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Thermoelectric Generation: Utilizing the Thermoelectric Effects to Increase Engine Efficiencies and Reduce Harmful Emissions to the Environment

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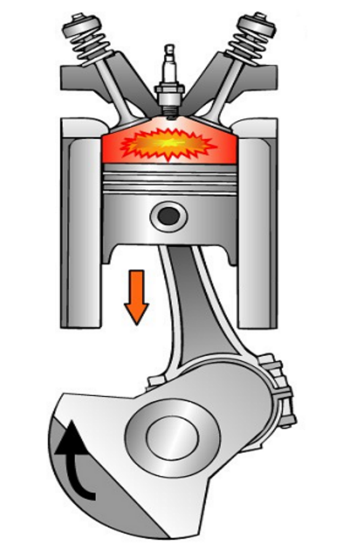

Abstract/Introduction

- Transportation accounts for 27% of total Greenhouse emissions (see Figure 2); 31% of total CO_2 emissions and 5% of N_2O emissions. These gases, along with other greenhouse gases, contribute to climate change and have other harmful effects on the environment, including the production of acid rain. Engineers look for ways to cut back these emissions, and create more sustainable practices. Through use of a thermoelectric generator, fuel consumption and greenhouse emissions can be reduced by roughly 5-10%.
- The thermoelectric effect explains how a temperature difference across two junctions of dissimilar semiconductors can generate electricity or vice versa. This generated power can operate electrical devices and reduce the load on the engine, saving fuel and cutting back emissions. A thermoelectric module can be seen in Figure 1.
- In an internal combustion engine, upwards of 60% of energy produced is lost as heat. Through the Seebeck effect, as temperature difference increases, voltage produced also increases. At higher engine speeds, exhaust becomes hotter and more power can be generated, but this technology is still viable for low speeds.

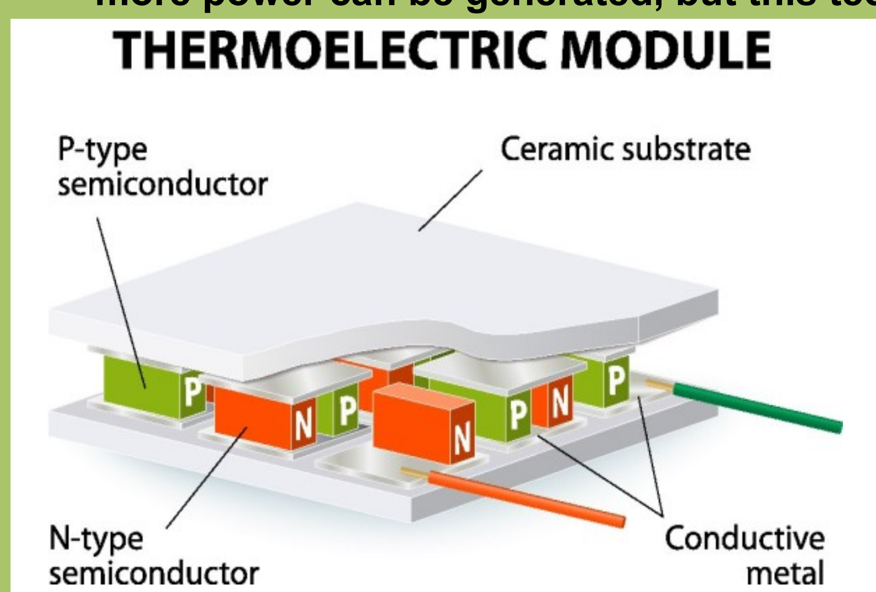

FIGURE 1: Thermoelectric Module

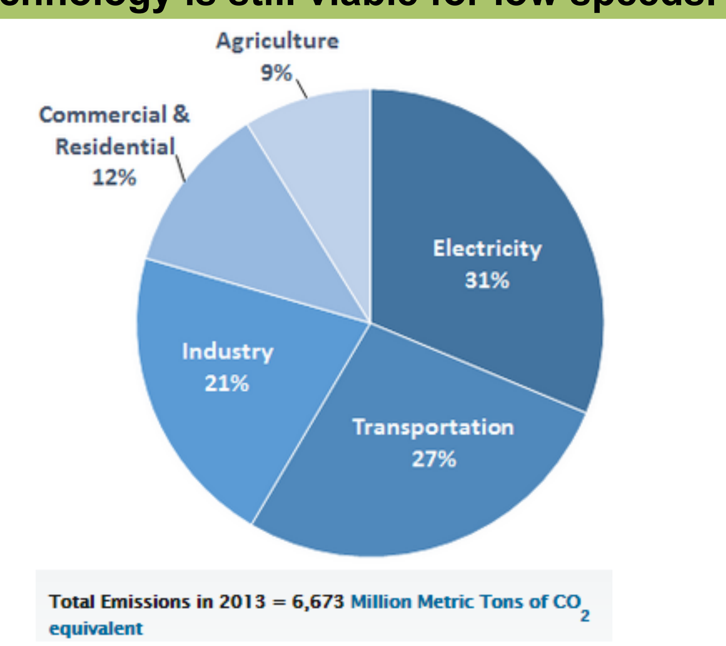

FIGURE 2: Total U.S. Greenhouse Gas Emissions in 2013

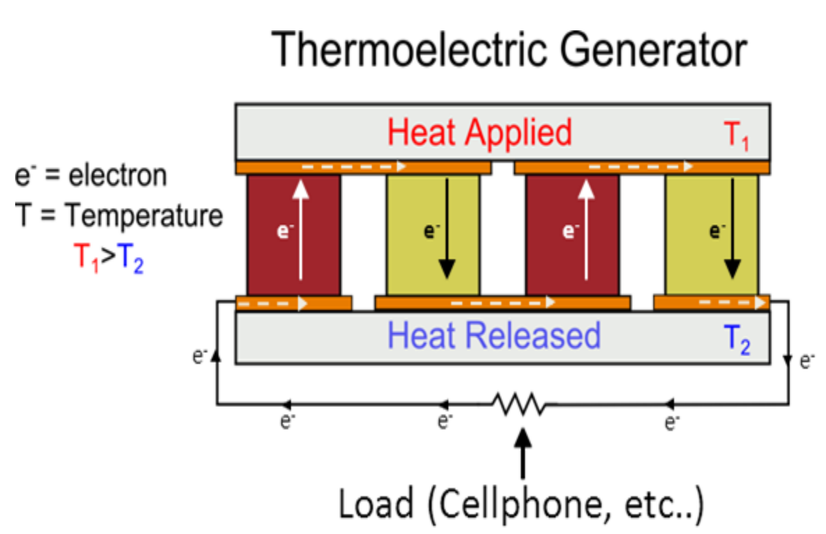

FIGURE 3: Schematic of a thermoelectric generator

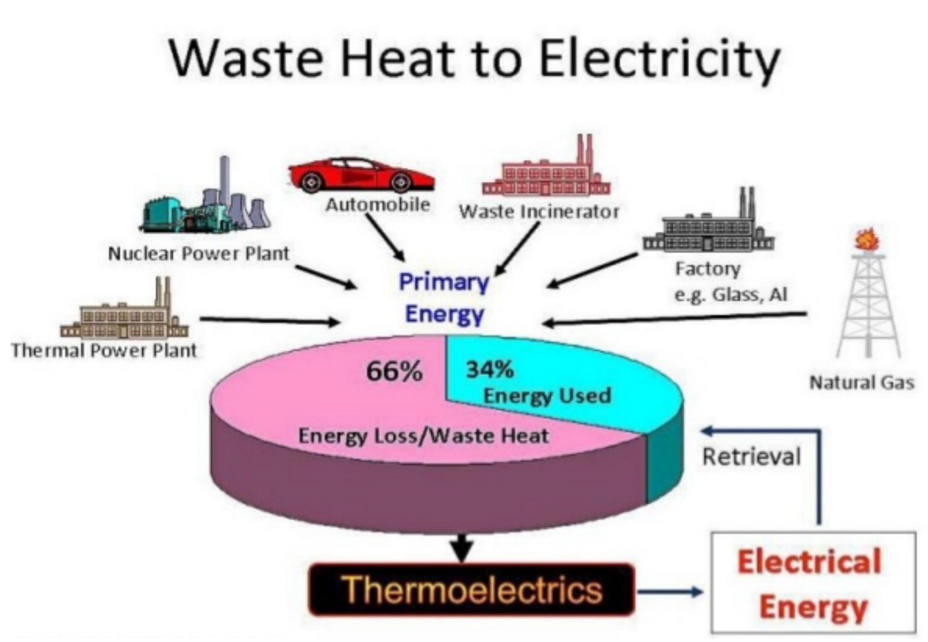

Figure 4: Industrial Potential for Thermoelectricity

Literature Review

The thermoelectric effect consists of three related components: The Seebeck, Peltier, and Thomson effects. The Seebeck effect operates with thermoelectric materials that have negatively and positively charged semiconductors that when heated, transfer the electrons from one side to the other, producing a current. The Peltier effect is inversely related to the Seebeck effect. The Thomson effect describes the heating or cooling of a current-carrying conductor with a temperature gradient. These effects allow waste heat to be converted to electrical power without moving parts.

Several companies and prominent research institutions have looked into this technology to convert waste heat into useable electric power. Some companies include BMW and General Motors (GM). Results can be seen in Table 3 and 4. The results prove that utilization of this technology reduces emissions and increases fuel economy of vehicles, generators, etc.

Experimental Setup

In order to better determine how well thermoelectric modules can assist in protecting the environment, an experiment was designed to test the efficiencies and outputs of a thermoelectric module. A schematic of the experiment can be seen in Figure 5.

The experiment consists of an electric heater, powered by a DC power supply, used to heat one side of the thermoelectric module (TEM). A heat sink is used to dissipate the heat on the other side of the TEM to keep it relatively cool. The heater and heat sink are attached with double sided thermal tape. The temperatures on each side are measured using thermocouples. The lead wires of the TEM power a small fan with the electricity produced from the temperature difference. A National Instruments Data Acquisition (DAQ) module is used to measure the temperatures and the electrical outputs of the TEM. I chose this setup due to the ability to interchange TEMs easily, as well as being able to achieve real time values through use of LabView. Results I experimentally obtained can be seen in Table 2.

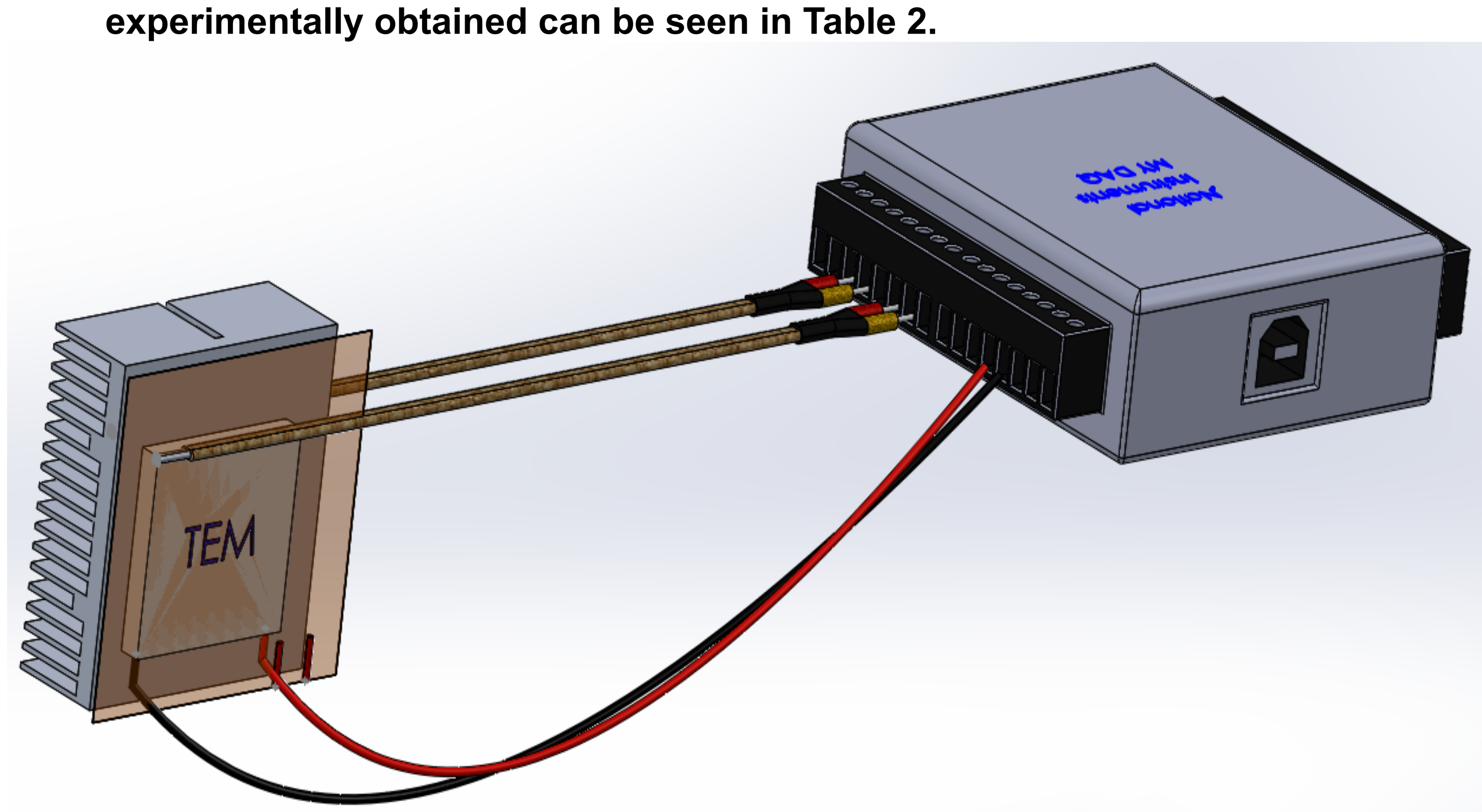

FIGURE 5: Schematic of Experiment in Solidworks

The National Instruments DAQ system will be setup accordingly to read the voltage and current outputs of the thermoelectric module. Given those measurements, the efficiency can be calculated using the following equation:

$$n = P_{out}/Q_{in}.$$

where P_{out} output power and Q_{in} is input heat from the heater in watts.

The output power can be calculated using the equation:

$$P_{out} = V_{out} * I_{out}$$

Where V_{out} is the output voltage and I_{out} is output current.

The input heat can be calculated for the heater using the equation:

$$Q_{in} = V^2_{heater}/R_{heater}$$

$$\text{or } Q_{in} = V_{heater} * I_{heater}$$

where V is voltage, R is resistance, and I is current of the heater.

Data/Results

TABLE 1: Billions of U.S. Dollars to be saved from potential increases in fuel economy from thermoelectricity

Application	Segment	Savings (% of fuel)	Savings in U.S. $
Auto-light duty trucks	Personal	1% Fuel Savings	$5.0 Billion
Heavy duty trucks	Commercial	1% Fuel Savings	$1.4 Billion
Auto-light duty trucks	Personal	5% Fuel Savings	$25.0 Billion
Heavy duty trucks	Commercial	5% Fuel Savings	$6.9 Billion

TABLE 2. Voltage output of TEM under various conditions

V_{in} (V)	I_{in} (A)	Heater Temp (°C)	Heat Sink Temp (°C)	Delta T (°C)	V_{out} (mV)
6	0.32	34.8	28.8	6	142
7.4	0.39	39.3	32.0	7.3	205
9.1	0.48	50.0	36.6	14	308
10.2	0.54	55.5	39.5	16	515
11.1	0.58	58.0	41.4	16.6	444

TABLE 3. Comparison of Power Generated

Company/ Research Institution	Power Generated	Increase in Fuel Economy
General Motors	350-600 Watts	3%
BMW	700 Watts	3-5%
Hi-Z Technologies SUV	459.3 Watts	1.5% due to parasitic loss
Jiatong University	146.5 Watts	1%

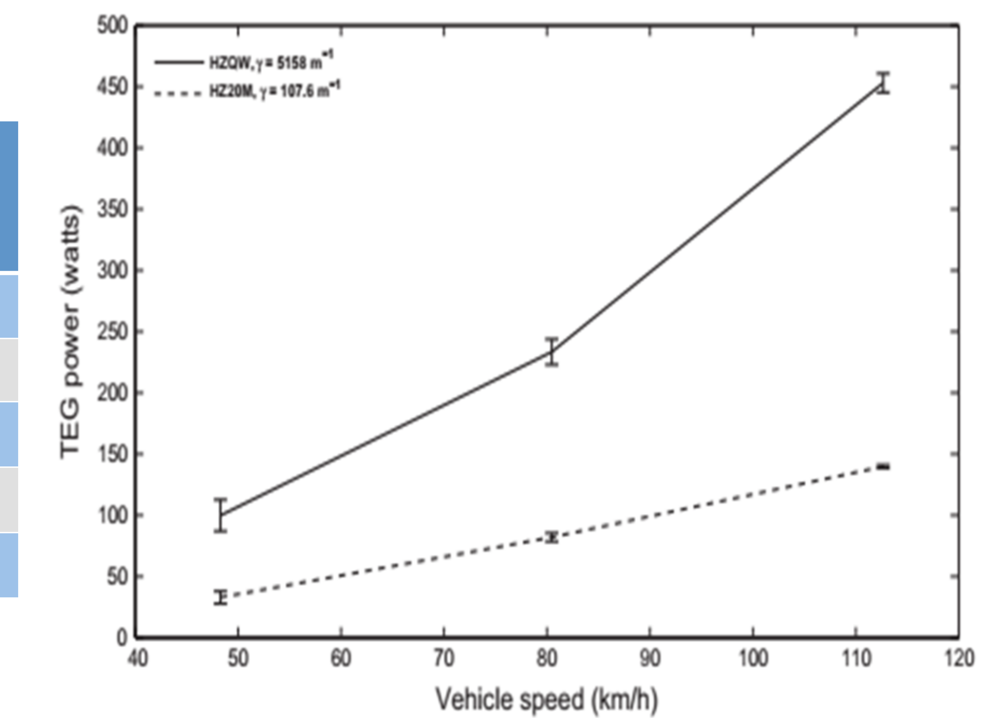

FIGURE 4. VehicleSpeed vs TEG Power

Table 4. Fuel Savings and Emissions Reductions for TEG systems

Company/Institution	Power Generated	Fuel Savings	CO2 Emissions Reduction
Linkoping University	0-500 Watts	n/a	1.3-2.8 kt per year of CO2
Alphabet Energy	25 kW per 1,000 kW engine	$50,000 per unit	156 Tons of CO2
RMIT University	53.75 W	n/a	1.125% reduction of CO2

Conclusions

Thermoelectric generation can be used to cut back on harmful emissions and reduce fuel consumption. There are opportunities to save billions of dollars using thermoelectricity. This technology can be applied to several industries, in particular the automotive industry. The exhaust gas is a high-potential heat source which offers the ability to increase temperature differences across modules and produce maximum power. Several large companies including General Motors and BMW continue to look into this technology to keep up with strict emissions and fuel economy guidelines. Alphabet Energy produced the largest TEG which is capable of producing over 25 kW of power per 1,000 kW engine.

Future Work

Future work will include further testing of thermoelectric modules as well as incorporating a thermoelectric generator onto a diesel engine system and testing results.

Acknowledgements

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