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► **To cite this version:**

Philippe Poure, Mashiul Huq. Thermoelectric Generator for Waste Energy Recovery in Transport. *Energies*, 2022, 15 (21), pp.8006. 10.3390/en15218006 . hal-03873528

**HAL Id: hal-03873528**

**<https://hal.science/hal-03873528v1>**

Submitted on 26 Nov 2022

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# Thermoelectric Generator for Waste Energy Recovery in Transport

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Waste heat present in exhaust gas produced from various industrial processes or internal combustion engines in transport are a reservoir of untapped energy. If this heat energy is recovered, then the overall efficiency of the system will increase while reducing the fuel demand. This can have major benefits, both technically and economically. The key drawbacks of waste heat recovery units are the high capital cost and the maintenance costs. Research is being carried out on how this waste heat can be recovered in an efficient yet also more cost-effective manner. For this purpose, some very insightful papers have been published utilizing thermoelectric generators (TEGs). The research takes advantage of the longevity and working principle of TEGs. The waste heat would be recovered and converted into electricity, based on the temperature gradient across the TEG. Thus, thanks to the Seebeck Effect, electrical energy would be produced and can be utilized in other processes.

In this Special Issue, some selected papers are highlighted which address various transport sectors and applications such as Heavy-Duty Vehicles (HDV) [1,2], maritime transport [3,4], and even fuel cells [5]. A brief summary of each paper is given below.

The major technological challenge of utilizing TEG systems in HDV are the improvement of the cost-benefit ratio. For example, the reduction of fuel consumption considering the total cost of ownership and quick return on investment. Heber et al. [1] addressed this but focusing on HDV run with natural gas. According to the presented state of the art, critical information is missing and thus, direct optimization of the cost-benefit ratio for TEG suitable commercial vehicles is not feasible. Therefore, their work aims to provide an answer to this question. Thus, the authors of [1] took a holistic approach for the design of the TEG which included the overall system interactions with the vehicle. This was carried out using a multi-criteria TEG simulation environment using ANSYS. Through their efforts, the resulting fuel reduction was 930% higher than that stated in the best state of the art specification.

The primary objective of Sousa et al. [2] was to assess the performance of a thermal control strategy. Understanding the potential of heat extraction from exhaust gases from heavy-duty vehicles (HDV), the authors developed a temperature-controlled thermoelectric generator (TCTG). This was carried out with the aid of simulation using both Engine simulation and CRUISE Driving cycle simulation software parts of AVL Suite from Company AVL List GmbH. The exhaust gas temperature and mass flow rate were found for each point of two driving cycle runs. According to Sousa et al. [2], to maximize the exploitation of the TEG, the operation should take place at a uniform temperature near the temperature limit of the TEG. Therefore, the heat of the exhaust gases was conditioned and evenly distributed using “wavy fin” heat exchangers and variable conductance vapor chambers. The effects and properties of the TEG were simulated using COMSOL Multiphysics. Additionally, Sousa et al. [2] also propose the analysis of electrical generation and thermal power absorption by the heat exchanger as possible evaluation of system performance.

The Ship Energy Efficiency Management Plan (SEEMP) and Energy Efficiency had put into place to motion to improve energy efficiency and reduce the greenhouse emissions



**Citation:** Poure, P.; Huq, M. Thermoelectric Generator for Waste Energy Recovery in Transport. *Energies* **2022**, *15*, 8006. <https://doi.org/10.3390/en15218006>

Received: 26 September 2022

Accepted: 12 October 2022

Published: 28 October 2022

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of maritime transport. Exhaust gases from maritime transport also share potential energy extraction similar to that of HDVs. Uyanık et al. [3] extract this potential with TEGs by identifying potential usage areas. This would ultimately increase the overall efficiency of the ship. This was carried out and analyzed by creating heat maps based on zones with high temperature differences using actual data from the main engine exhaust and jacket cooling water heat exchanger from the ship. The electrical energy and fuel consumption in one year were also used in the analysis. Uyanık et al. [3] concluded that due to the installation of TEGs, fuel consumption reduced by approximately 2%.

Konstantinou et al. [4] focus primarily on the recovery of energy from exhaust gases of marine internal combustion engines. The literature review by the authors have shown success from the utilization of TEGs to extract energy from exhaust gases. The electrical energy generated were used to charge batteries and power LED lights. Therefore, Konstantinou et al. [4] intended to design a TEG system that produced the maximum power possible using the exhaust gases of a maritime internal combustion engine. Konstantinou et al. [4] provide sufficient background regarding the working principle of TEG as well as the sampling methods they utilized such as the finite element method. Next, the most suitable location for the TEG placement ultimately was found to be the manifold of the ship due to its surface structure. The geometry of the TEG was designed using COMSOL and acted as validation for the Finite Element Method (FEM) models. It was found that the geometric parameters of the heatsink greatly affected the power production. The main parameters considered were the number, thickness of the fins and height of the heatsink.

Finally, approximately half the hydrogen used in a Proton Exchange Membrane Fuel Cell (PEMFC) is converted to heat and must be expelled to maintain the optimal temperature range. Pourrahmani et al. [5] implemented an agglomerate model to represent the fuel cell as it provided an improved representation of the catalyst layer. The main novelty of the study was to examine the performance of TEGs for recovery of waste heat from the PEMFC coolant channels using liquid cooling. The waste heat was calculated by a modeling approach. The recovery performance and corresponding distribution of temperature along the TEG heat exchangers were simulated and then discussed. The limitations and the assumptions regarding the heat flux were also mentioned. The equations used to model the components on the fuel cell were well defined and described in detail. Pourrahmani et al. [5] included a flowchart describing the simulation procedure to perform the Computational Fluid Dynamic (CFD) analysis for the TEG unit. Pourrahmani et al. [5] emphasized the uncoupled manner of CFD simulations and TEG calculations. The constructed models were validated against other published work. Pourrahmani et al. [5] concluded that there is still a large scope for improvement as the optimized geometry for the application is still lacking.

**Author Contributions:** Writing—original draft preparation, P.P. and M.H.; writing—review and editing, P.P. and M.H. All authors have read and agreed to the published version of the manuscript.

**Funding:** The authors acknowledge that this work has been supported by the ANR (project HYDRES, ANR-21-CE50-0003).

**Conflicts of Interest:** The authors declare no conflict of interest.

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