Thermoelectric Power Generation

Linking Material Properties to Real World Conditions

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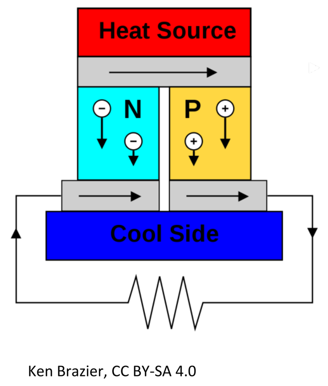
Abstract

Thermoelectric generators (TEGs) hold promise for the direct conversion of waste heat to electricity. A systematic study of TEG financial and design parameters was performed in order to assess the feasibility of small-scale TEG installations. Device performance was modeled using finite-element software ANSYS that integrate material properties from leading candidate materials and experimental time-variant temperature data. Financial forecasting and sensitivity studies indicate that TEG installations provide a feasible source of green electricity but are highly sensitive to source temperature, device efficiency, maintenance cost, and projected device lifetime.

Background

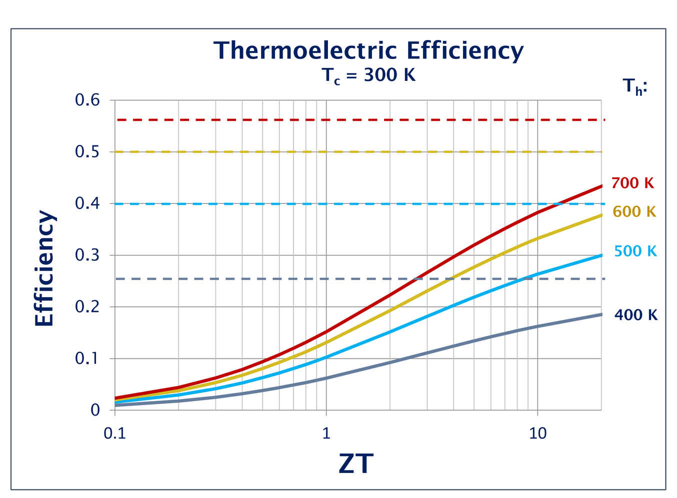
- Direct conversion of heat to electricity via Peltier, Seebeck Effects
- Figure of merit based on thermal, electrical transport properties:

$$zT = \frac{S^2 \sigma T}{\kappa}$$



- Efficiency based on zT, hot and cold side temperatures:

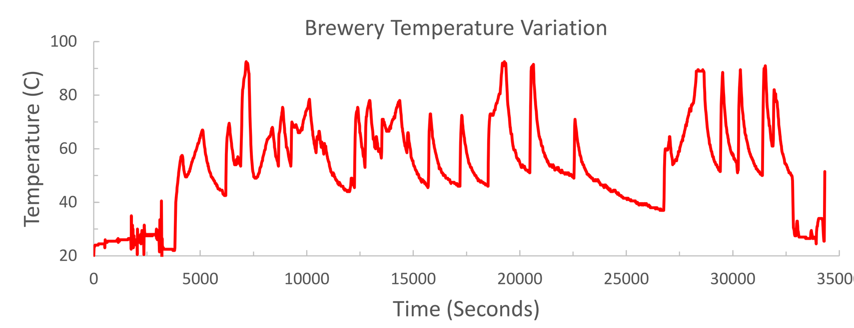
$$\eta = \frac{\Delta T}{T_h} \cdot \frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_c}{T_h}}$$



- Goals of this Project:
  - Identify sources of waste heat
  - Model performance using real materials constants, real temperature data
  - Determine financial feasibility of real installations
  - Account for externalities beyond financial impetus

Methods

- Temperatures measured at UC Davis Brewery via Type-K Thermocouple

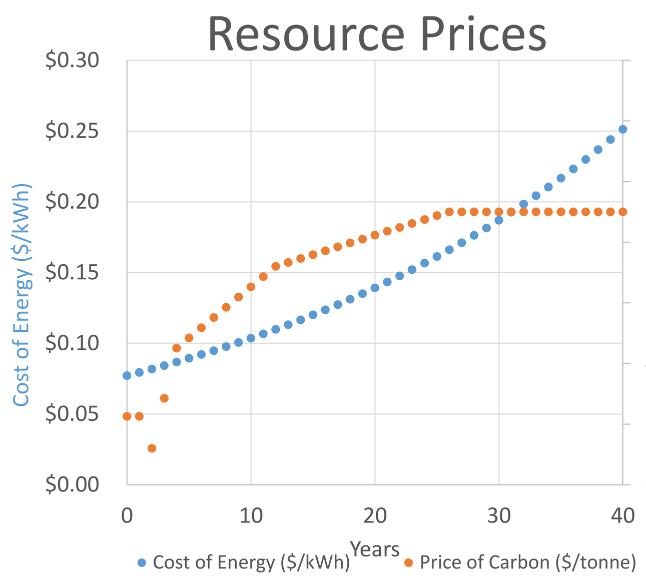


- ANSYS model provides physical properties
  - Hot side temperature varies
  - Cold side temperature held constant at 25°C
  - Material properties from literature values at average temperature[1-4]
  - Operation modeled at optimum power ($R/R_L = 1$)

- Net Present Value based on
  - --Capital Costs
  - --O&M Costs
  - --Value of electricity produced
  - --Value of carbon offsets
  - --Project Lifetime
  - --Discount Rate (WACC)

$$NPV = -C_0 + \sum_{i=0}^{T} \frac{C_e + C_{CO_2} + C_{O\&M}}{(1+r)^i}$$

- Assumptions
  - •Discount rate of 6%, constant
  - •Value of electricity, CO_2 from UC Davis Campus Energy Plan[5]
  - •Variable CO_2 price
  - •3% increase in electricity price per annum
  - •Materials costs and device parameters from LeBlanc et al.[6-8]



Future Work

- Refine ANSYS model with optimized material-specific parameters (leg length, e.g.)
- Validate results through prototype installation
- Explore vehicle applications[9]
- Improve temperature measurements with in-stream monitoring

Results

Key

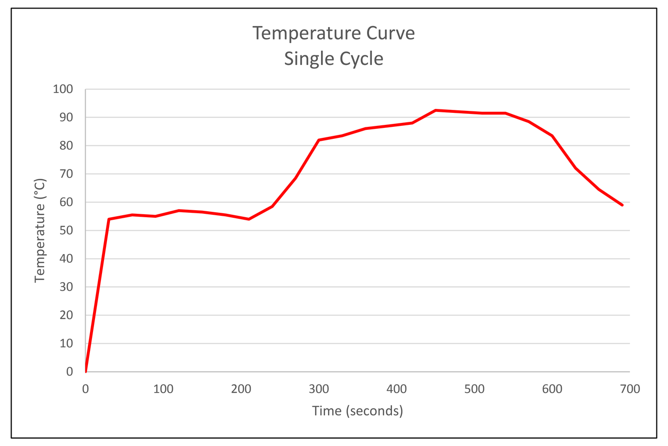
$Yb_{0.2} In_{0.2} Co_4 Sb_{12}$

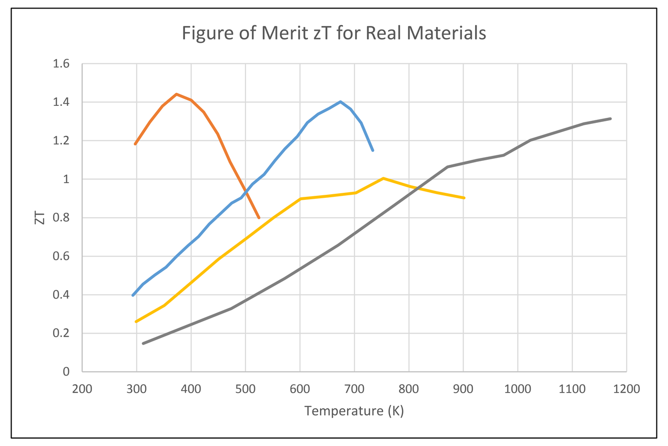
SiGe

$Bi_{0.52}Sb_{1.48}Te_3$

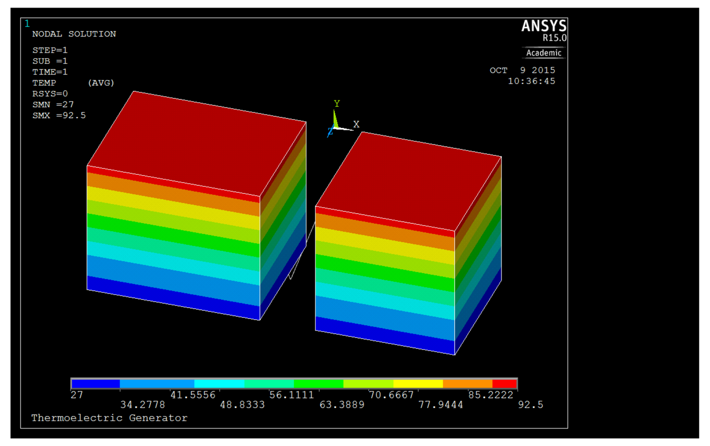
$Zr_{0.25}Hf_{.25}Ni_{0.8}Sn_{0.994}Sb_{0.01}$

Inputs

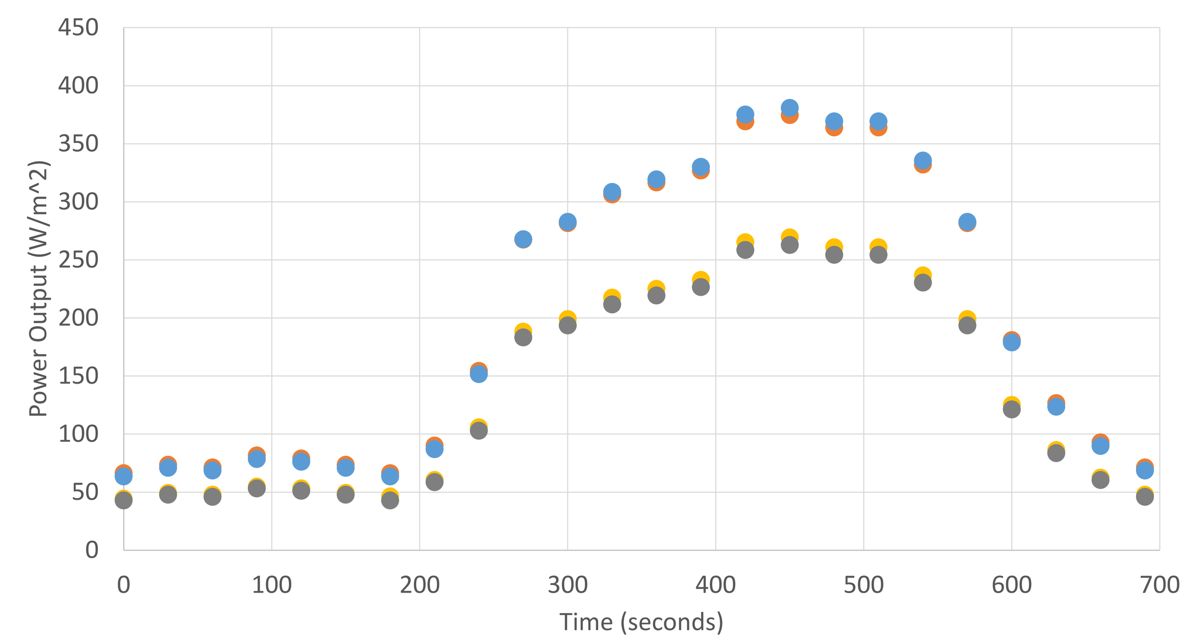




ANSYS Model

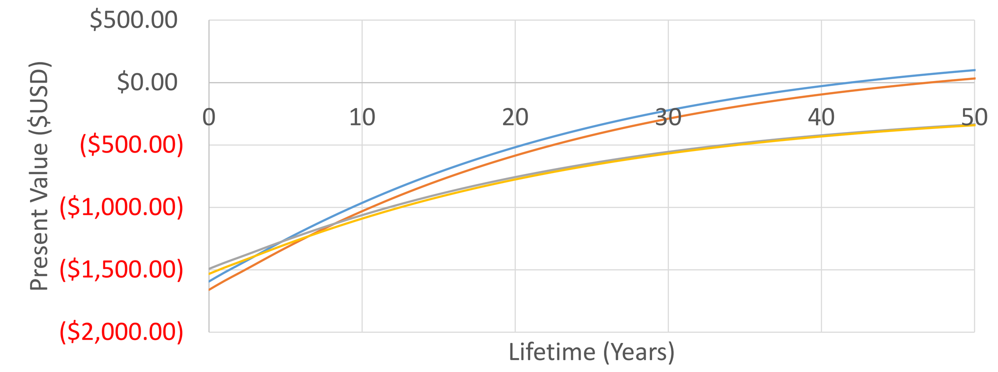


Power Output

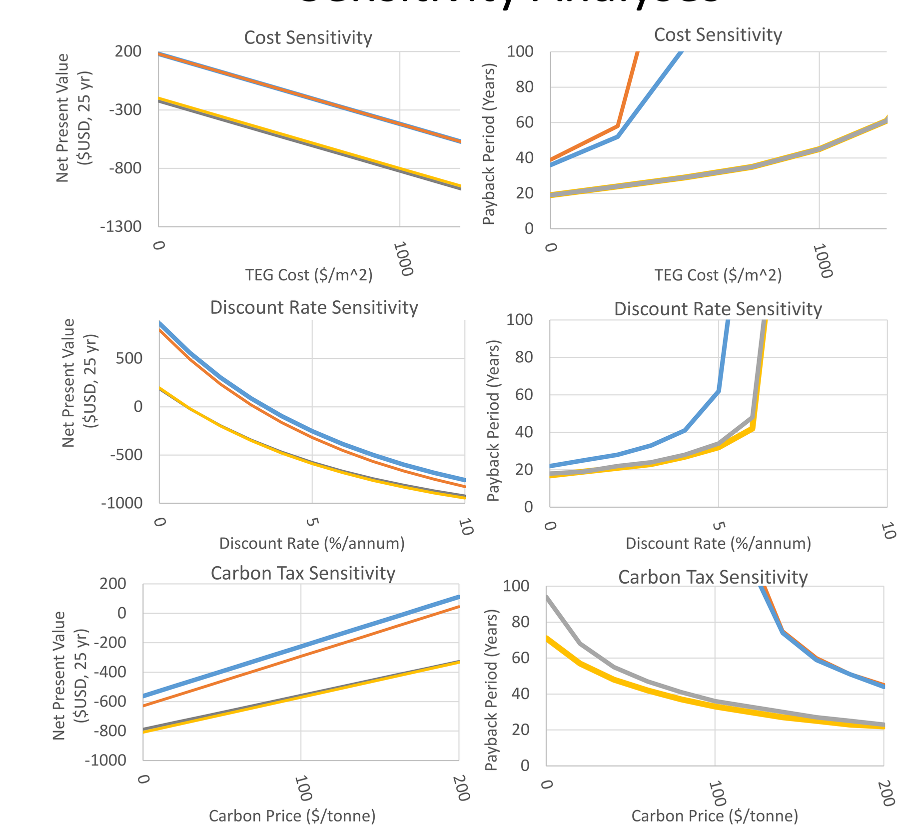


Material	Power (W/m²)	Raw Material Cost ($/m²)	Net Present Value at 25 Years	Payback Period
$Yb_{0.2} In_{0.2} Co_4 Sb_{12}$	141	805	-682	∞
SiGe	137	735	-666	∞
$Bi_{0.52}Sb_{1.48}Te_3$	200.4	1053	-451	48
$Zr_{0.25}Hf_{.25}Ni_{0.8}Sn_{0.994}Sb_{0.01}$	200.4	942	-385	42

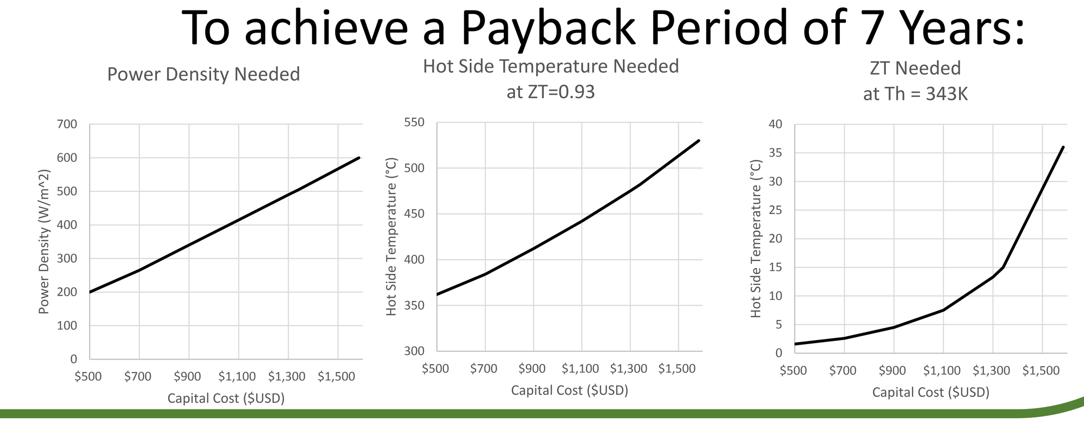
Present Value for Real Materials



Sensitivity Analyses



To achieve a Payback Period of 7 Years:



Conclusions

TEGs may be a viable technology for long-term energy generation. Models indicate that feasibility is highly sensitive to input temperature, discount rate, and device efficiency. Improvements are required in device efficiency and manufacturing cost in order to achieve reasonable payback periods for low-temperature heat sources.

References and Acknowledgements

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