Introduction
Energy is a vital resource that drives industry and sustains economic growth. Promising new technologies capable of producing power are continually being investigated. Technologies capable of harvesting power from low-grade thermal energy are of significant interest. Low-grade thermal energy is a byproduct of virtually all processes, and in most cases, this waste heat is simply transferred to the atmosphere and becomes unavailable for further use. Approximately 435 GW of waste heat is generated in the U.S. [1], and a large portion is due to the processes used to compress air. Compressed air is widely used in industry and in commercial and non-commercial applications. The processes used to compress air are very inefficient—between 60-90% of input power ends up as waste heat [2].

Our objective is to design optimal power harvesting systems based on thermoelectric generators (TEG) for air compressors.

Methods
- As shown in Fig. 1, air exits a compressor at a high temperature. As shown in Fig. 3, the compressed air stream heats the surfaces of the compressor. An exergy analysis of this case indicates that a significant amount of power may be harvested.
- A TEG based power harvesting system is represented as a thermal circuit in Fig. 4, and Eq. 1 is the expression for the power generated base on this model. As illustrated in Fig. 2, the thermal pathways between the source and the TEG ($R_s, T_s$) and between the TEG and the sink ($R_i, T_i$) and the performance of the TEG can be varied and optimized.

$$W_{net} = \frac{1 + Z}{(1 + Z) + 2 \cdot 0.6 \cdot (1 - \frac{Z}{T_H}) \left( \frac{1}{R_{load}} \left( T_s - T_L \right) \left( T_s - T_H \right) - \frac{1}{R_{parallel}} \left( T_s - T_L \right) \right)}$$

Equation 1: Model for predicting the power from a TEG Power Harvesting System [3]

Analysis and Discussion
Optimizing a TEG power harvesting system requires:

Engineering the Thermal Pathways
Increase the bypass thermal resistance relative to the thermal resistance of the TEG to prevent heat from leaking around the TEG. The power produced by the TEG is proportional to the amount of heat flowing through the TEG, so reducing the heat bypassing the TEG is critical.

Minimizing the thermal resistance between the source and the power harvesting system will maximize $Q$ and increase the power output.

The thermal efficiency of the power harvesting system is a complex function of $T_s/T_i$. This ratio may be tuned by careful engineering of thermal pathway between the TEG and the sink ($R_i, T_i$). Thermal Pathway dependence is demonstrated in Fig. 5.

Load Matching
The power output is maximized when the impedance of the load matches the impedance of the TEG. The data shown in Fig. 6 shows the output power decreases rapidly when the load is mismatched.

Results
- A thermal model capable of analyzing and optimizing the power output of a TEG based power harvesting system.
- The variables that significantly effect the power output have been identified.
- Even though the case study is for an air compressor, it is applicable to many different applications with significant waste heat.

Future Exploration
- Economic analysis of the performance of TEG based power harvesting systems when applied to air compressors to show potential return-on-investment (ROI).
- Using an IR camera to conveniently identify locations for TEG based power harvesting systems with good potential ROI.
- Improved thermal models of TEG based power harvesting systems.
- Confirm experimental results of the model with an air compressor

References