START

SUSTAINABLE ENERGY HARVESTING SYSTEMS BASED ON INNOVATIVE MINE WASTE RECYCLING

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WORLD PM2022 CONGRESS & EXHIBITION

EPMA european powder metallurgy association
9 - 13 October 2022
LYON

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Overview of the START project

(started in June 2022)

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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Overview of the START project

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** with potential applications in heavy industry, maritime industry or as primary power source for off-grid sensors and IoT devices.

How to achieve

By **producing advanced sulphide p-type thermoelements that incorporates discarded waste secondary sulphides**, mainly tetrahedrite (which is relatively abundant in some Cu mine tailings and at present an environment hazard), to replace the current commercial tellurium-based p-type thermoelements (expensive and rare element, which is predominantly sourced in China).

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START Concept

Transform mining waste into waste heat recovery materials

RECOVERY AND REUSE OF MINE WASTE

Sulphide minerals: tetrahedrite series treated for TE supply chain **(WP2)**

MATERIAL PROCESSING

DFT modelling, powder technology and rapid solidification **(WP3)**

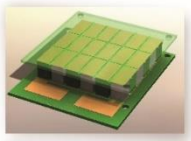
Advanced characterization **(WP4)**

DEVICE

SCALE UP

VALIDATION

Technology demonstration in relevant environment **(TRL6)**



TE device design, simulation, production and characterization **(WP5)**

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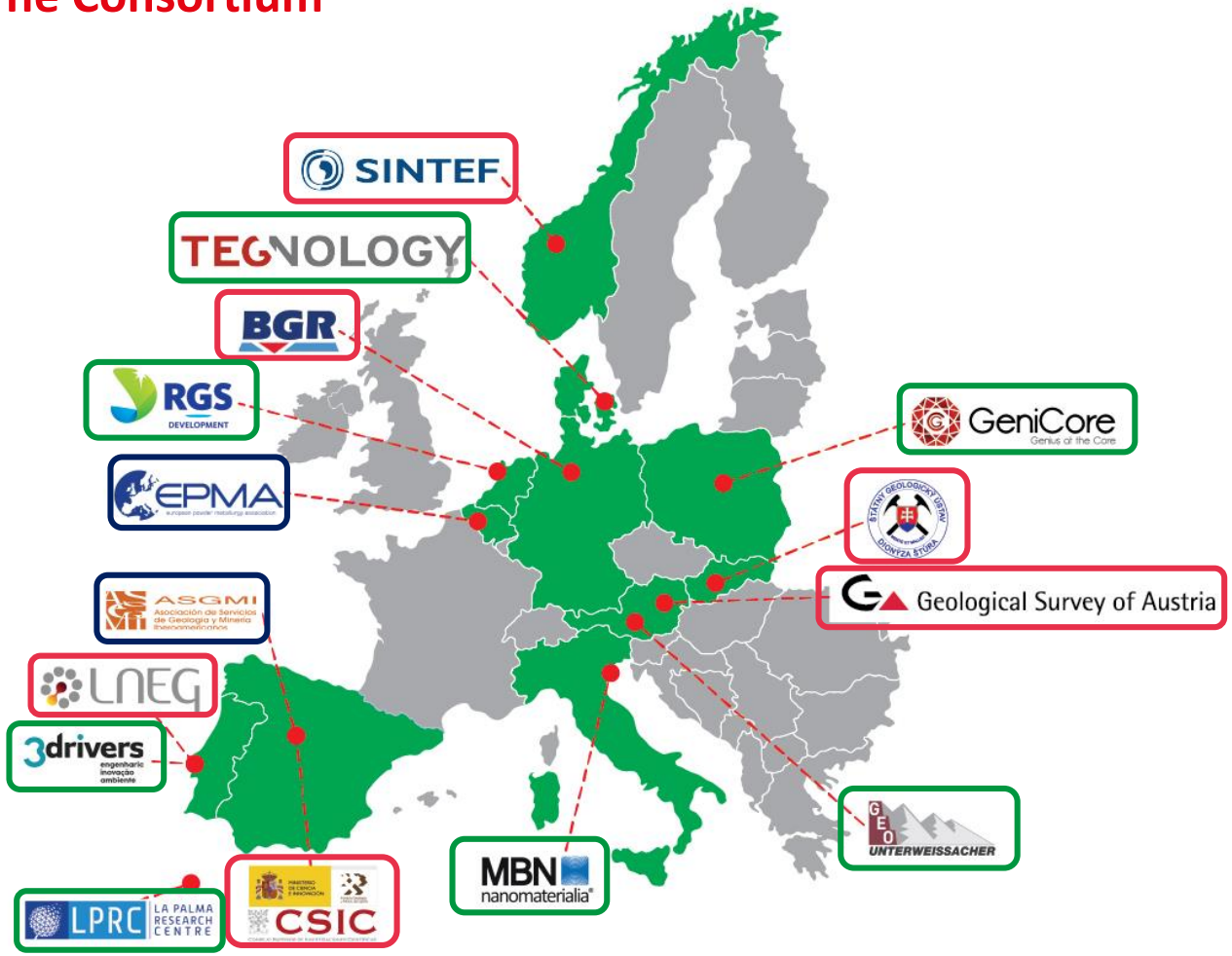
Overview of the START project

The Consortium



- **Coordination**
  LNEG
- **Multidisciplinary Consortium**
  15 partners from 10 EU member states and 1 associated country, including **6 research organizations** with strong background and knowledge on geology, materials science and renewable energies, **7 SME's companies** that guarantee the entire supply chain, from production, exploitation and ecological footprint assessment, and **2 non-profit international associations** with a consolidated network of partners and stakeholders
- **Duration**
  48 months (1 June 2022 - 31 May 2026)
- **Total eligible costs**
  9 194 441.25 €
- **Maximum grant amount**
  7 667 878.00 €
- **Website**
  www.START-HEproject.com

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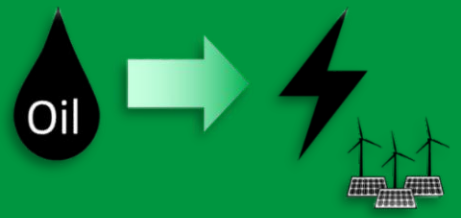
Motivation

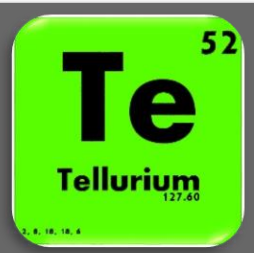
Climate change is one of the greatest challenges faced by humankind

- Fighting global warming is critically dependent on the rapid implementation of a green transition
- European Union (EU) is fully committed through the **European Green Deal**



Green transition

- Based on a **shift from a fossil fuel-intensive to a material-intensive energy system**, which implies an increased need of minerals resources
- This growing demand for essential minerals and the declining quality of ores is leading to a **substantial increase in waste volumes from mining operations**
- **Use of mine wastes as valuable secondary raw materials** for the development of advanced energy conversion devices creates an increased economic incentive to eliminate environmentally hazardous tailings



Current commercial thermoelectric (TE) devices

- Rely on **tellurium-based thermoelements**
- **Element derived or refined from minerals that are scarce in Europe**, making the continent heavily import dependent

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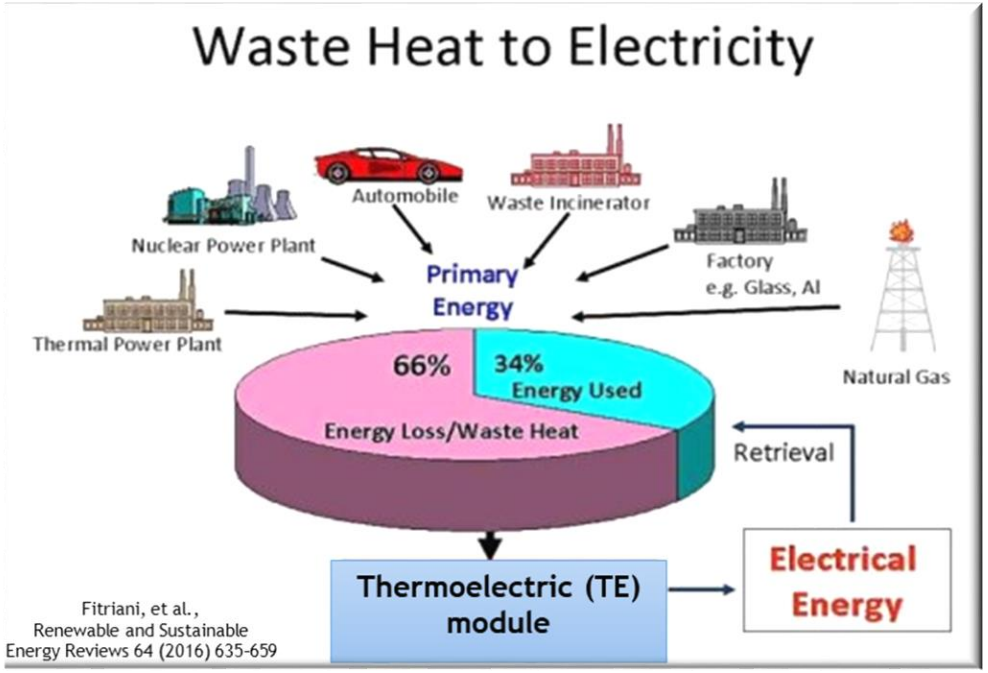
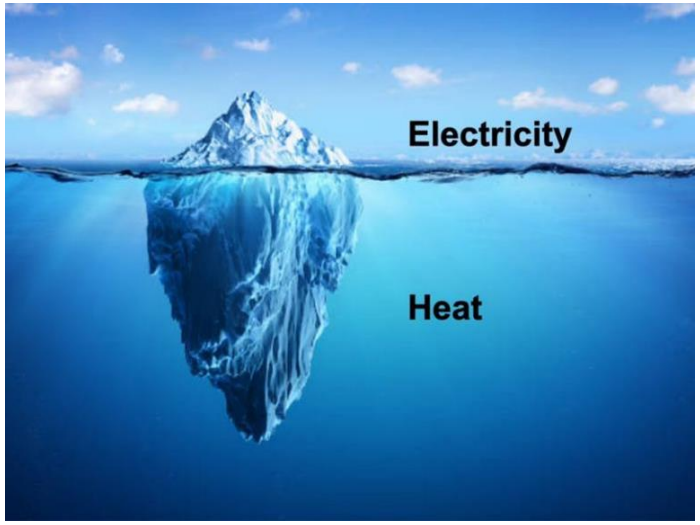
GREEN ENERGY HARVESTING

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



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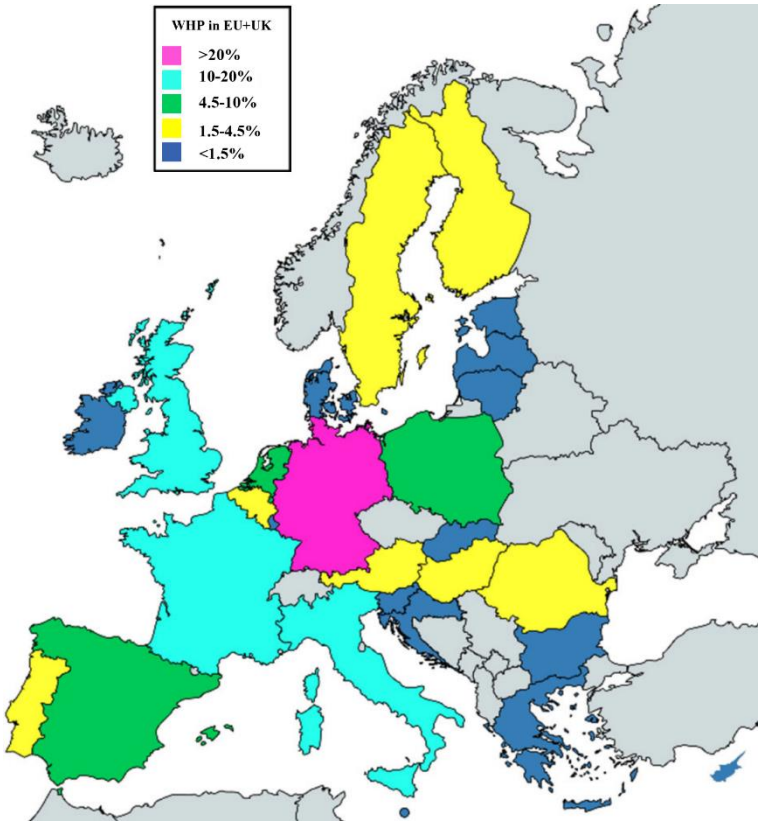
GREEN ENERGY HARVESTING



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 recover 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 CO2 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**.

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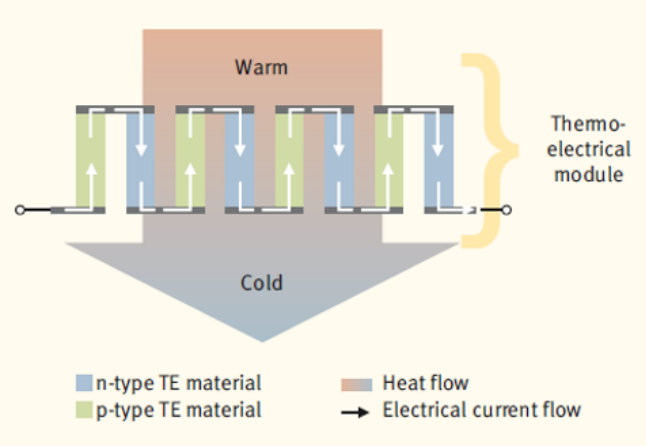
GREEN ENERGY HARVESTING

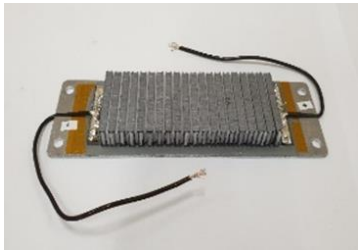
TE energy harvesting has a unique edge as a sustainable power supply in all scales and, by turning the **waste heat energy released to the environment in emissions-free electricity**, it has become an increasingly important contributor to **sustainable renewable energy ecosystems**



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

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GREEN ENERGY HARVESTING

MATERIALS PERFORMANCE

zT

(dimensionless figure of merit)

Power Factor
PF = $S^2 \sigma$

$$zT = \frac{S^2 \sigma T}{k}$$

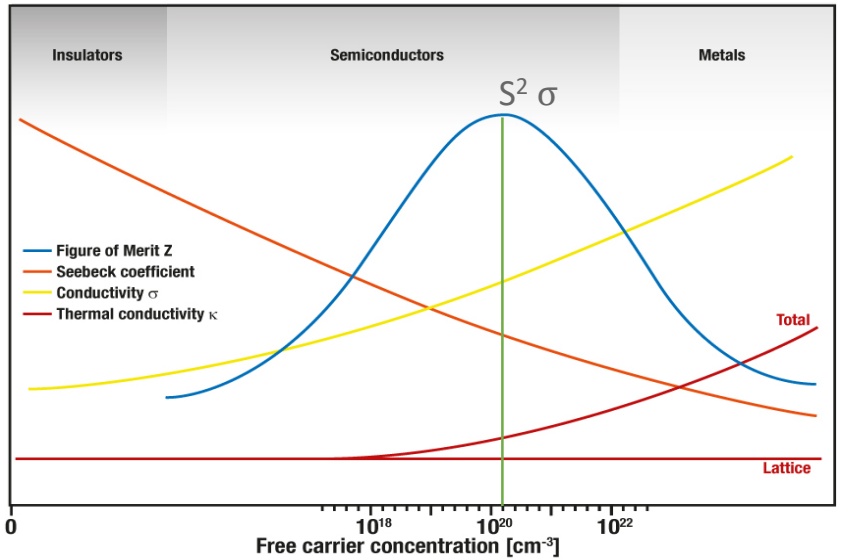
S - Seebeck coefficient

σ - electrical conductivity

κ - thermal conductivity

T - absolute temperature

The goal is to maximize zT



A good TE material should have:

- high σ to minimize Joule heating,
- low κ to retain heat at the junctions and maintain a large temperature gradient,
- large S for maximum conversion of heat to electrical power or electrical power to cooling.

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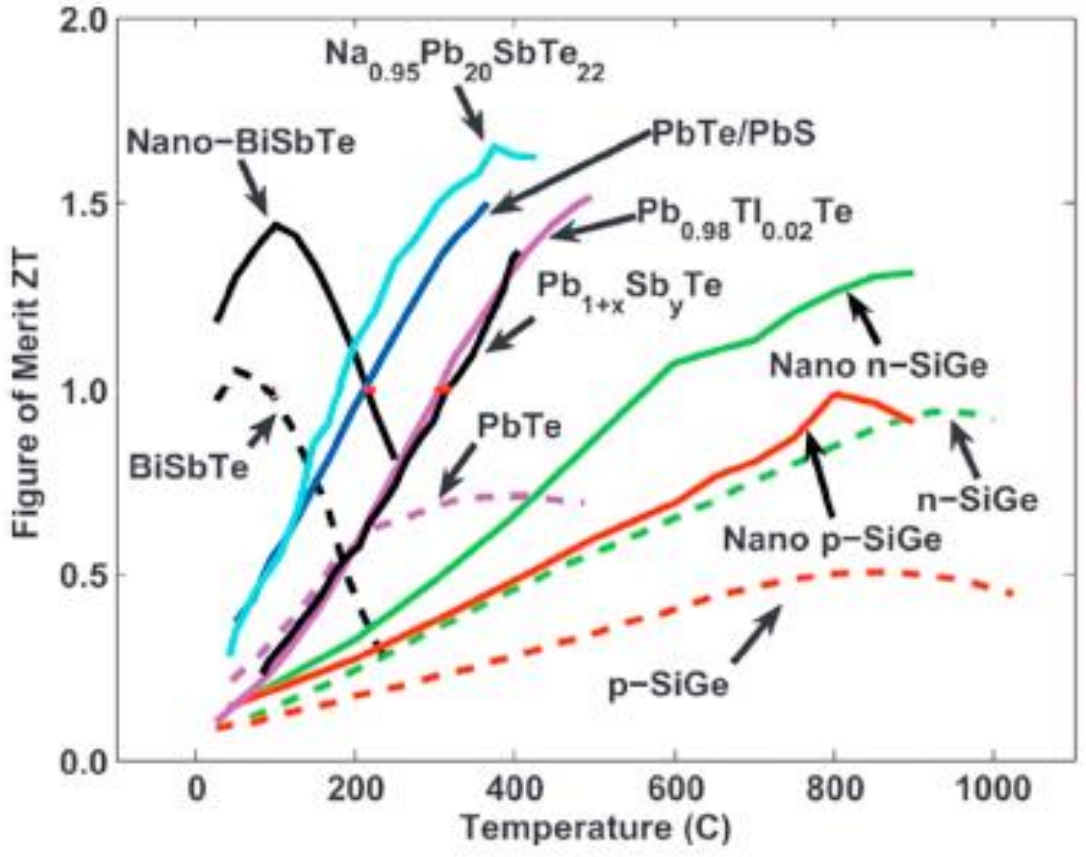
GREEN ENERGY HARVESTING

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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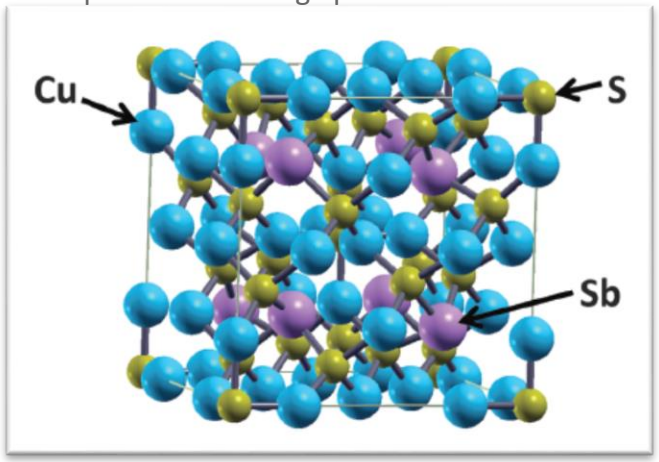
GREEN ENERGY HARVESTING

Tetrahedrite-based materials have excellent properties for TE applications

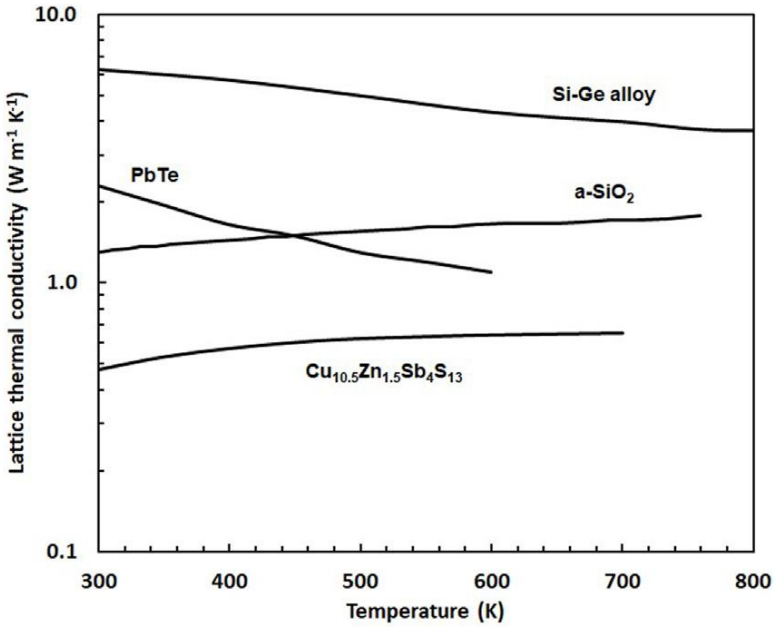
p-type semiconductor material behavior + High Seebeck coefficient + Extremely low thermal conductivity

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.



Weller DP and Morelli DT (2022); Front. Electron. Mater. 2:913280

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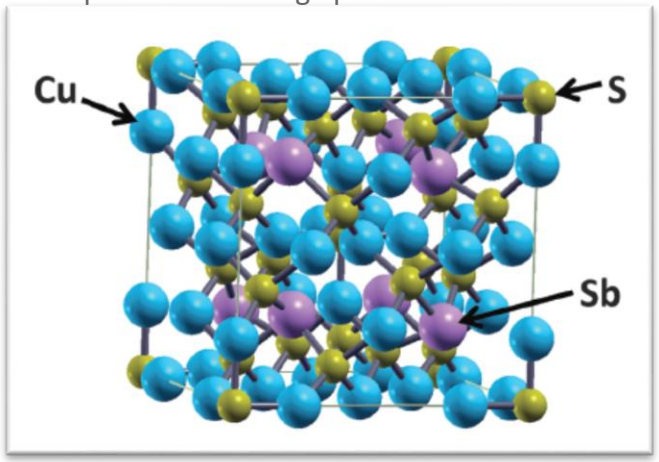

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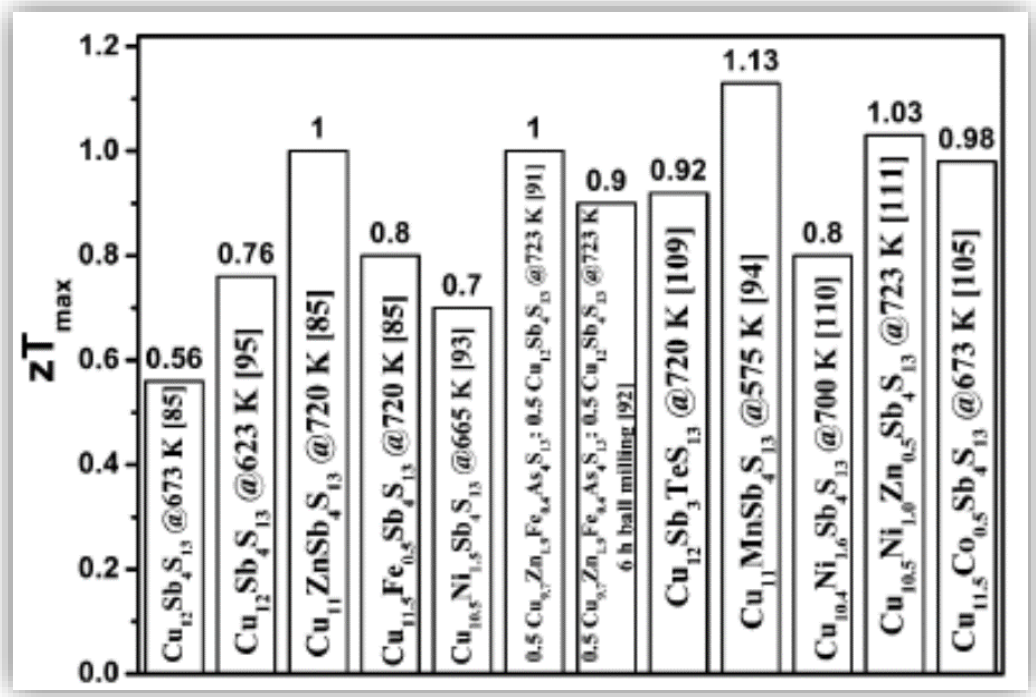

R. Chetty, A. Bali and R. C. Mallik
J. Mater. Chem. C, 2015, 3, 12364-12378

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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	🟥	🟥	🟩	🟩	🟩
Environmental aspects	🟥	🟥	🟩	🟩	🟩
Raw materials availability	🟥	🟥	🟥	🟩	🟩
Large scale manufacture	🟨	🟨	🟩	🟩	🟩
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 sulfosalt, 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 use are solar, 40%; **thermoelectric production, 30%**

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

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

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

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Unique technological solution

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

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Expected impact towards a more sustainable and resilient EU

Reducing EU dependence on primary critical raw materials

Promotion of circular economy processes

Production of TE energy harvesting systems to:

- reduce fossil fuels consumption,
- increase overall efficiency of energy production and consumption systems,
- reduce greenhouse gas emissions

Powder technology in START

START Concept

Transform mining waste into waste heat recovery materials

RECOVERY AND REUSE OF MINE WASTE

Sulphide minerals: tetrahedrite series treated for TE supply chain **(WP2)**

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DFT modelling, powder technology and rapid solidification **(WP3)**

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Technology demonstration in relevant environment **(TRL6)**

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DEVICE

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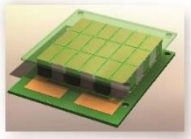

TE device design, simulation, production and characterization **(WP5)**

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

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Powder technology in START

Mechanochemical synthesis, a solid-state synthesis route using high-energy ball mills.
Lab-scale production by LNEG.

Development and production of innovative nanostructured powders, for several applications in powder technology, by a proprietary mechanochemical synthesis process technology (Mechanomade®).

Large-scale production by MBN. Pilot production line and scaled at higher production to meet the market requirement of TE at lower costs.

Material engineering-based company providing unique sintering technologies for a variety of innovative powder materials and applications.

Consolidation of the TE materials by pulse plasma compaction (PPC), a method developed by GeniCore. Sintering efficiency results from hot pressing, in which the powder is heated up using short high current impulses.

Leading company that specializes in TE energy harvesting.

Design and manufacture of TE devices incorporating the mineral-derived tetrahedrite p-type thermoelements.

Nanostructured **powder production** from minerals and pure elements by mechanochemical synthesis

Consolidation by pulse plasma compaction (PPC) to produce the thermoelements

Assembly and production of the TE device

More info at **Stand #167**

Mechanochemical reactor

Courtesy MBN Nanomaterialia S.p.A., Italy

More info at **Stand #207**

Pulse plasma compaction device

Courtesy GeniCore Sp. z o.o, Poland

Flexible ThermoElectric Generator

Courtesy TEGnology ApS, Denmark

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Main Outcomes

Innovative value chain

START project proposes **disruptive technologies for direct use of minerals in thermoelectric renewable energy ecosystems**, based on a "waste material-waste heat to power" methodology.

New market opportunity for European mineral resources

By **converting discarded waste secondary sulphide materials** largely available in Europe into **useful and valuable mineral resource**.

Boost EU competitiveness on raw materials

Recycling will contribute to the **security of supply of raw materials** and will help to improve the sustainability of materials in the EU economy.

Renewable energy ecosystems

START will enable the transition to a greener society and economy through eco-innovation, more sustainable economic models and **by promoting energy security**

New commercial ecosystem

START will create a new rapid growth commercial ecosystem that will attract new stakeholders exploiting market opportunities for replication and market development

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A Horizon Europe project

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