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Maximizing Energy Efficiency: Harnessing Thermoelectric Power from Car Exhaust for Battery Recharge

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Abstract

This research project explores the area of sustainable energy by exploring new ways of using waste heat to generate electricity. The focus is on using thermoelectric generator (TEGs) to capture the heat energy in the vehicle exhaust and convert it into electricity, which is stored in batteries. This approach incorporates information from an extensive literature review and uses previous findings to inform the design and manufacture of exhaust TEG systems. An important part of this research is to understand the relationship between the voltage generated by the TEG module and its distance from the heat source, which is car exhaust. This project investigates the output voltage change under different conditions, which provides valuable insight into the optimal TEG layout for better energy harvesting. In addition, the study examines exhaust gas temperatures from gasoline and diesel vehicles, showing the thermal characteristics of different types of engines. Tests for this purpose include the careful configuration of the TEG system, including components such as heat sinks, cooling blocks, and lithium batteries for energy storage. This study evaluates the time required for a lithium battery to charge to a certain level, which is relevant to the efficiency of energy storage systems. These results not only provide a better understanding of TEG applications but also provide insight into developing efficient and sustainable energy solutions. An important finding is that the closer the TEG is to the exhaust of the car, the higher the voltage it produces. Knowing this will help us design the best TEG system for each type of vehicle. Finally, we learned how long it takes to charge a lithium battery using the energy generated by the TEG. This will help us improve energy storage systems to achieve sustainable energy solutions. These findings will help us make better use of waste heat from the car exhaust to produce electricity.

1. Introduction

In today's energy use landscape, it is important to recognize different forms of energy, including chemical, electrical, mechanical, and thermal energy [1]. As energy experts emphasize, energy cannot be destroyed, it is transformed. Most of the energy is necessarily converted into thermal energy or heat. The generation of thermal energy involves various mechanisms such as convection, radiation, and conduction. In particular, our environment has many sources that generate heat, such as car engines and generators [1]. Unfortunately, a significant portion of this heat is often disposed of as waste and released into the atmosphere, creating a huge reservoir of untapped energy potential. According to the U.S. government's Advanced Research Projects Agency on Energy (ARPA-E), approximately 70% of all energy produced by humans is released as waste heat, highlighting the widespread reach of this largely overlooked energy resource [2].

Against this background, our project seeks to exploit the untapped potential of waste heat, especially from automotive exhaust, using thermoelectric generators (TEGs) [4]. A TEG, also known as a Seebeck generator, is a solid-state device that directly converts temperature differences into electrical energy based on the Seebeck effect. In contrast to traditional heat exhaust, TEGs are characterized by a compact design and no moving parts. The aim of this project is to delve into the intricacies of this technology, focusing on the efficiency of TEGs in converting waste heat from car exhaust into usable electrical energy [4]. By investigating various forms of waste heat, including industrial waste heat, and recognizing the significant portion of the world's energy emitted in this form, our project aims to transform waste heat into a valuable and sustainable energy source of the future. It is consistent with a broader vision of reuse as a resource use [3].

In order to achieve the goals, set in the project, our research spans several aspects [5]. From identifying suitable heat sources in vehicle exhaust systems and industrial processes to strategically placing TEG modules, the project encompasses a holistic approach to optimizing power generation. In addition, the project includes advanced measurement equipment such as an infrared thermometer and a multimeter to accurately record temperature fluctuations in the exhaust system and the voltage output of his TEG [5]. Additionally, the project includes the development and evaluation of a prototype that connects the TEG to a battery storage system [5]. This practical dimension aims to verify the feasibility and practical applicability of thermoelectric thermal energy harvesters. By combining theoretical insights and practical experiments, our project contributes to the ongoing dialogue about sustainable energy solutions and explores the potential of waste heat utilization for a more energy-efficient future [5].

There is so much waste of heat energy around us that is not used. It is because there are no ways, or people do not know how to use the heat energy except to cook or create pressure in a steam generator. Due to excessive waste of heat energy, global warming and the limitations of energy resources have become a great concern in recent decades. The scope of this invisible waste is vast which is approximately 70% of all energy produced by humanity is emitted as waste heat [2]. Heat is generated every time an engine revs, a machine rattles, or any work is performed. This is a law of thermodynamics. In most cases, this heat is released and drips into the atmosphere. Thus, a thermoelectric generator is used in this project to study the conversion of heat energy to electrical energy. The important thing is to determine the optimum temperature for a thermoelectric generator in order to produce electrical energy. The car produces thermal energy and most of the heat energy will just lost as waste heat. Different car can produce different amount of waste heat depending on the amount of fuel combustion process and mostly the heat is released by exhaust. In this project will discuss optimal temperature and the effect of the temperature drop on the car exhaust to the electric produce by thermoelectric generators.

2. Methodology

This part discusses the process of how the project is being constructed from the beginning until the end. There are a flowchart and a block diagram. Those will show clearly the steps and the flow of work. There is also the type of insulator selection data analysis that will be used in this project.

2.1 Flowchart of the experimental procedure for automotive exhaust TEG

Fig. 1 displays the flowchart of experimental procedure for this project, which involves mounting a module, applying thermal paste, attaching the module to the exhaust, and applying a heat source. The thermoelectric generator module is connected to a dc-dc boost converter, increasing the voltage output and setting the desired output.

2.2 Modelling of module test

In order to examine the module test, the thermal and electrical contact resistances need to be considered. Since the module consists of many numbers of thermocouples, the design should be planned to ensure the size and it can fit on the designable exhaust and the design as shown in Fig. 2. By modelling the module, the thermoelectric can be utilize to the optimum in producing the electrical energy supply. With careful of modelling it can avoid unwanted damage due to thermoelectric module is a sensitive component.

2.3 Block Diagram

The project design uses a full block diagram as shown in Fig. 3 to describe the heat source configuration. The heat source flows through the exhaust, transferring to a thermoelectric module via a heatsink. Thermal paste is filled to improve efficiency. A radiator cooling block is activated to support high exhaust temperatures. A voltage is produced, supplied to a TP4056, connected to a battery and DC-DC boost converter, and then to a USB port power bank module.

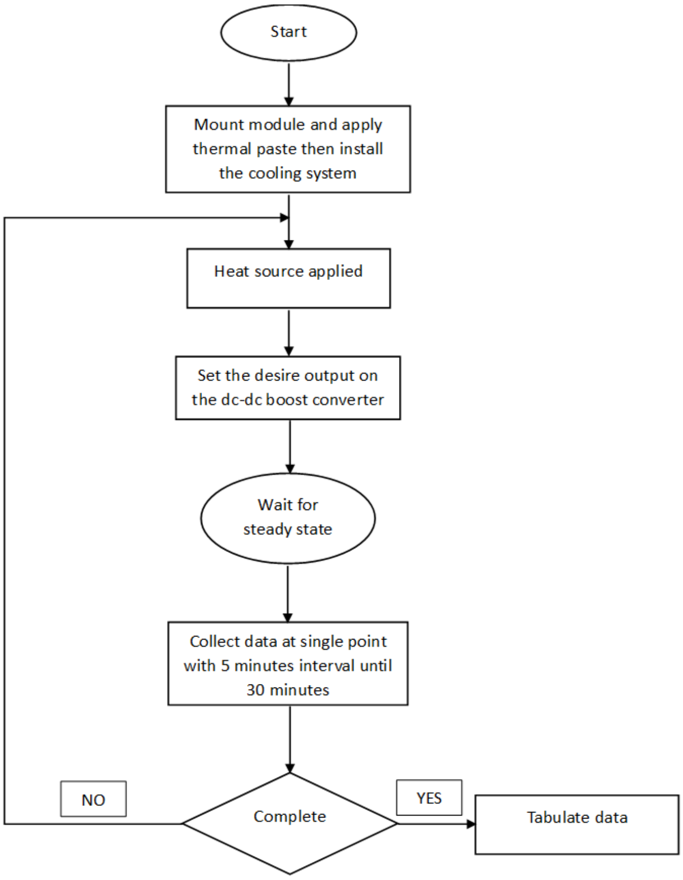

Fig. 1 *Flowchart of experimental procedure*

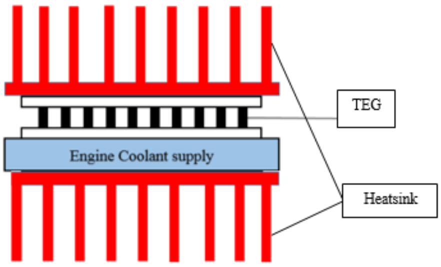

Fig. 2 *Model of module test for thermoelectric generator*

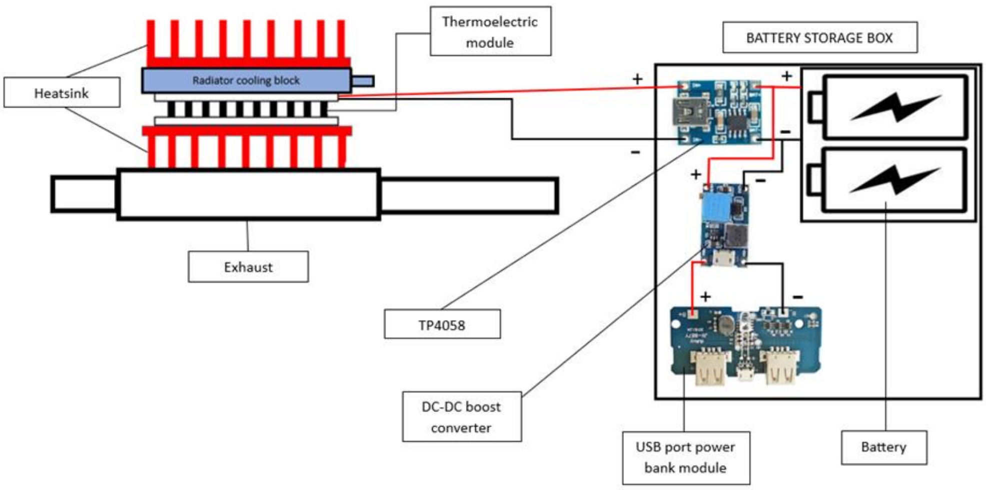

Fig. 3 *Block diagram of project*

2.4 Thermoelectric series connected

Thermoelectric generator (TEG) modules are often connected in series for various reasons, including improving electrical and thermal performance. This allows for higher voltage levels, better alignment, and uniform heat distribution. It also aids in optimizing load matching, particularly when load impedance is known. This leads to increased system efficiency, especially in applications requiring energy harvesting from waste heat. However, the optimal configuration depends on specific application requirements, thermal management, and load characteristics. Careful design is necessary to achieve desired performance and efficiency in thermoelectric energy harvesting setups.

2.5 Voltage TEG recorded with distance from heat source

The methodology of this study follows a systematic approach of recording the voltage produced by each thermoelectric generator (TEG) in relation to its distance from the heat source. The experiment involves setting up a controlled environment in which multiple TEG modules are strategically placed at different distances from a heat source, such as a car exhaust. Next, use a multimeter to record accurate measurements of the voltage output of each TEG. The experiments are performed under steady-state conditions to ensure uniform heat flow and temperature differences. Factors that influence the voltage value are carefully considered, such as the type of thermoelectric material used in the TEG and the specific structural design of the generator. This methodology aims to systematically evaluate the effect of distance on voltage generation and provide valuable insights into the optimal placement of TEG modules for efficient energy harvesting. The results obtained from this experiment will contribute to the overall understanding of TEG system performance and help refine strategies to maximize power generation from waste heat.

2.6 Time taken to charge the lithium battery

In this project, a lithium battery serves as the storage unit for the electrical power generated by the Thermoelectric Generator (TEG) module. To gauge the practicality and efficiency of the energy storage system, the project includes an assessment of the time required to charge the lithium battery fully. This time measurement becomes instrumental in understanding the rate at which the TEG system can replenish the battery's power reserves. The stored energy in the lithium battery, once charged, can be subsequently harnessed to power low-voltage components, contributing to the project's overall aim of optimizing energy utilization and promoting sustainable energy practices. The time taken to charge the battery serves as a crucial metric in evaluating the system's performance and its potential applications in providing reliable and accessible power sources. The battery level indicator is used to find out how much power can be stored in the batteries.

3. Result and Discussion

This section will explain about the findings obtained by implementing the methodologies mentioned in the previous chapter. The hardware setup for the test is shown in the Fig. 4 on how the result is collected. Then the results obtained by collecting the temperature data and the amount of voltage and current produced will be attached bellow.

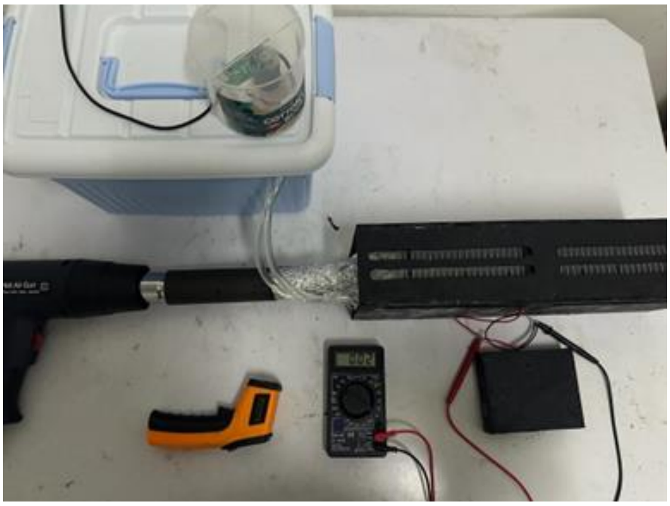

Fig. 4 *Hardware setup*

3.1 Exhaust temperature taken from petrol and diesel vehicles

The exhaust temperature from car model a crucial role in the efficiency of a thermoelectric generator (TEG) system. Understanding these temperatures is vital for optimizing the TEG's performance. In this research, exhaust temperatures from both petrol and diesel vehicles are measured using an infrared thermometer. It is important to find out what optimum temperature can be achieved at the car exhaust. These measurements are essential for assessing the feasibility of waste heat recovery, as they provide valuable insights into the thermal energy available for conversion into electricity. The data obtained will contribute to the overall understanding of the diverse heat profiles in different vehicle types and guide the design considerations for TEG systems, ensuring they are tailored to the specific characteristics of petrol and diesel exhaust temperatures. The data taken is shown in Table 1 and plotted in Fig. 5.

Table 1 *Exhaust temperature each type of vehicles with time*

	Temperature of gas flow (°C)		Temperature of exhaust surface (°C)	
Times (minutes)	Petrol vehicle (Perodua viva)	Diesel vehicle (Toyota Hilux	Petrol vehicle (Perodua viva)	Diesel vehicle (Toyota Hilux)
0	32.3	35.4	32.6	34.5
3	37.4	44.9	48.8	41.7
6	44.8	51.8	50.4	47.7
9	48.6	55.6	53.8	48.4
12	51.0	57.8	54.8	50.6
15	50.3	60.9	53.7	52.7
18	50.0	62.3	53.4	54.6
21	51.0	61.3	53.7	52.8

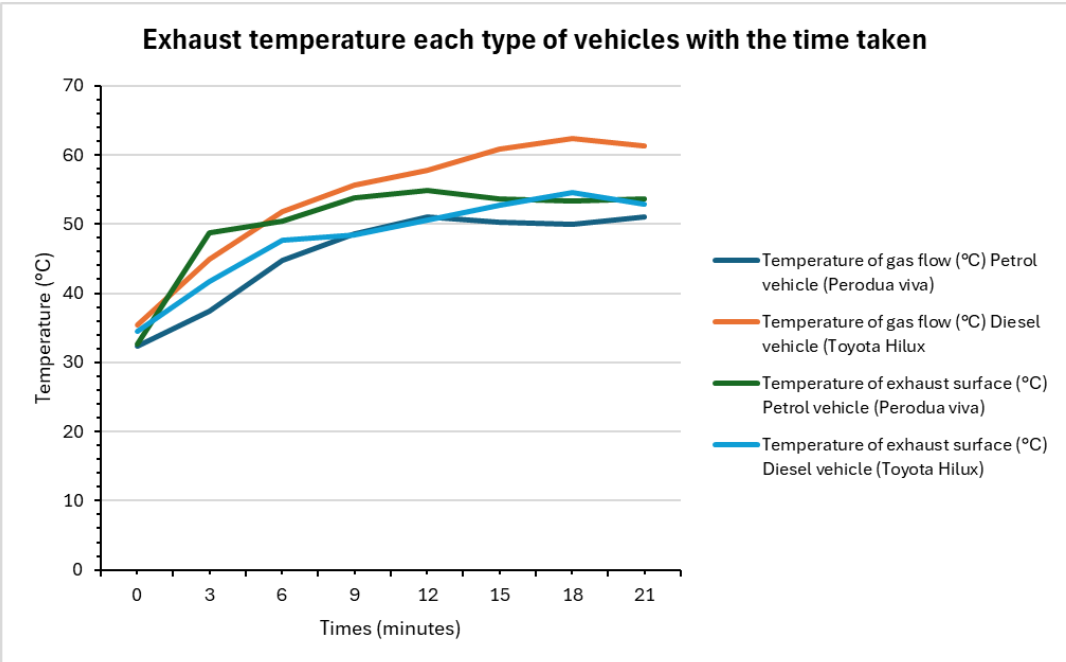

Fig. 5 *Graph for exhaust temperature for each type of vehicles*

3.2 Thermoelectric generator module testing

The data of thermoelectric generator module is measured by using infrared thermometer and multimeter to find the temperature reading and the value of current and voltage that produce by thermoelectric generator with the time taken for the reading is taken by 3 minutes interval until 21 minutes. The reading of voltage and time is taken before the output from thermoelectric generator module is connected to TP 4056. The data is shown in the Table 2 and plotted in Fig. 6.

Table 2 *Temperature with the voltage and time*

Time (minutes)	Voltage (V)	Temperature of gas flow (°C)	Temperature of exhaust surface (°C)
0	0	21.1	21.2
2	3.21	87.3	57.6
4	3.97	87.5	69.9
6	4.00	89.8	74.2
8	4.25	91.7	78.6
10	4.78	100.7	81.9
12	5.09	106.6	85.4
14	5.50	105.9	94.6

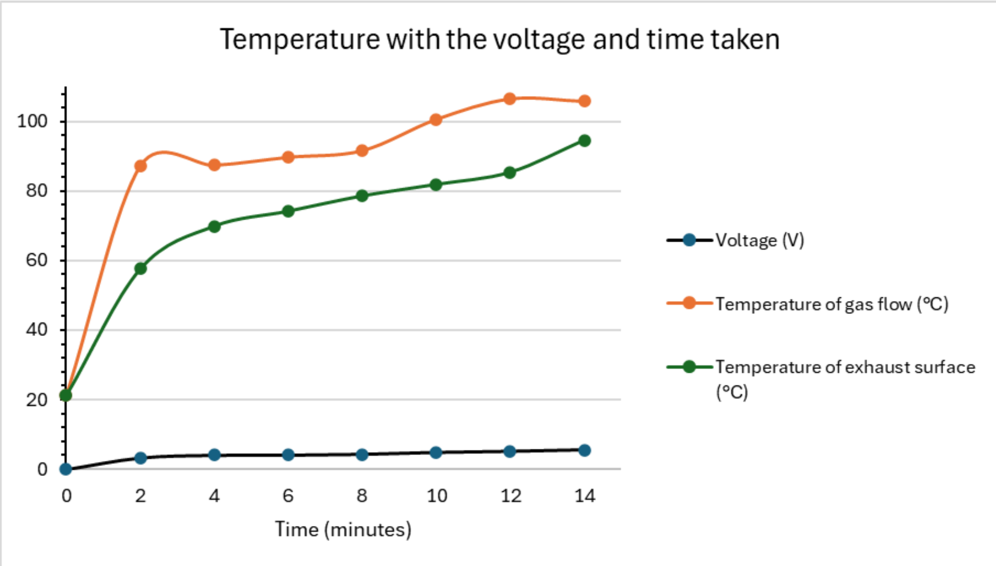

Fig. 6 *Graph for temperature of gas flow and exhaust surface*

3.3 Effect of distance and voltage drop

The effect of voltage drop with distance from the heat source is an important aspect investigated in research. Thermoelectric generators (TEGs) are strategically placed at varying distances from a heat source, such as a vehicle's exhaust, so that their voltage output is systematically recorded. This experiment allows us to investigate how the distance between the TEG and the heat source affects the voltage generated. The results provide insight into the optimal placement of TEG modules for effective energy harvesting, considering factors such as temperature gradients and thermal distribution. These results contribute to understanding the relationship between distance and voltage drop, which is important for the development of TEG systems that efficiently utilize waste heat for power generation. During the measurement is taken there are a few parameters that be set which is the engine is heat up until 5 minutes and at the temperature 52.4°C and the measurement of voltage and the distance is shown in the Table 3.

Table 3 *Distance from heat source and voltage produced*

Distance (cm)	80	84	88	92	96	96
Voltage (V)	1.34	1.21	1.15	1.06	1.03	0.98

3.4 Battery storage

Battery charging status is visually displayed through a clear and intuitive display system. Charging progress is displayed as a series of bars, each bar corresponding to a specific battery percentage. Once charging begins, the border lights up red to give you an early warning when the battery level drops below 25%. The first bar will be lit at 20%, followed by his second and his third bar will be lit at 50% and 75% respectively. Finally, when the battery is fully charged to 100%, the fourth bar will light up, completing the visual display. This display not only provides real-time feedback on charging status, but also ensures user-friendly interaction by conveying information in a simple and easy-to-understand visual format. Table 4 shows the findings on how long it takes for the TEG to charge the battery, time is measured in minutes.

Table 4 *Battery level with time taken to charge*

Battery level (%)	<25	25	50	75	100
Time taken (min)	0	8	17	28	43

4. Discussion and implication of research

The study results have several implications for both sustainable energy and automotive technology. First, understanding how thermoelectric generator (TEG) placement affects voltage generation provides practical guidance for designing more efficient energy harvesting systems. By strategically placing TEG modules closer to the vehicle's exhaust, engineers can optimize energy capture, improve overall system performance, and increase power generation efficiency. Second, the analysis of exhaust gas temperatures from gasoline and diesel vehicles emphasizes the importance of adapting the TEG system to specific engine types. This information allows the development of optimized TEG configurations for different vehicles, improving energy harvesting efficiency and ensuring compatibility between different automotive platforms. Third, evaluating lithium battery charging times provides valuable insights into the optimization of energy storage systems integrated into TEG configurations. This knowledge facilitates the creation of more efficient and reliable energy storage solutions needed to ensure uninterrupted power supply and enhance system sustainability. In addition, the research results also provide practical guidelines for implementing TEG technology in the automobile industry to exploit waste heat from vehicle exhaust. By demonstrating the feasibility and effectiveness of the TEG system in converting exhaust heat into electricity, this study supports the adoption of sustainable energy solutions in automotive design and manufacturing. Ultimately, by using waste heat from automobile exhaust to generate electricity, TEG technology has the potential to reduce greenhouse gas emissions and minimize environmental pollution associated with traditional energy production methods, thereby promoting environmental sustainability. Overall, this study advances our understanding of thermoelectricity generation from automobile exhaust and provides practical implications for the design of efficient and sustainable energy solutions in industry automobiles, promoting innovation and contributing to environmental conservation efforts.

5. Conclusion

This current project was focused on how to harvest the electrical supply from automotive exhaust thermoelectric generators (AETEG). In this work, the model was designed to optimize the heat transfer to the AETEG due to the thermoelectric module are sensitive component with the experiment validation. It because too high temperature can lead to damaging the thermoelectric module while too low temperature the electrical output cannot be produce. The first part in this project is to identify the heat source on the vehicles which is the exhaust the temperature is taken. With the temperature can be led too high the design was adjusted to which is the heatsink is installed instead of installed directly on the exhaust surface. The number of thermoelectric peltier also is add up to produce higher output needed. In another matter the cooling block is installed to allow the excessive heat can be discharged thus can create temperature difference on the thermoelectric module so it can generate the electricity. The model was used in order to validate the model that was designed. Hence, the voltage and current is investigated with the difference of temperature. After that, the temperature of petrol and diesel vehicle exhaust is recorded in order to analyse the optimum temperature can be used efficiently with thermoelectric generator. Hence, it can conclude that the thermoelectric generator can be alternative electrical source on the vehicle and it can be stored for later use in the battery.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors attest to having sole responsibility for the following: planning and designing the study, data collection, analysis and interpretation of the outcomes, and paper writing.

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