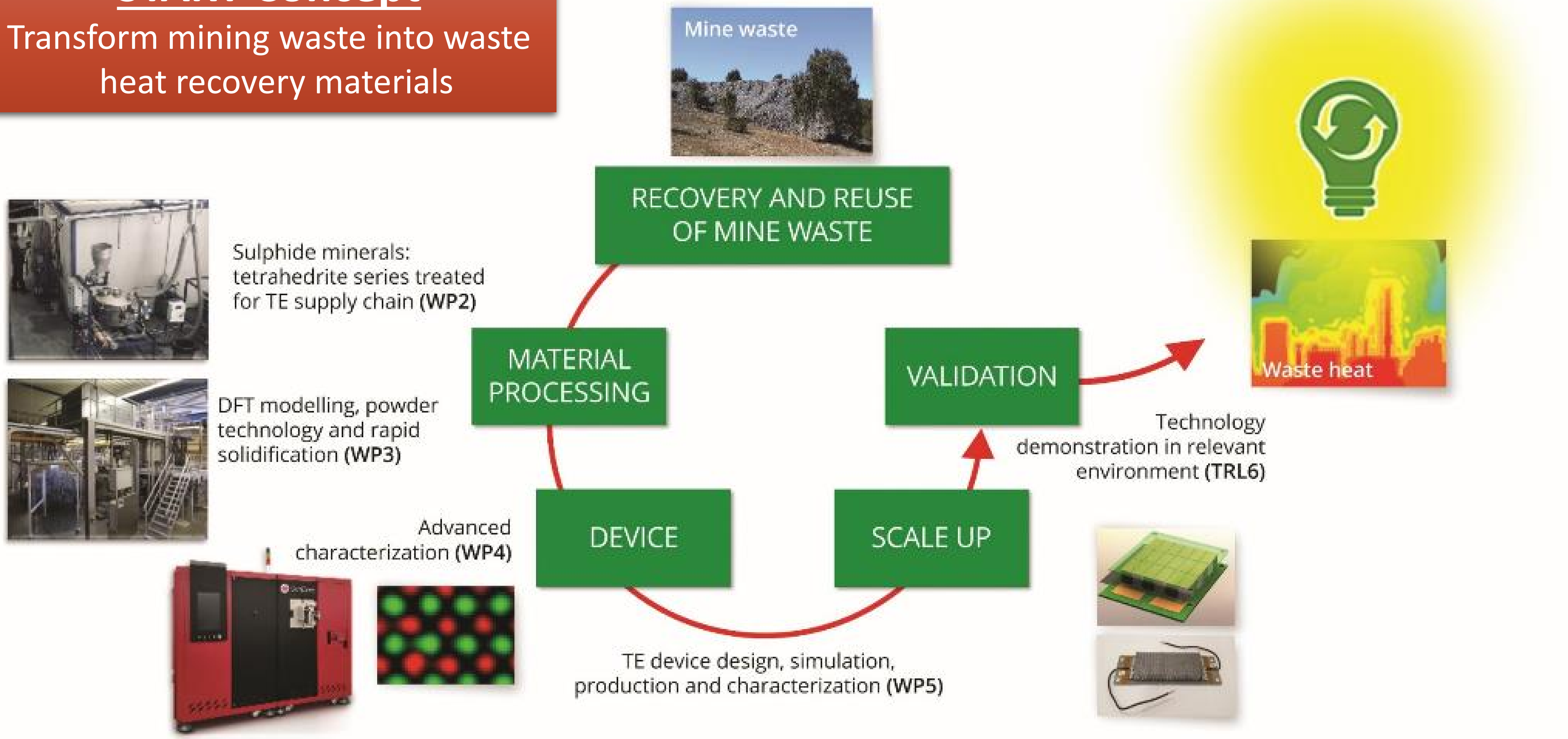
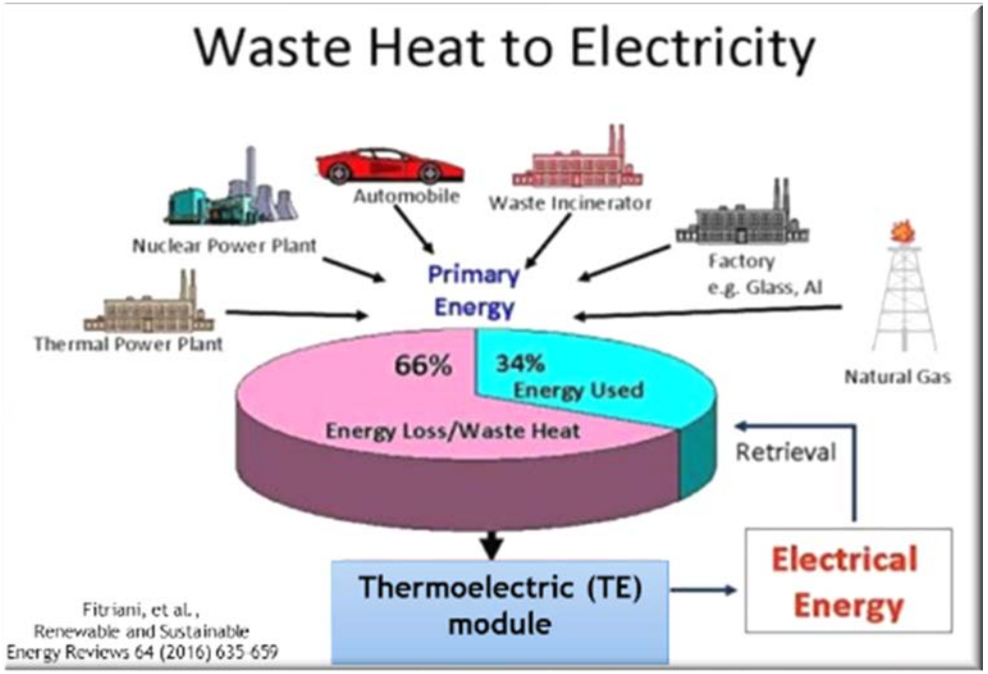
START Concept

Transform mining waste into waste heat recovery materials



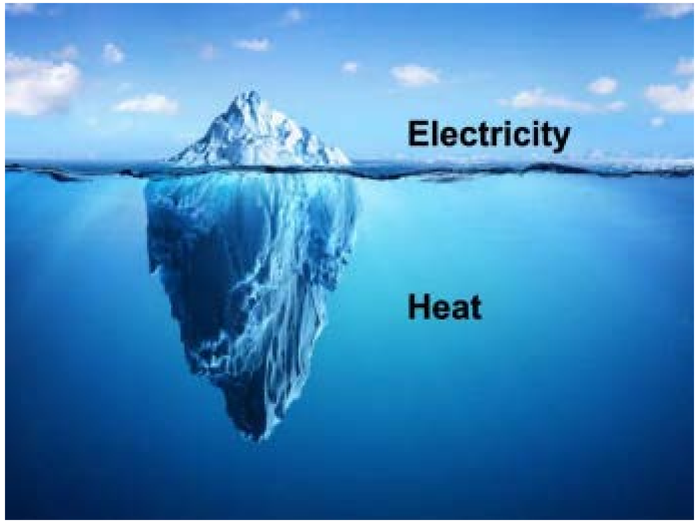
GREEN ENERGY HARVESTING

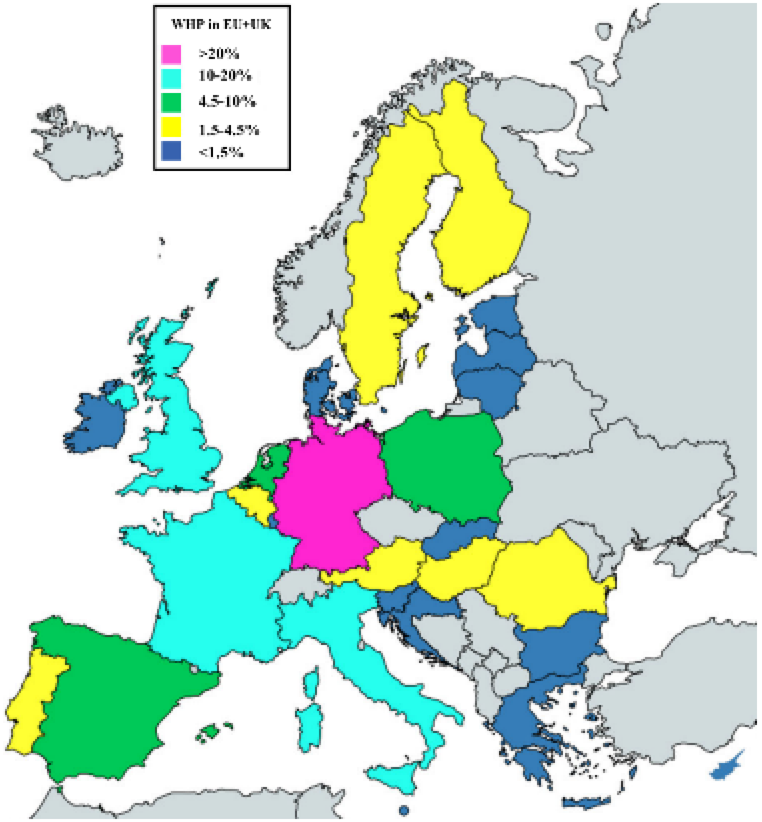
Green energy harvesting aims to supply electricity to electric or electronic systems from an energy source present in the environment [e.g., thermal energy (**thermoelectricity**)] **without grid connection or utilization of batteries**.



Almost all manufacturing processes and machines generate heat, the so called "waste heat"

Around two-thirds of the primary energy produced worldwide is lost as waste heat





Shares of waste heat recover potential in the EU Industry by member state.

(R. Agathokleous, et al., Energy Procedia 161 (2019) 489–496)

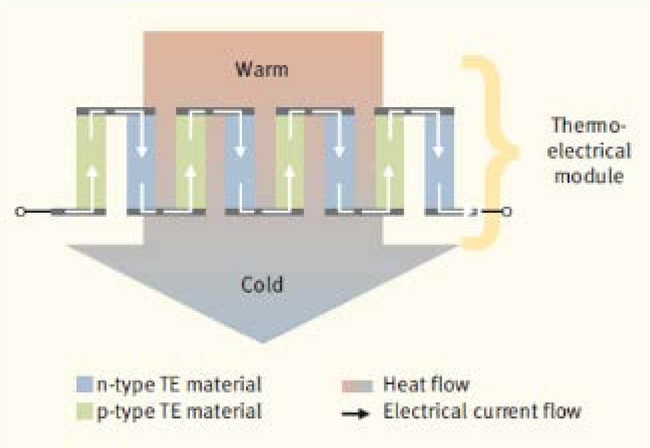
The **waste heat recovery potential in EU** has been estimated to be **300 – 350 TWh/year**

This amount of recoverable heat has the potentiality to avoid tens of millions of tons of CO_2 emissions

The possibility of using a **thermoelectric (TE) device** to **capture and** to **directly convert the waste heat into electric power** is a very attractive and valuable approach **to improve the overall energy efficiency**.

GREEN ENERGY HARVESTING

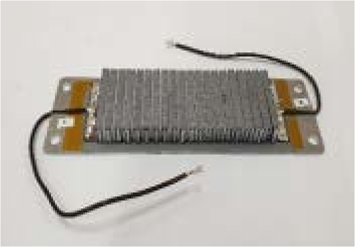
- **TE energy harvesting** has a unique edge as a sustainable power supply in all scales and, by turning the **waste heat energy released to the environment in to emissions-free electricity**
- it has become an increasingly important contributor to **sustainable renewable energy ecosystems**



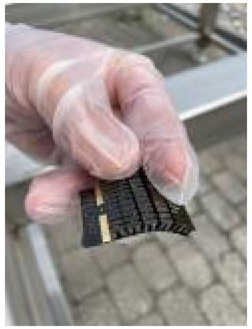
Design and operation of a TE device. The heat flow creates an electric current (Seebeck effect).
(BINE Themeninfo: Thermoelectrics: power from waste heat (I/2016).)

The **TE device is a robust and highly reliable solid-state energy converter,** made from several TE junctions electrically connected in series that consist of n- and p-type TE semiconductor materials (thermoelements), with unique features:

- no moving parts
- no maintenance
- quiet operation
- absence of production of environmental harmful waste



Courtesy RGS Development B.V. (RGS), Netherlands



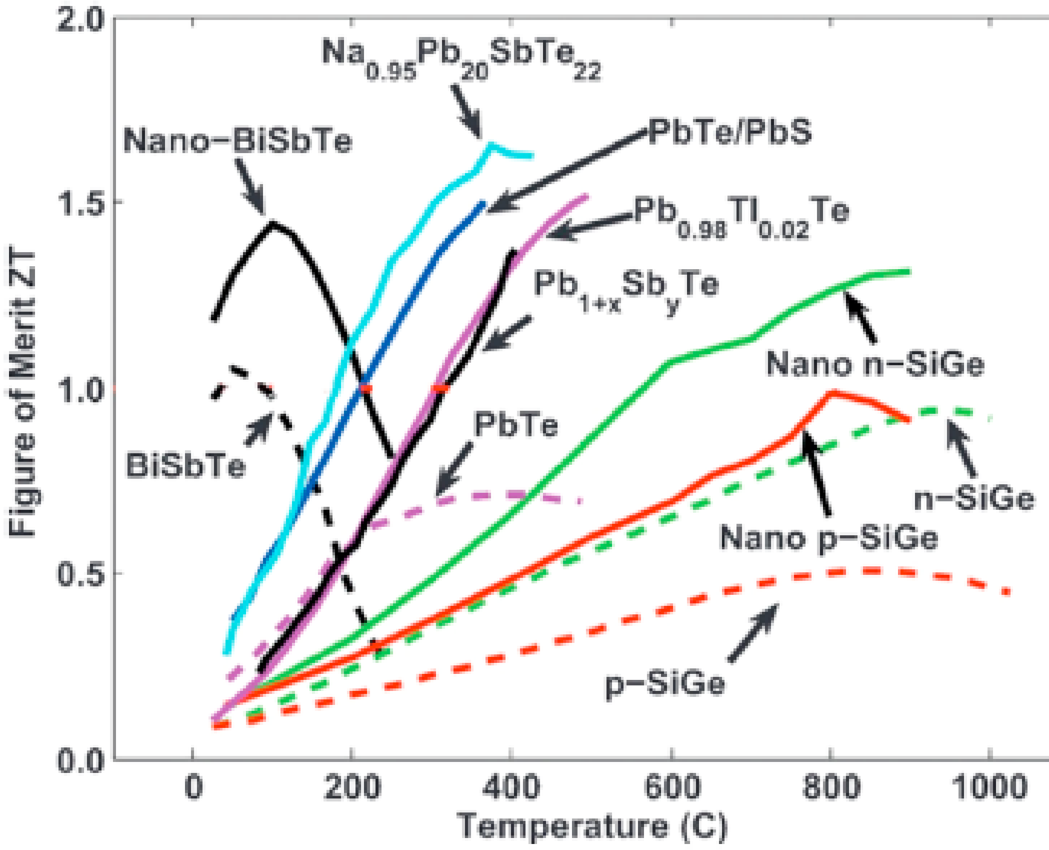
TEGMAT
Flex-TEG

Flexible ThermoElectric Generator

Courtesy TEGnology ApS, Denmark

zT = EFFICIENCY

zT as a function of temperature
for state-of-the-art TE materials



D. Zabek, F. Morini
Thermal Science and Engineering Progress 9 (2019) 235–247

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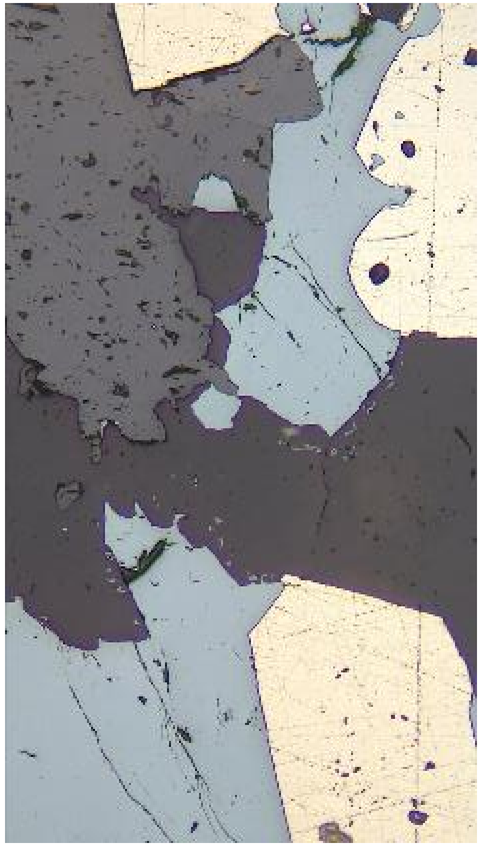
GREEN ENERGY HARVESTING

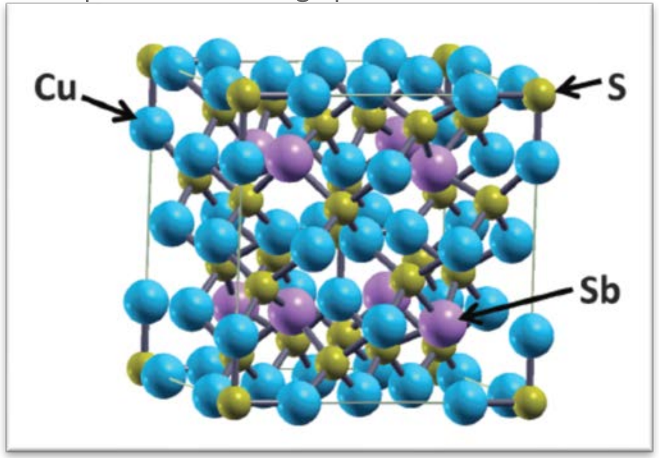
Tetrahedrite-based materials have excellent properties for TE applications



p-type semiconductor material behavior + High Seebeck coefficient + Extremely low thermal conductivity

The low thermal conductivity is partially a consequence of the large primitive unit cell volume

Is characterized by a body-centred cubic structure (space group I-43m) and its cell parameter is around 10.3Å.



Its large unit cell contains 58 atoms on 5 distinct crystallographic sites.

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GREEN ENERGY HARVESTING

Characteristics of commercially relevant TE materials and comparison with tetrahedrites

Materials	Bi_2Te_3	PbTe	SiGe	Mg_2Si-based materials	Tetrahedrite
Current commercial materials					
Figure of merit (zT)	> 1	> 1	> 1	> 1	> 1
Operational temperature	< 300 °C	< 500 °C	< 900 °C	< 550 °C	< 550 °C
Toxicity	Negative	Negative	Positive	Positive	Positive
Environmental aspects	Negative	Negative	Positive	Positive	Positive
Raw materials availability	Negative	Negative	Negative	Positive	Positive
Large scale manufacture	Less favourable	Less favourable	Positive	Positive	Positive

Positive assessment ■ Negative assessment ■ Less favourable ■

(A.V. Powell, J. Appl. Phys. 126, 100901 (2019).; H. Huang, et al., J. Alloys and Compounds 881 (2021) 160546)

Tetrahedrite ($Cu_{12}Sb_4S_{13}$) is a copper antimony sulphosalt, and forms a complete solid solution with **Tennantite** in which the antimony (Sb) is replaced by arsenic ($Cu_{12}(Sb,As)_4S_{13}$)

The **Tetrahedrite-Tennantite mineral series** is relatively **abundant in some copper (Cu) mine tailings** (are considered as "dirty concentrates" because antimony and arsenic are impurity elements in the copper concentrate – waste material)

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GREEN ENERGY HARVESTING

Telluride-based TE technology

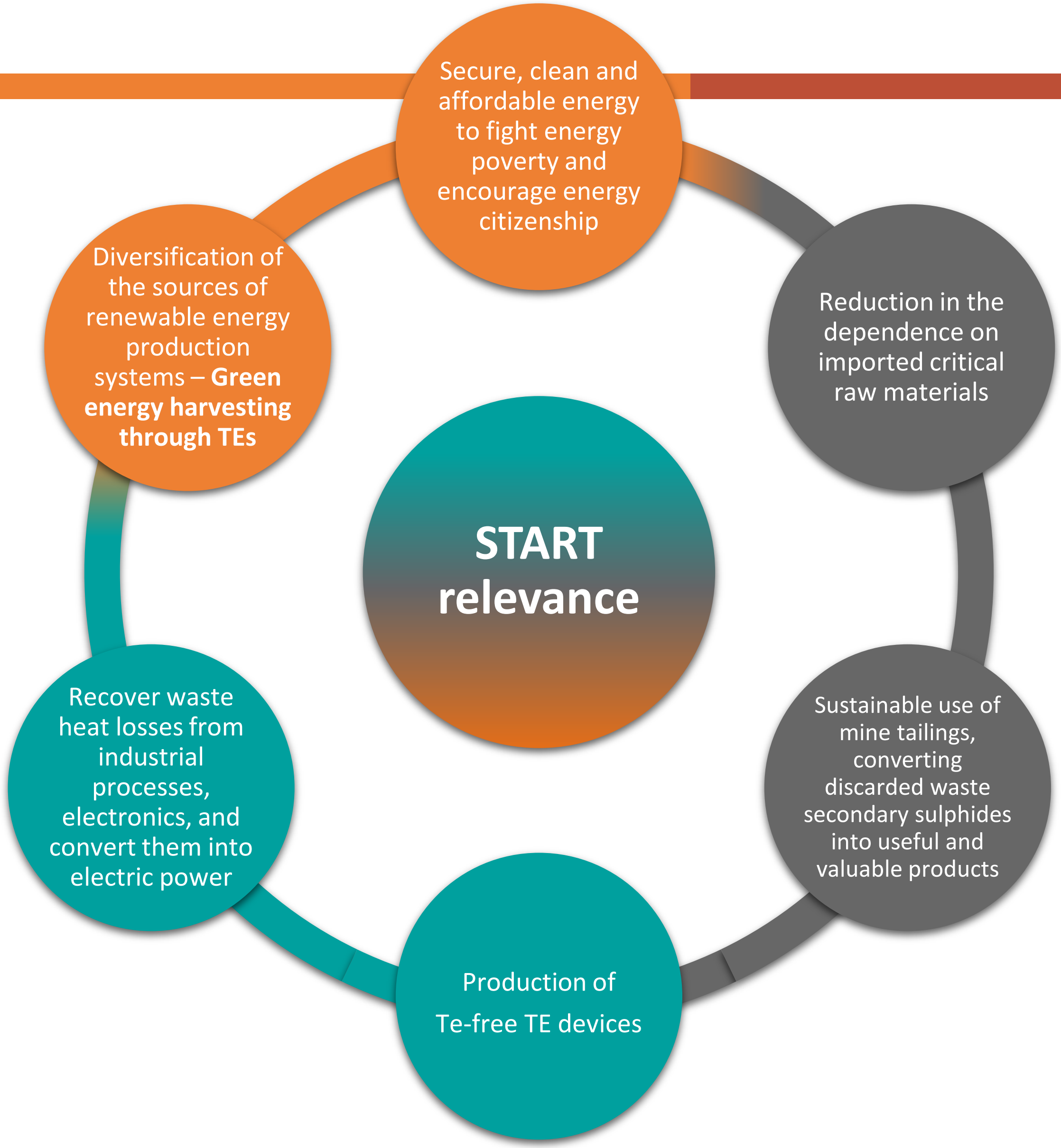
- **Global consumption** estimates of **tellurium** by end user are:
  - solar, 40%
  - **thermoelectric production, 30%**

Abundance and geographic concentration of production:

- ***tellurium is a relatively scarce element***,
- terrestrial abundance of ca. 1 ppb, and, simultaneously,
- Europe is **heavily dependent on imports,**
- ***China accounts for more than 60% of its production***

Tetrahedrite is very abundant and can be found all around the world

(U.S. Geological Survey, 2020, Mineral commodity summaries 2020: U.S. Geological Survey, 200 p., https://doi.org/10.3133/Mcs2020)



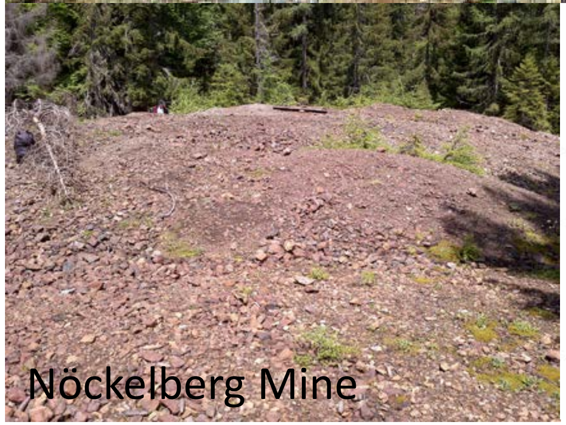
START project proposes a unique technological solution, based on the conversion of mining waste into materials for waste heat recovery, thus contributing to an efficient use of resources while promoting the use of green energy harvesting through thermoelectrics

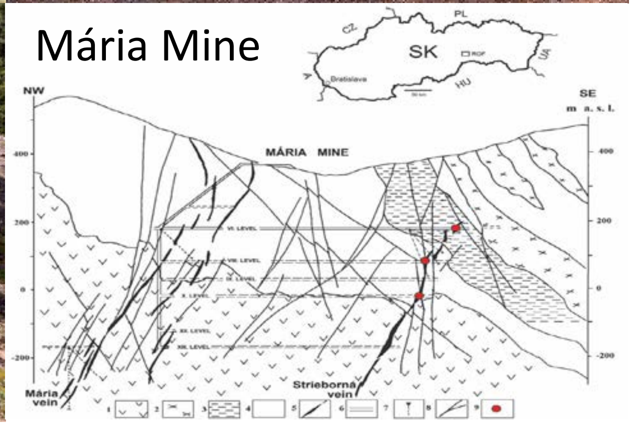
In line with:

- European Green Deal
- EU Action Plan on Critical Raw Materials
- EU Action Plan on Circular Economy

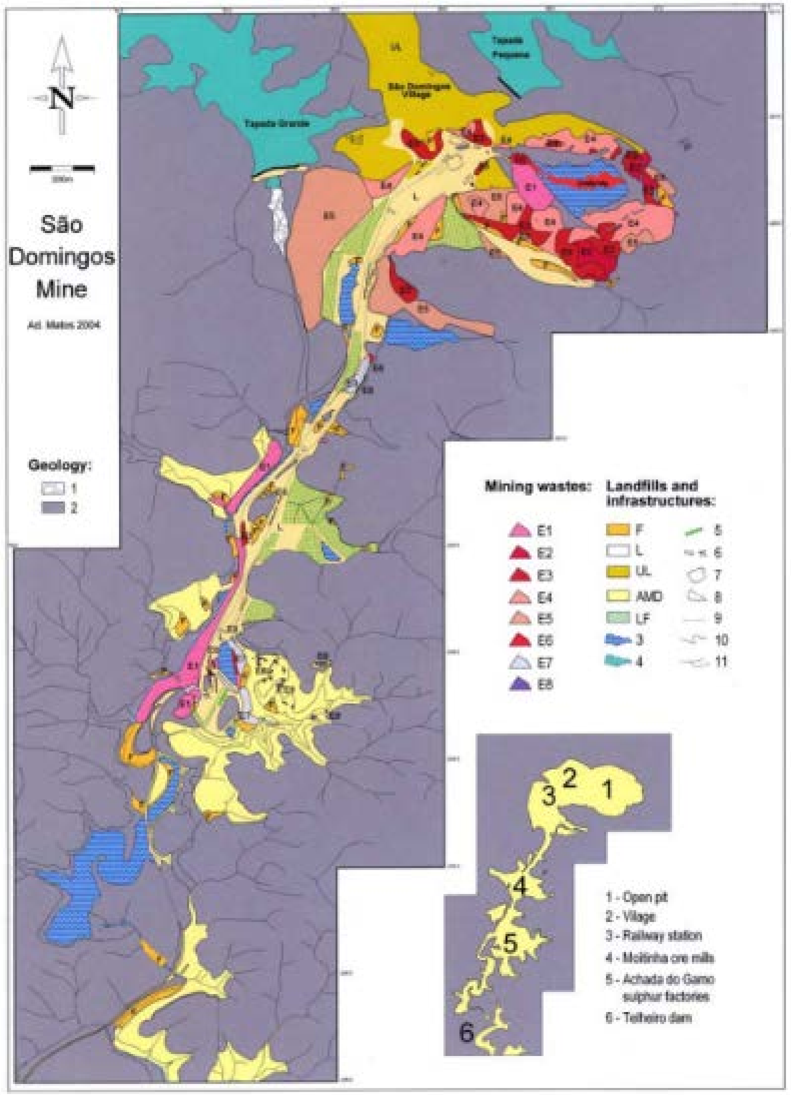
BACK to BASICS

Obtaining Raw Materials means, Mining and Quarrying

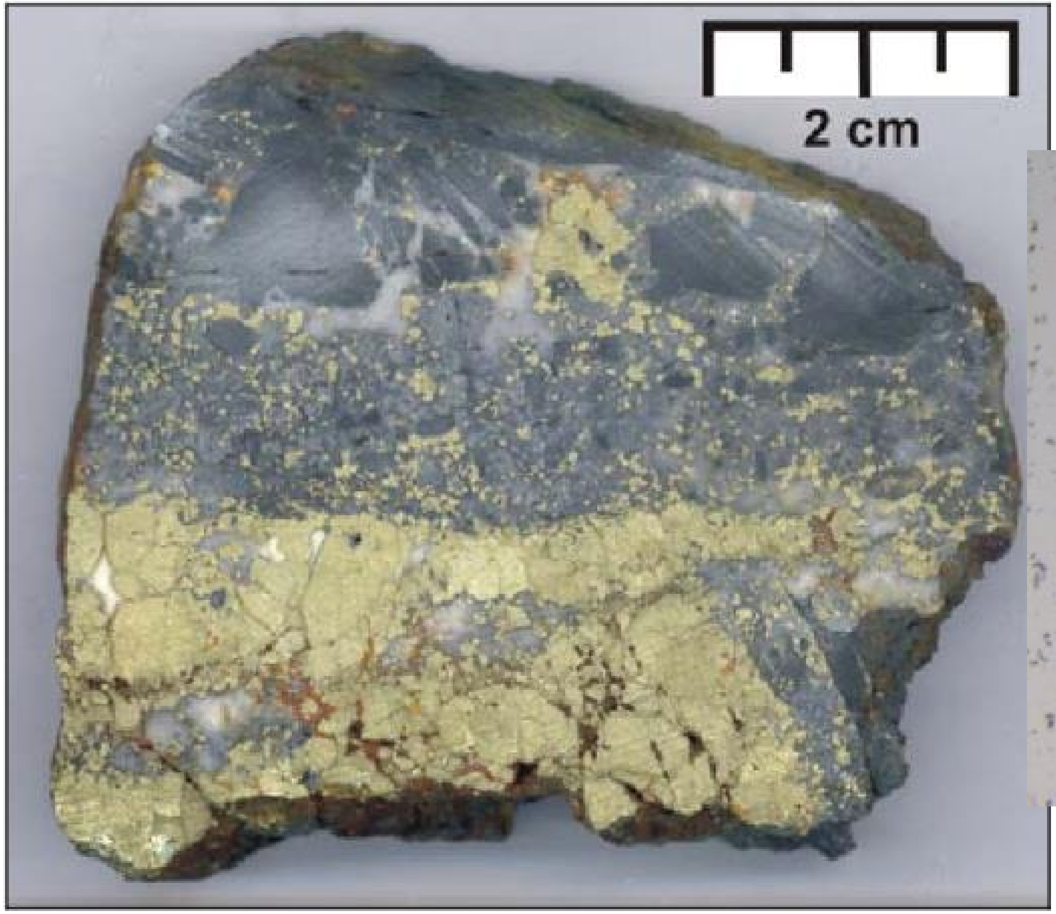


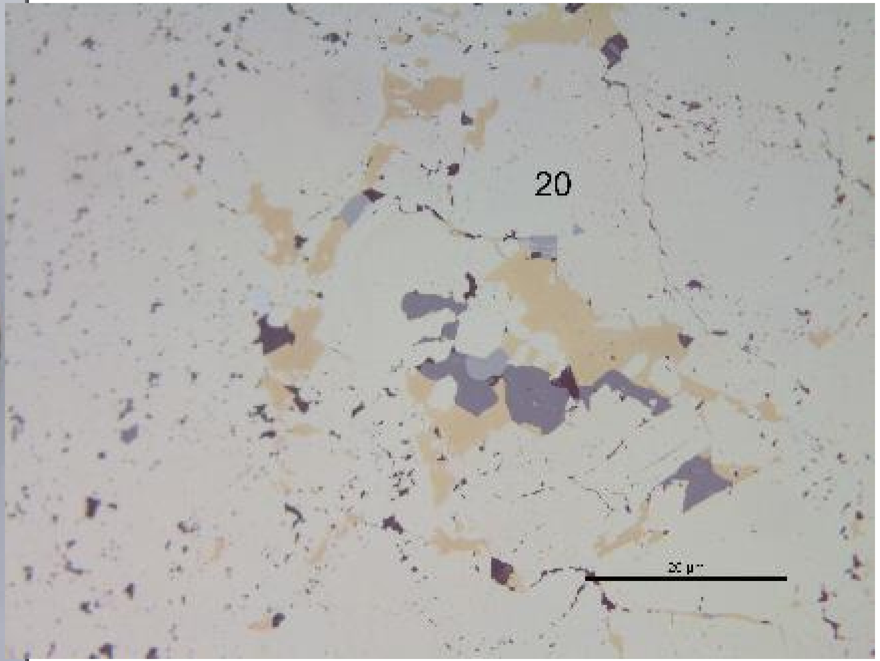


Potential tetrahedrite supply sites:

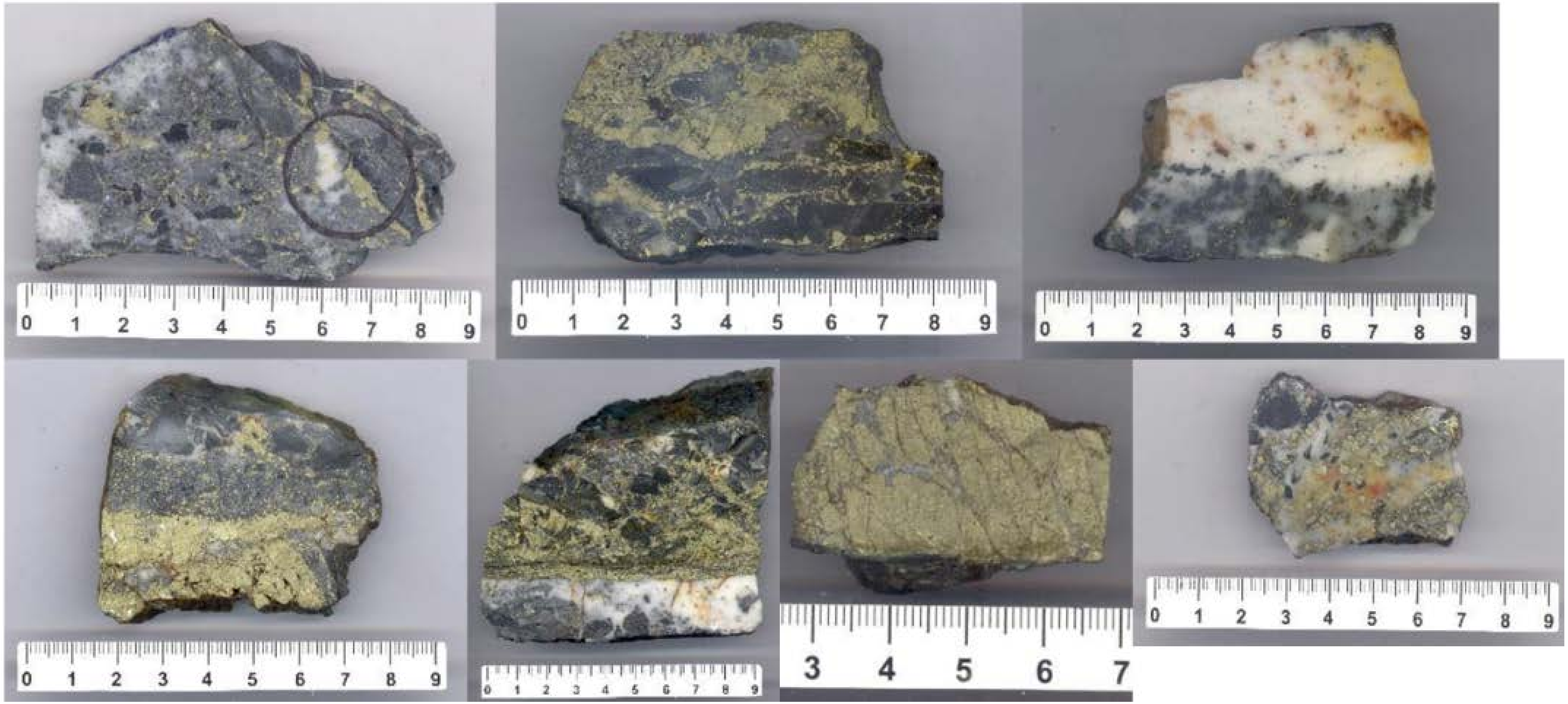


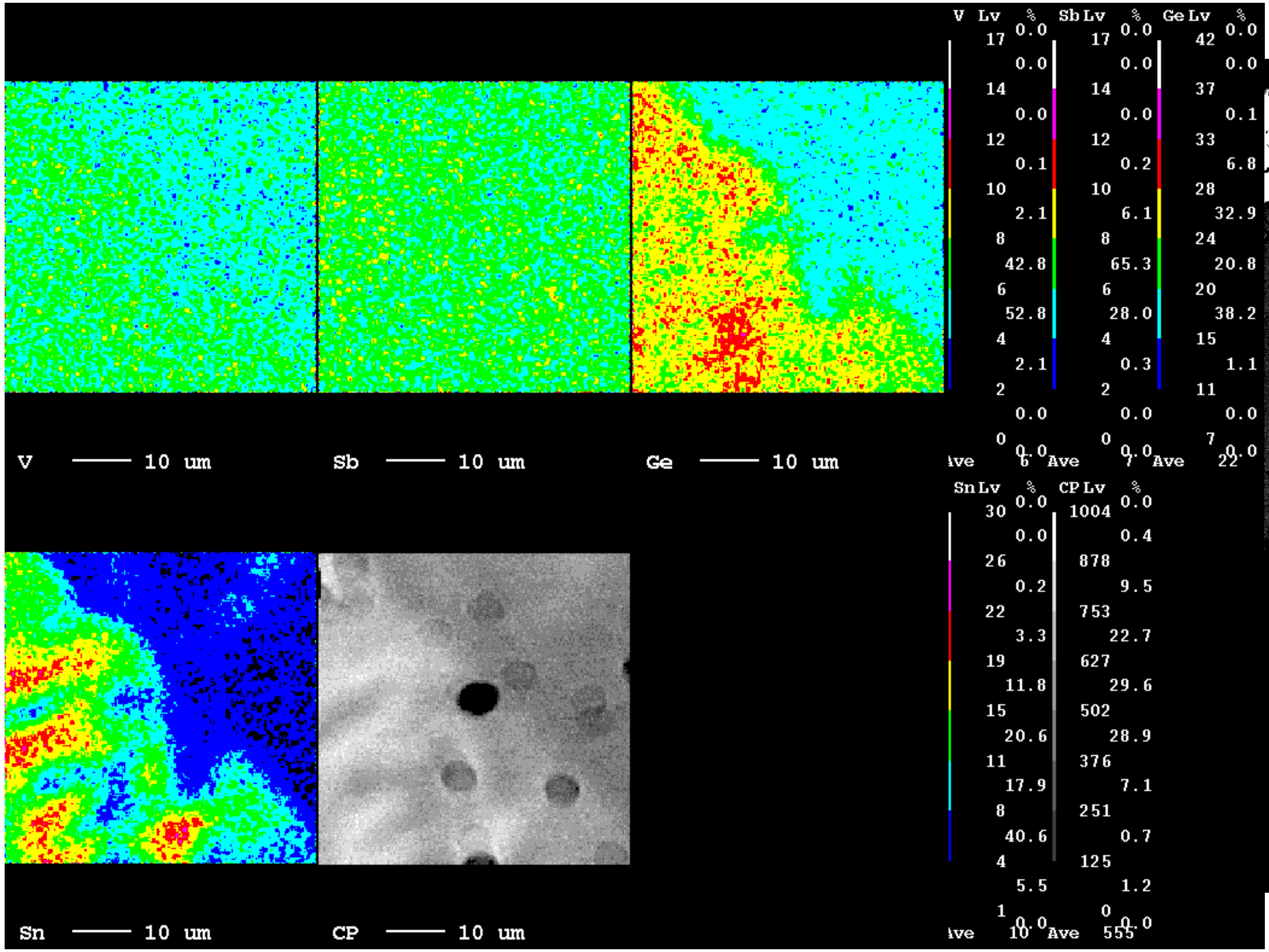
Potential environmental impact at São Domingos mining district (Iberian Pyrite Belt, SW Iberian Peninsula): evidence from a chemical and mineralogical characterization AM Álvarez-Valero, R Pérez-López, J Matos, MA Capitán, JM Nieto, R. Sáez, J. Delgado, M. Caraballo, Environmental Geology 55 (8), 1797-1809

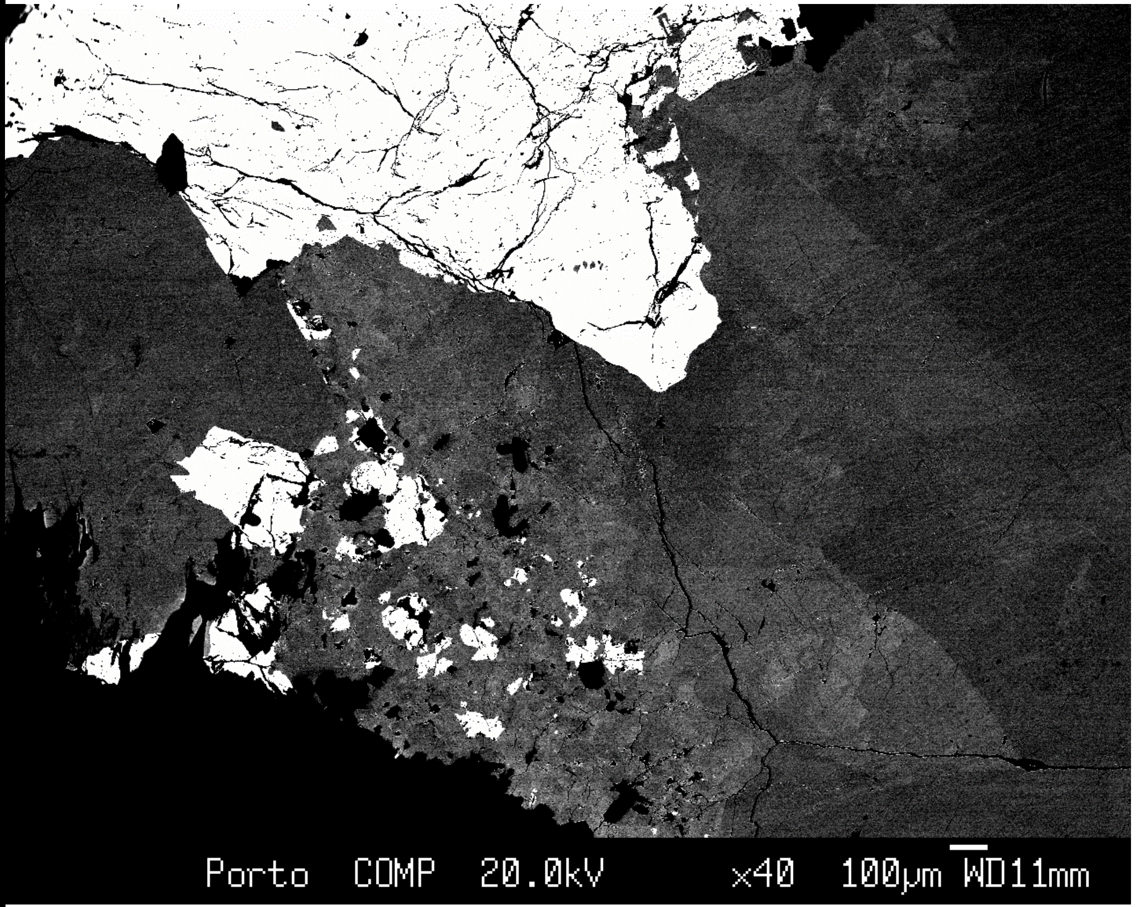

2 cm


20

CHALLENGES




V 10 um
Sb 10 um
Ge 10 um
Sn 10 um
CP 10 um


Porto COMP 20.0kV x40 100μm WD11mm

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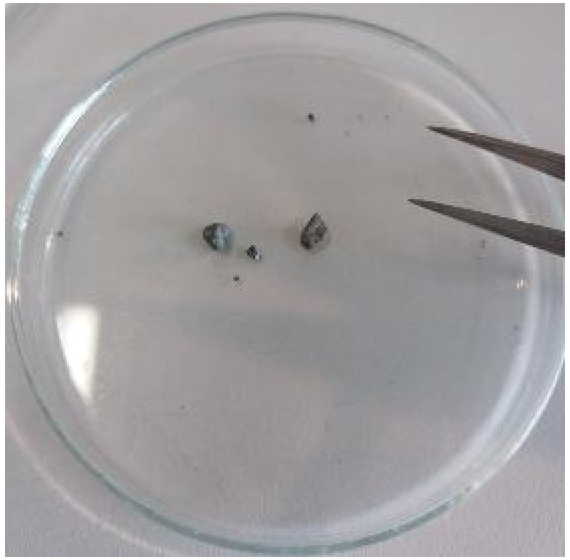
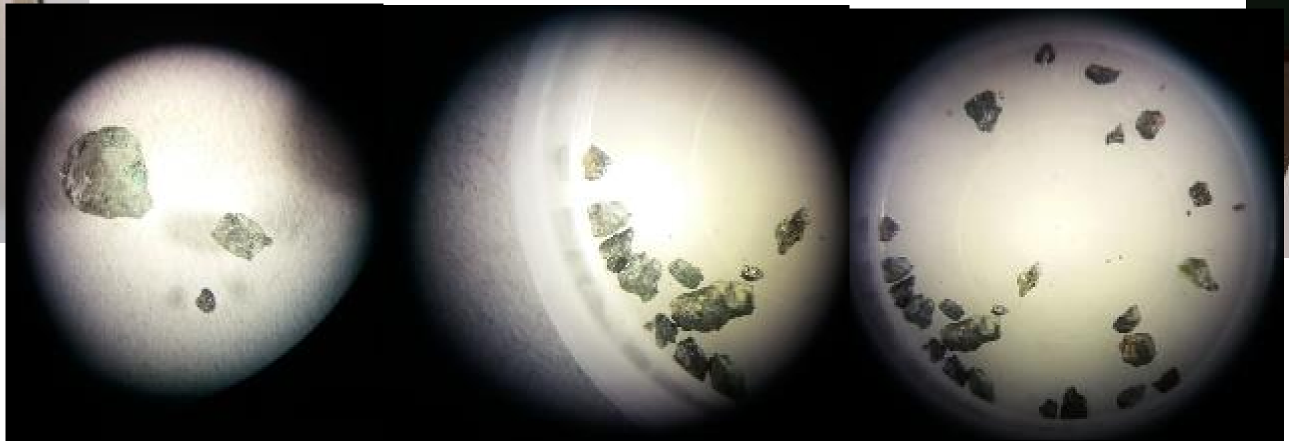
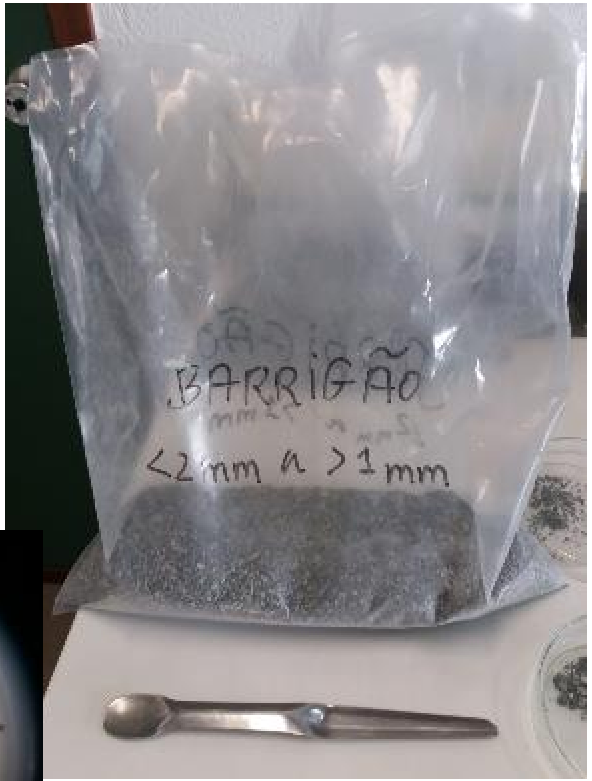
Separation of raw materials into final usable concentrates





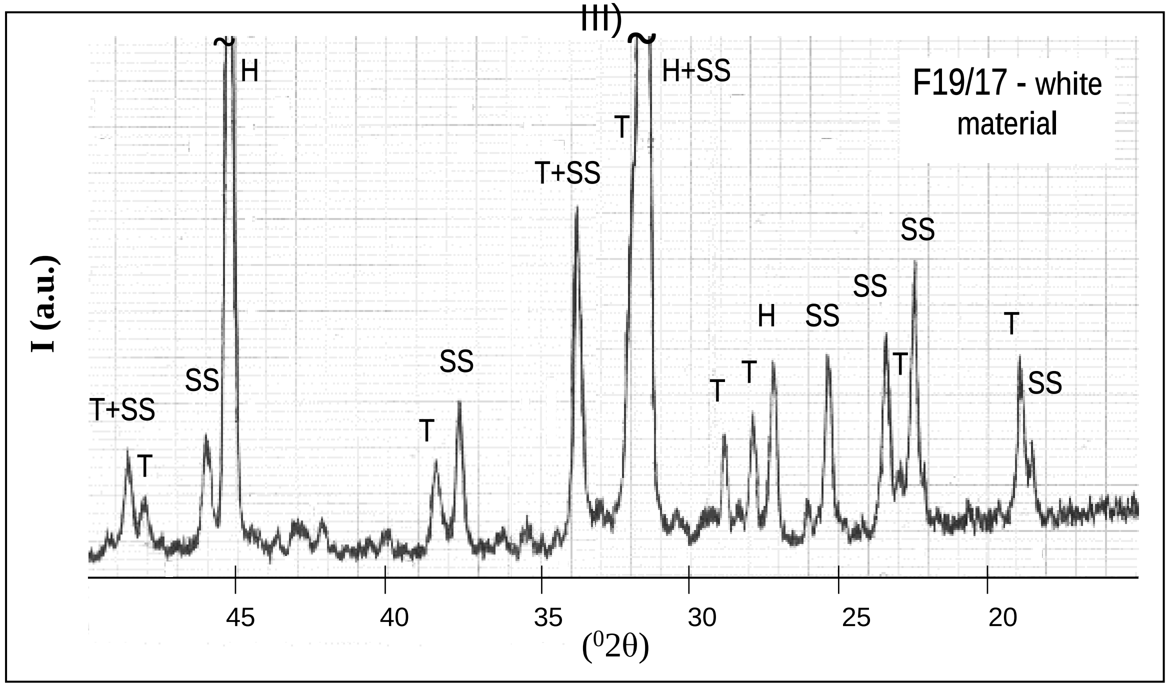


X-ray diffraction (XRD)

Philips PW 1500 powder diffractometer (Bragg-Brentano geometry), equipped with a large-anode copper tube operating at 50 kV - 40 mA and a curved graphite crystal monochromator

XRD pattern. Assigned phases in decreasing percentage:

H, halite (NaCl); **T**, thenardite (Na_2SO_4); **SS** (sodium sulphate, form III)



Thank you for your attention

daniel.oliveira@lneg.pt

Project Coordination:
Filipe Neves, LNEG
filipe.neves@lneg.pt