Final Report

Project acronym: *MarTEnergy*
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Coordinator:
Prof. Theodora Kyratsi | kyratsi@ucy.ac.cy | University of Cyprus | Cyprus

Project website:
https://www.ucy.ac.cy/martenergyproject/

2. Publishable project summary

The main objective of the MarTEnergy research was to develop a highly efficient half-Heusler (HH) based prototype thermoelectric (TE) converter, covering most of the potential practical applications conditions, including maritime gasoline engines. TE is one of the emerging technologies for effective recovery of waste heat from power plants, factories, motor vehicles, computers or even human bodies and conversion of this into useful electricity. This will contribute greatly to enhancing energy efficiency and reducing global reliance on fossil fuels, reducing greenhouse gas emissions, and promoting sustainable development. Various researchers have developed novel highly efficient TE materials, yielding conversion efficiencies of more than 11%, mainly by using advanced nano-structuring approaches for the reduction of lattice thermal conductivity. Nevertheless, although well-established TE electrical power generation applications are operative since 1950, such applications still involve TE alloys containing scarce (e.g. Te), expensive (e.g. Ge) and environmentally unfriendly (e.g. Pb) raw elements, in addition to having still limited (~6%) efficiencies.-No European commercial TE converters based on affordable and environmentally friendly TE alloys with enhanced efficiencies, approaching the European Strategic Energy Technology Plan goals, were reported up to date. Overcoming the technological 'valley of death' associated with development of such practical TE converters, requires the combined efforts of TE materials development experts and practical conversion devices' designers. Furthermore, in the maritime shipping industry, there is actually a huge loss of wasted heat as well as high level of CO_2 emissions. In such industry, it is critical to integrate new technological knowledge to recover waste energy, increase the energy efficiency, and decrease CO_2 emissions.

Overall, the objectives of the MarTEnergy project were:

- Identification and synthesis of highly efficient HH based TE compositions capable of up-scaling into prototypes and final devices. Development of highly durable, compatible and stable joining techniques between the TE semiconductors and the involved metallic joints.
- Integration of the entire components into practical devices exhibiting the maximal possible device efficiencies.
- Finite element analysis on the HH prototype converter performance prediction in the maritime shipping industry.

The achievements of the MarTEnergy project were:

- Thermoelectric HH materials have been successfully synthesized using various techniques (mechanical alloying, arc melting, flux method). Among these techniques, mechanical alloying was selected as the most advantageous based on practical considerations (i.e. simplicity and scalability) as well as thermoelectric performance. HH compositions were optimized following the all-scale hierarchical structuring strategy. All studies were based on complementary techniques (XRD, SEM/EDX, TEM, electrical and thermal conductivity, Seebeck coefficient etc) aiming to understand the relationship between composition / process / structure / properties of the synthesized materials. Maximum achieved ZTs were 1.1 for p-type and 0.7 for n-type members.
- Prototype module based on HH materials has been developed. Work on the design of the module using finite element analysis, the development of the metallic contacts, setting up the prototype and its characterization were carried out at different steps. The prototype was tested at a hot side temperature of 500ºC and cold side temperature 30ºC and the maximal electrical power and efficiency were 0.545W and 5.7%, respectively. As far as we know, this is the maximal electrical power ever reported per couple for a half-Heulser based thermoelectric converter.
- Simulations regarding the applications in maritime were carried out to explore the potential of converting waste heat from ships to electricity with TEG. End users conditions were set in collaboration with Synergy Group as well as Columbia Shipmanagement. Several cases on different possible positions for the generator have been proposed and studied. The designed generators can give ~670 W for 40 modules at $\Delta T=250^{o}C$. Cost benefit analysis as well as life

cycle analysis were also done to include all aspects of such applications.

Overall, MarTEnergy project combined research at different aspects of thermoelectrics: optimizing materials and methods, design and development of modules and simulations for application in maritime sector. MarTEnergy project showed high performance for HH prepared with simple and scalable method as well as their potential of TE technology on maritime applications. The results were presented in various conferences and published in scientific journals while dissemination activities for the general public and the students were organized.