

# START

## SUSTAINABLE ENERGY HARVESTING SYSTEMS BASED ON INNOVATIVE MINE WASTE RECYCLING

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28th February 2023 | 14:30-15:30 CET



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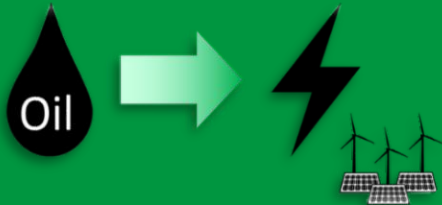
## Motivation



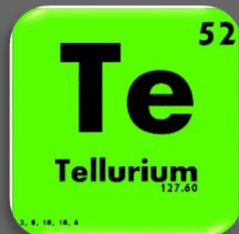
Climate change is one of the greatest challenges faced by humankind

- 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

## Overview of the START project

### 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

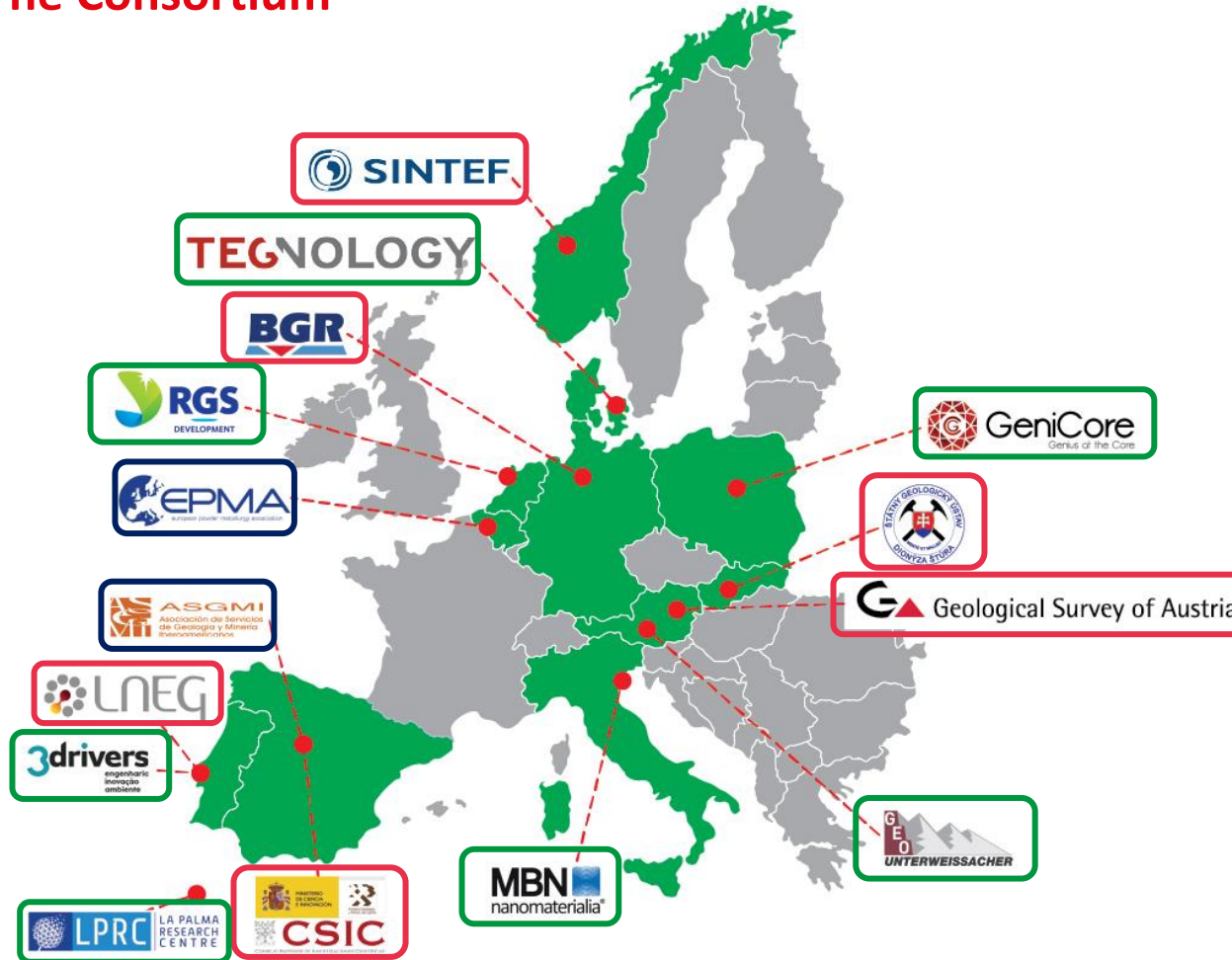
#### Innovation Action

**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.

## Overview of the START project

### The Consortium



- **Coordination**

LNEG, National Laboratory of Energy and Geology

- **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 €

## 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.

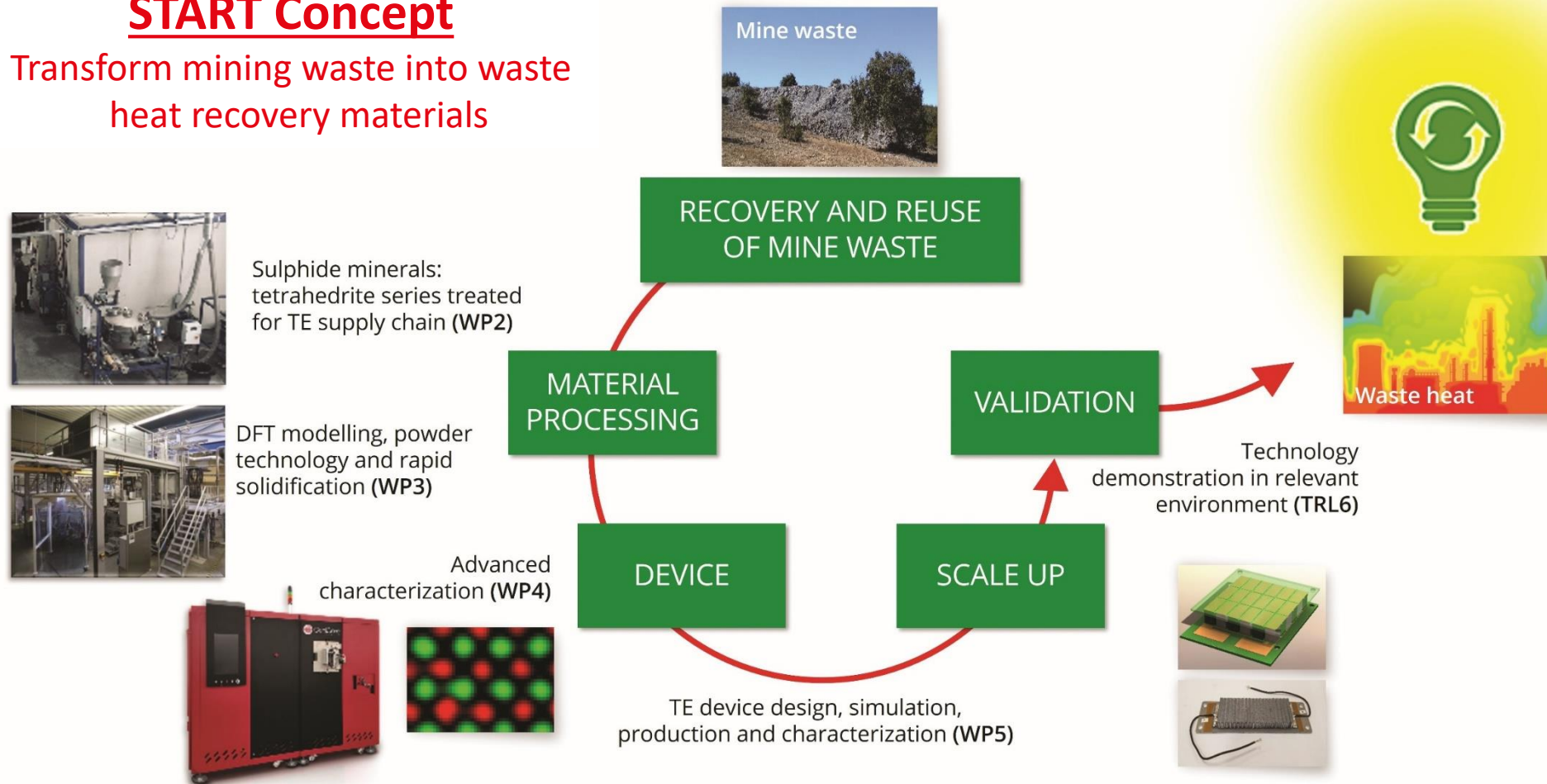
### How to achieve

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).

## Overview of the START project

### START Concept

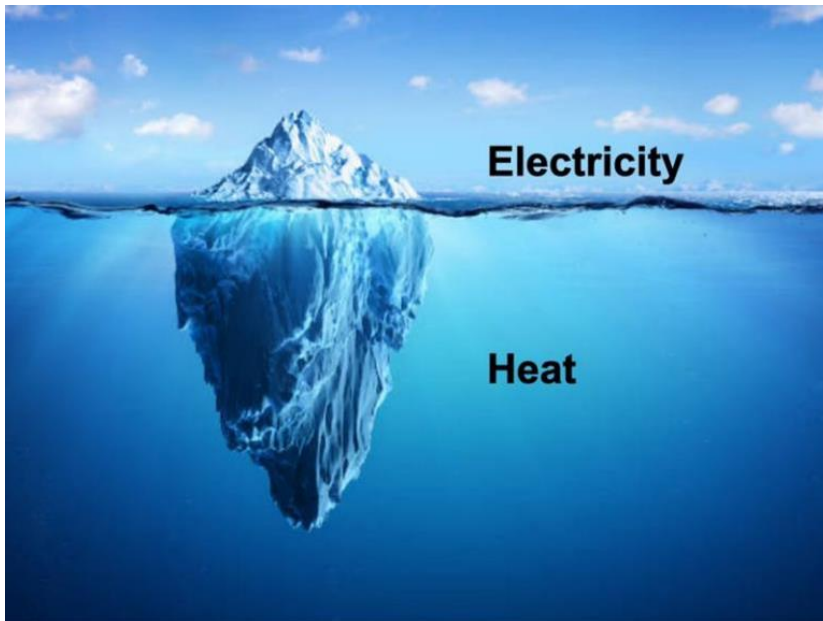
Transform mining waste into waste heat recovery materials



## GREEN ENERGY HARVESTING

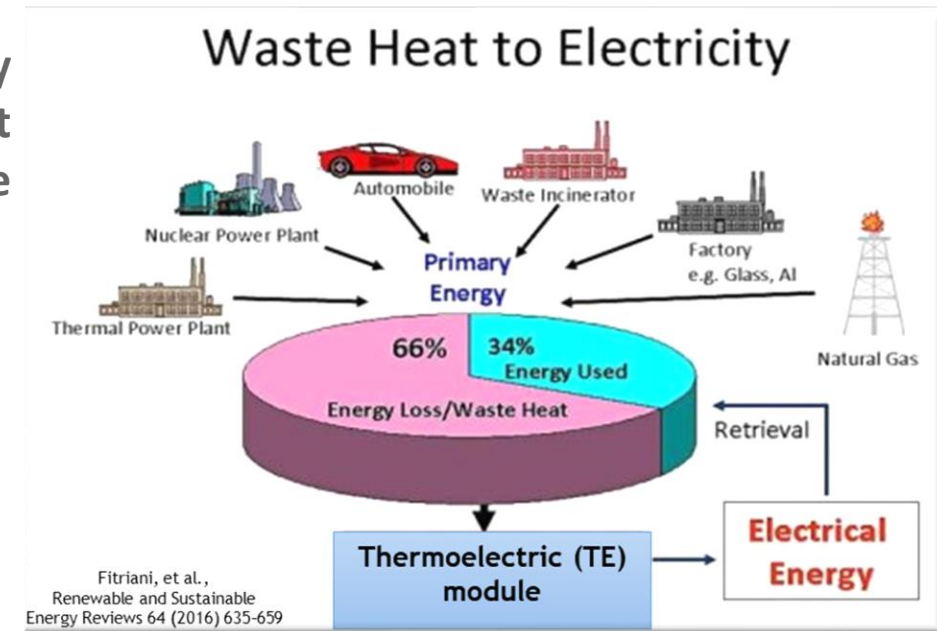
**Green energy harvesting** is the process in which energy is captured from a system's environment and converted into usable electric power (e.g., thermal energy (**thermoelectricity**)).

### Waste heat

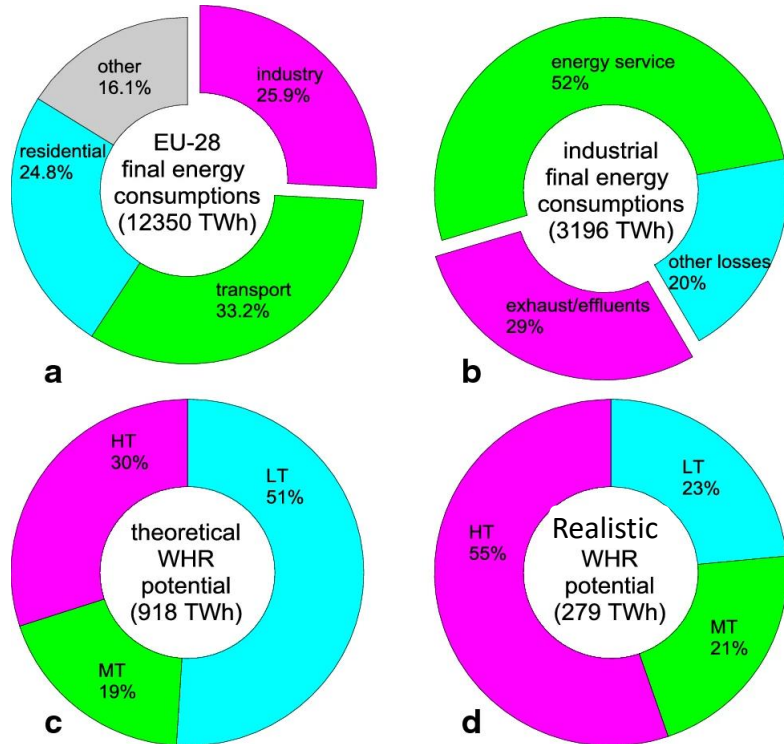


Around two-thirds of the primary energy produced worldwide is lost to the environment as “waste heat”.

The most significant amounts of **waste heat** (unavoidable thermal energy) are generated in industrial and energy generation processes.

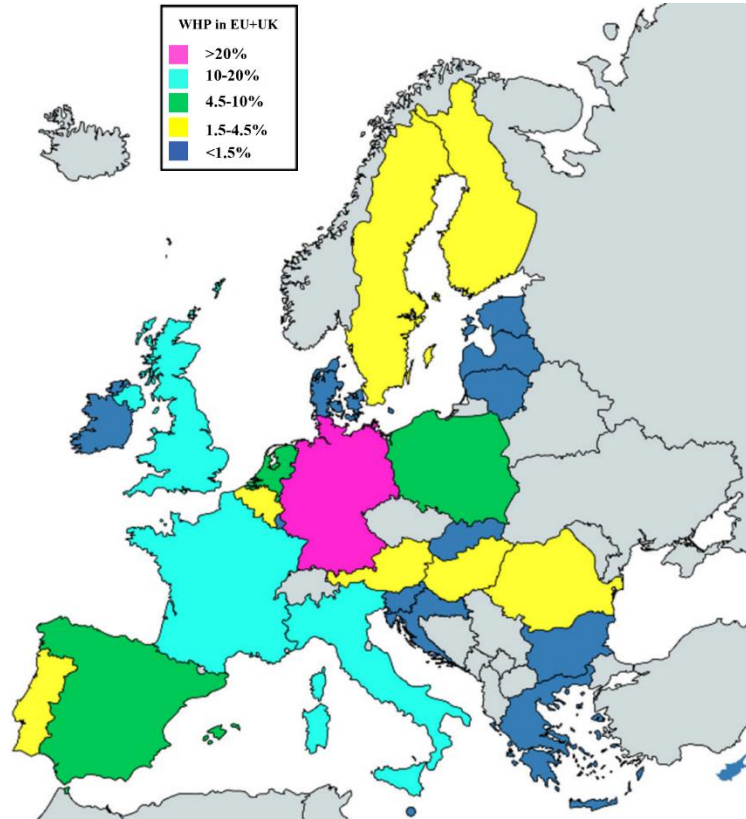


## GREEN ENERGY HARVESTING



Theoretical and realistic WHR potentials in EU industry detailed by **temperature levels**.

Low temperatures (LT): 100 °C  
Medium temperatures (MT): 100-300 °C  
High temperatures (HT): 300 °C



Shares of WHR potential in the EU Industry by member state.

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

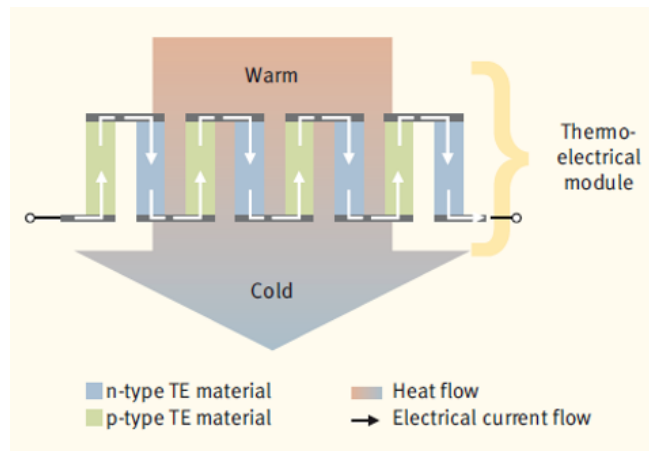
This amount of recoverable heat has the potentiality to avoid tens of millions of tons of CO<sub>2</sub> emissions

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**.

(adapted from Bianchi, et al., Estimating the waste heat recovery in the European Union Industry. *Energ. Ecol. Environ.* 4, 211–221 (2019). <https://doi.org/10.1007/s40974-019-00132-7>)

## 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 the progress of sustainable renewable energy ecosystems

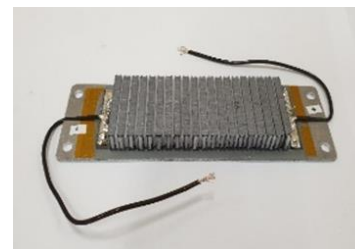


Design and operation of a TE device.  
The heat flow creates an electric current  
(Seebeck effect).

(BINE Themeninfo: Thermoelectrics: power from waste heat  
(1/2016).)

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

# GREEN ENERGY HARVESTING

## MATERIALS PERFORMANCE

$zT$

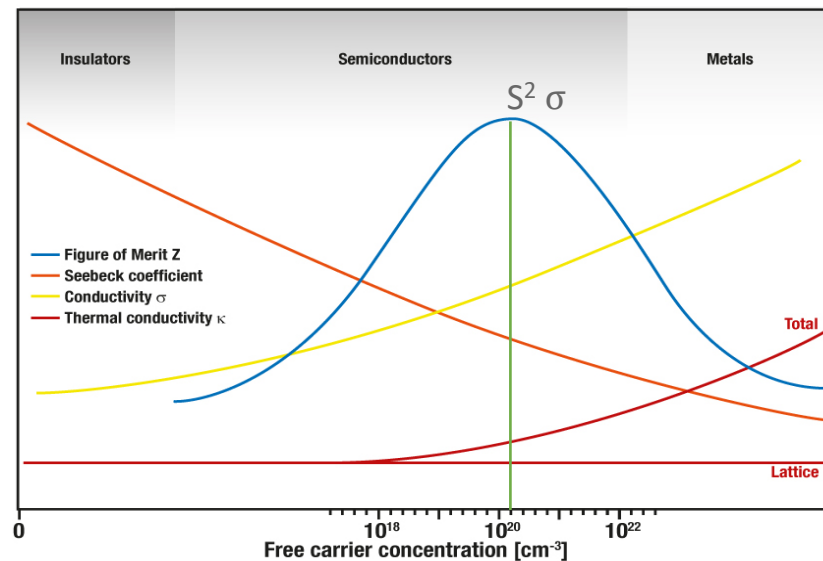
(dimensionless figure of merit)

Power Factor  
PF =  $S^2 \sigma$

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

- S - Seebeck coefficient
- $\sigma$  - electrical conductivity
- $\kappa$  - thermal conductivity
- T - absolute temperature

The goal is to maximize  $zT$

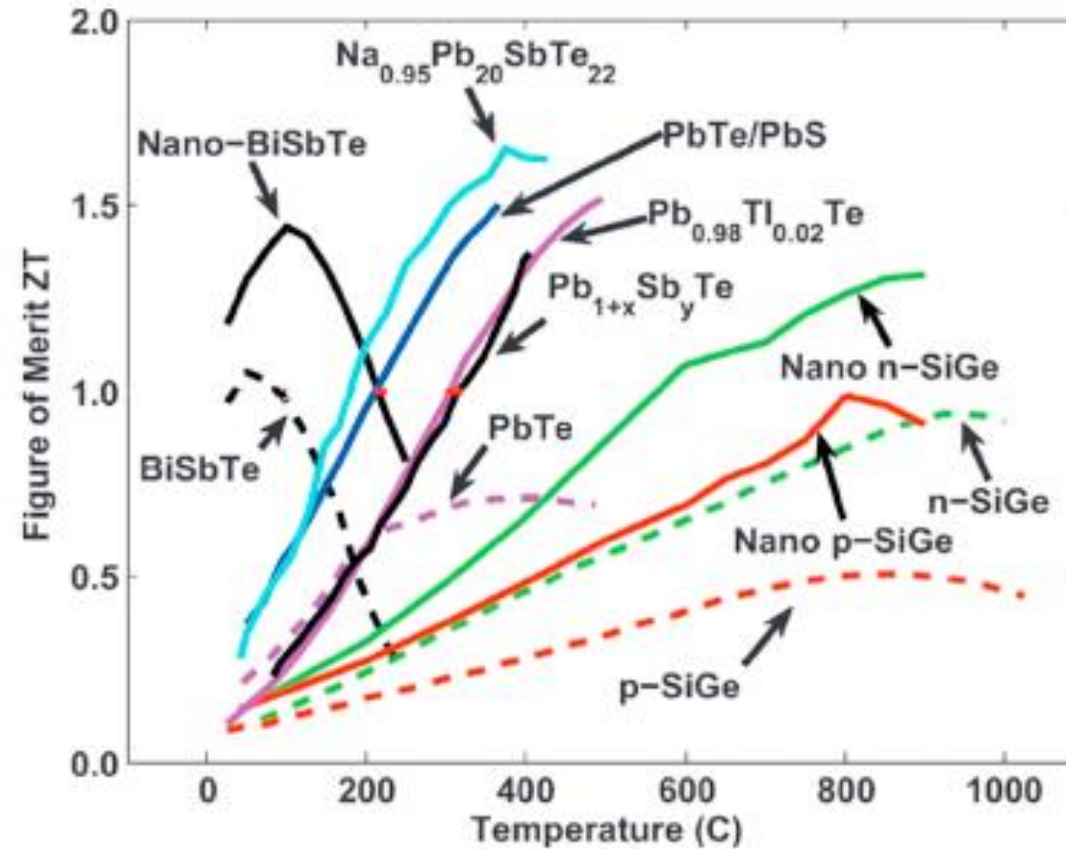


A good TE material should have:

- high  $\sigma$  to minimize Joule heating,
- low  $\kappa$  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.

## 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

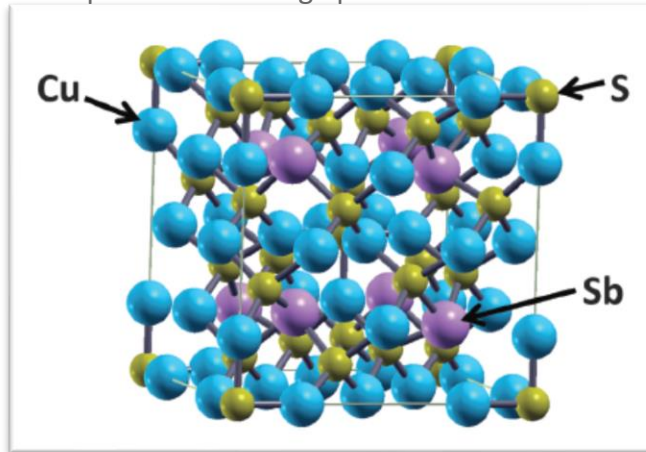
# GREEN ENERGY HARVESTING

Tetrahedrite-based materials have excellent properties for TE applications

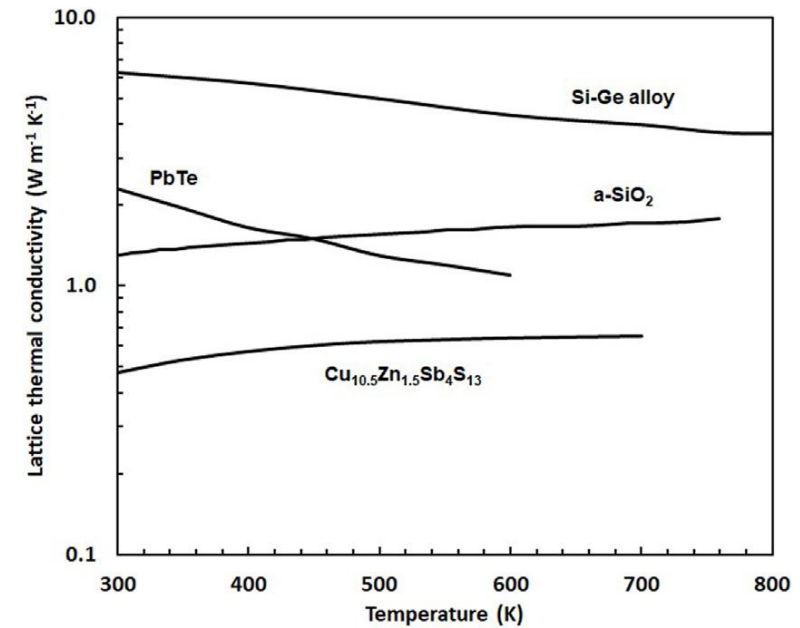


The low thermal conductivity is partially a consequence of the large primitive unit cell volume

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

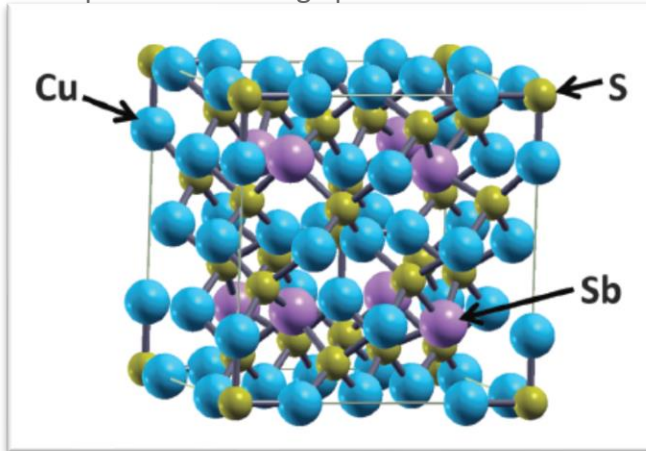
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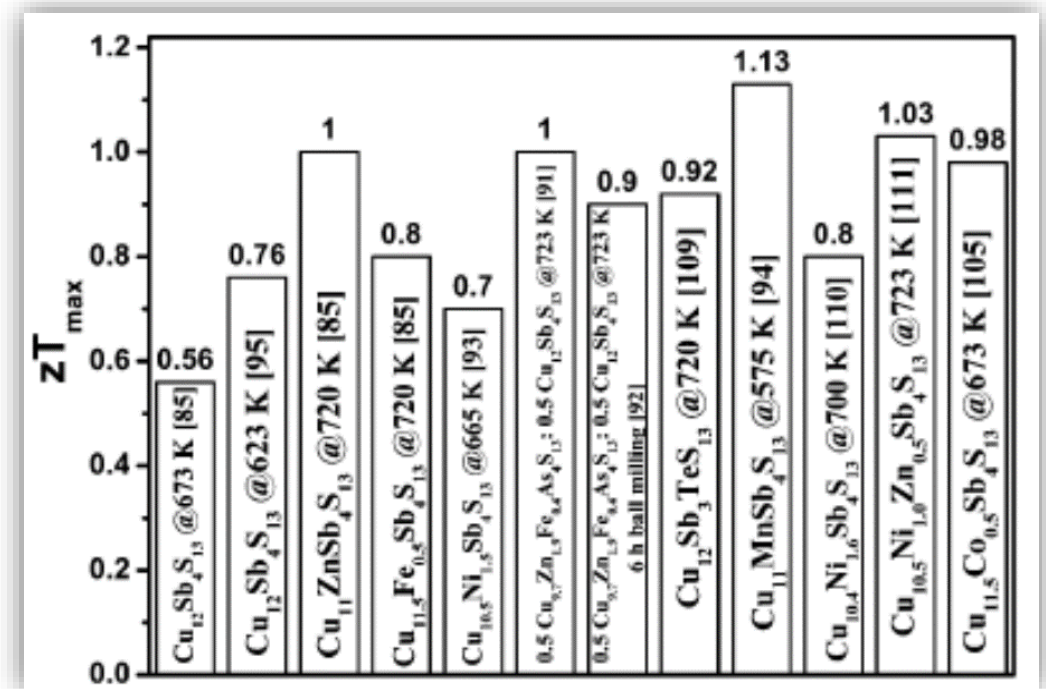


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R. Chetty, A. Bali and R. C. Mallik  
J. Mater. Chem. C, 2015, 3, 12364-12378

## GREEN ENERGY HARVESTING

Characteristics of commercially relevant TE materials and comparison with tetrahedrites

Materials	Bi <sub>2</sub> Te <sub>3</sub>	PbTe	SiGe	Mg <sub>2</sub> Si-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<sub>12</sub>Sb<sub>4</sub>S<sub>13</sub>)** is a copper antimony sulfosalt, and forms a complete solid solution with **Tennantite** in which the antimony (Sb) is replaced by arsenic (Cu<sub>12</sub>(Sb,As)<sub>4</sub>S<sub>13</sub>)

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)



Abandoned Barrigão copper mine in southern Portugal

## 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





## 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

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Reducing EU dependence on primary critical raw materials

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Promotion of circular economy processes

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Production of TE energy harvesting systems to:

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

## 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** 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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Webpage: [www.START-HEproject.com](http://www.START-HEproject.com)



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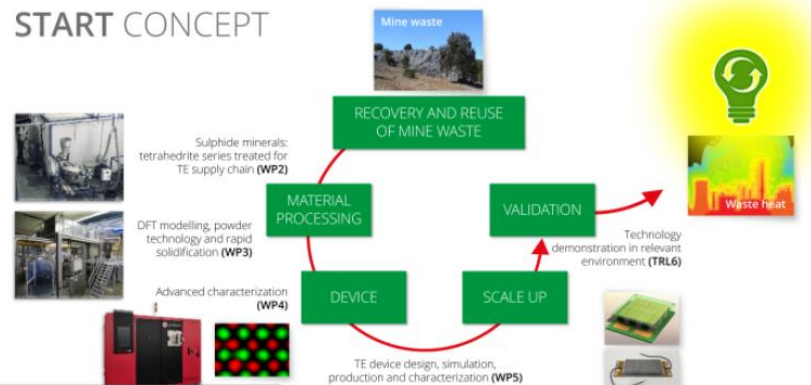
Consortium

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- START PROJECT OBJECTIVE
- HOW TO ACHIEVE
- IMPACT OF START
- START PROJECT ORGANISATION

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## START CONCEPT



**START** Sustainable energy harvesting systems based on innovative mine waste recycling - A Horizon Europe project

The thermoelectric materials will be sustainable, coming from EU-sourced ores and re-mined wastes, reducing dependence outside EU

Co-funded by

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency.

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[https://twitter.com/START\\_HEproject](https://twitter.com/START_HEproject)



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<https://es.slideshare.net/StartProject>



<https://zenodo.org/communities/start-heproject/?page=1&size=20>

### Presentaciones (2)



**Project START: From WASTE to ...**

Hace 3 meses • 8 Visualizaciones



**Presentations at World PM2022**

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### Sustainable energy harvesting systems based on innovative mine waste recycling

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November 10, 2022 (v1) Presentation Open Access View

#### COMO GENERAR ELECTRICIDAD A PARTIR DE ESCOMBRERAS MINERAS

Ester Boixereu Vila, Concepción Fernández Leyva,

This presentation on the START project, in Spanish, was given by Ester Boixereu Vila (IGME-CSIC) on November 10, 2022, at the headquarters of the professional association of Spanish geologists (ICOG), in Madrid, during the 'Semana de la Ciencia y la Innovación' (Science and Innova

Uploaded on December 9, 2022

November 29, 2022 (v1) Other Open Access View

#### RECOVER-REFORM-REUSE - START Newsletter Issue #1

START project,

RECOVER-REFORM-REUSE: a newsletter that is not just a project's diary The first issue of our newsletter is ready! Like many projects, we decided we should have a Newsletter, published on our website and social media, biannually, that means every 6 months, starting from Issue 1 at Month 6 of

Uploaded on December 8, 2022

November 4, 2022 (v1) Presentation Open Access View

#### Presentation of the START project at the 2022 EU-Latin America Convention on Raw Materials

New upload

Community



#### Sustainable energy harvesting systems based on innovative mine waste recycling

This community collects all types of open access publications generated in the **START project**, including publications in journals and conferences, deliverables and newsletters, as well as other published materials. **START**, which stands for **'Sustainable Energy Harvesting Systems Based on Innovative Mine Waste Recycling'** is an innovation action project supported by the European Union and its Horizon Europe programme under grant agreement No. 101058632.

For more information, please visit the **START website** at [START PROJECT - Official Website \(start-heproject.com\)](http://START PROJECT - Official Website (start-heproject.com))

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DOI: 10.5281/zenodo.7377126

BIANNUAL NEWSLETTER OF THE START PROJECT | ISSUE 1



**RECOVER-REFORM-REUSE**  
for a Sustainable Future

‘START CHRONICLES’: with news on the project’s activities;  
‘TECHNICAL PILLS’: short technical documents;  
‘CONSORTIUM TOUR’: meet the START partners.

### STARTY EXPLAINS START



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- Filipe NEVES [filipe.neves@lneg.pt](mailto:filipe.neves@lneg.pt)
- Bruno VICENZI [bv@epma.com](mailto:bv@epma.com)

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# SUSTAINABLE ENERGY HARVESTING SYSTEMS BASED ON INNOVATIVE MINE WASTE RECYCLING

*A Horizon Europe project*

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