Fire & Ice

Energy Recovery Team

Bryan Perkins Brandon Nafsinger Scott McMurdie Garrett Oman

Sponsored by University of Idaho Facilities Department

Mission Statement

- Our teams mission is to capture the waste heat at the steam plant by utilizing thermoelectric generators to produce an output voltage. The power generated will be used to charge batteries at the steam plant.

Project Learning

- Location and temperatures
- How a thermoelectric generator(TEG) works
- Heat transfer analysis
- Cooling options that utilize natural convection
- What to do with generated power

Location Options

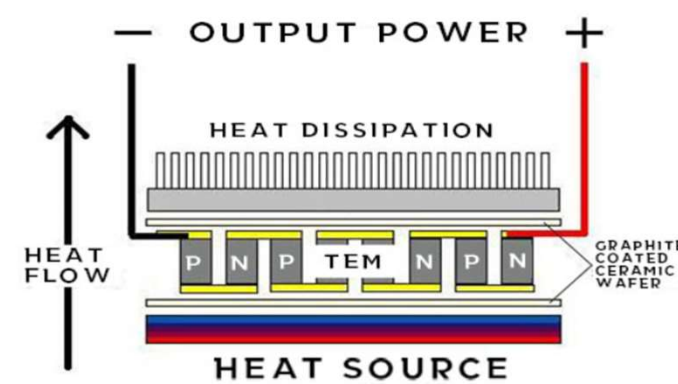
- Side flash hopper
  - Pro
    - High temp of 500°F
    - Lower ambient temp
    - Close to outside wall
  - Cons
    - Limited surface area
    - Surface is uneven

Other Location Options

- Ash Hopper
  - Pros
    - Large surface area
    - Smooth surface
  - Cons
    - Negatively sloped surface
    - High temp of 350°F
- Flue gas vent
  - Pros
    - Large surface area
    - Smooth surface
    - Positive sloped surface
    - Next to large industrial fan
  - Cons
    - High temp of 300°F

How a TEG works

- Operate according to the Seebeck Effect
  - Temperature difference across thermoelectric material can be converted directly into electrical power
- Constructed of n-type and p-type semiconductors
  - Formed into thermocouples



How a TEG works

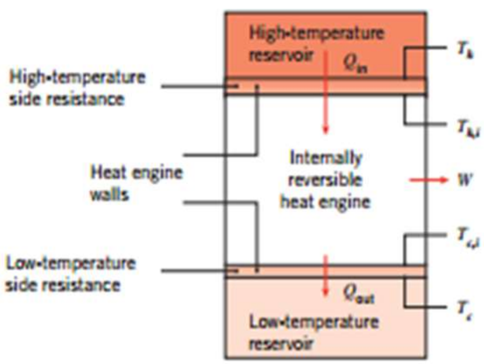
- Pro
  - No moving part
  - Maintenance free
  - Constant output with steady state input
  - Thermoelectric modules that are at steady state (constant power, heat load, temperature, etc.) can have mean time between failures (MTBFs) in excess of 200,000 hours. -http://www.everredtronics.com/EN/TEM/tech.html
- Cons
  - Low efficiencies 5-8 %

Heat Transfer Analysis

- Initial heat transfer model analysis used total heat flux across TEG and Heat sink and efficiencies of TEGs.
- TEG output dependent on temperature on surface not heat flux through TEG and heat sink.
- Variables dependent on heat distribution across TEG and heat sink
  - h -convective heat transfer coefficient
  - k - Thermal conductivity
  - q_in – heat flux in
  - q_out – heat flux out

Heat Transfer Analysis

- Internally reversible heat engine



$$T_{h,i} = T_h - q_{in} R_{t,h} \tag{1.19a}$$

$$T_{c,i} = T_c + q_{out} R_{t,c} = T_c + q_{in}(1 - \eta_m) R_{t,c} \tag{1.19b}$$

FIGURE 1.10 Internally reversible heat engine exchanging heat with high- and low-temperature reservoirs through thermal resistances.

  - q_in and q_out needed to solve for T_c_i, which is the base temperature of the fin.

Heat Transfer Analysis

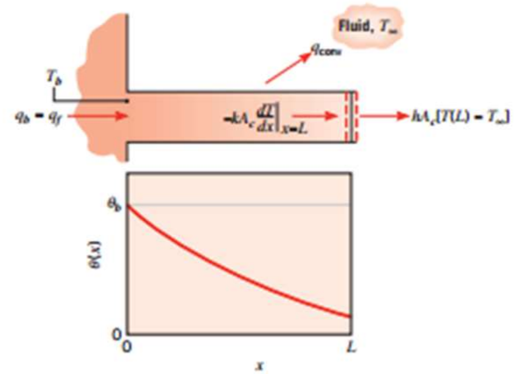
- Conduction and convection of horizontal cylinder

TABLE 3.4 Temperature distribution and heat loss for fins of uniform cross section

Case	Tip Condition ($x = L$)	Temperature Distribution θ/θ_b		Fin Heat Transfer Rate q	
A	Convection heat transfer: $h\theta(L) = -kd\theta/dx\vert_{x=L}$	$\dfrac{\cosh m(L-x) + (h/mk)\sinh m(L-x)}{\cosh mL + (h/mk)\sinh mL}$	(3.75)	$M\dfrac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}$	(3.77)
B	Adiabatic: $d\theta/dx\vert_{x=L} = 0$	$\dfrac{\cosh m(L-x)}{\cosh mL}$	(3.80)	$M \tanh mL$	(3.81)
C	Prescribed temperature: $\theta(L) = \theta_L$	$\dfrac{(\theta_L/\theta_b)\sinh mx + \sinh m(L-x)}{\sinh mL}$	(3.82)	$M\dfrac{(\cosh mL - \theta_L/\theta_b)}{\sinh mL}$	(3.83)
D	Infinite fin ($L \rightarrow \infty$): $\theta(L) = 0$	e^{-mx}	(3.84)	M	(3.85)

$\theta \equiv T - T_\infty$ $\qquad m^2 \equiv hP/kA_c$

$\theta_b = \theta(0) = T_b - T_\infty$ $\qquad M \equiv \sqrt{hPkA_c}\,\theta_b$



  - The temperature distribution of fin is dependent on temperature of base.
  - Heat transfer rate (q), is dependent on temperature distribution.

Heat Transfer Analysis

- <u>Thermoelectric Power Generation</u>

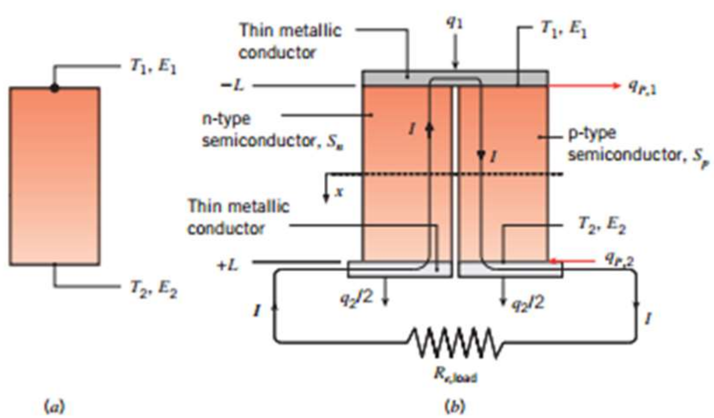


Figure 3.23 Thermoelectric phenomena. (*a*) The Seebeck effect. (*b*) A simplified thermoelectric circuit consisting of one pair ($N = 1$) of semiconducting pellets.

$$q_1 = \frac{1}{R_{t,\text{cond,mod}}}(T_1 - T_2) + IS_{p\text{-}n,\text{eff}}T_1 - I^2R_{e,\text{eff}} \quad (3.125)$$

$$q_2 = \frac{1}{R_{t,\text{cond,mod}}}(T_1 - T_2) + IS_{p\text{-}n,\text{eff}}T_2 + I^2R_{e,\text{eff}} \quad (3.126)$$

$$P_N = q_1 - q_2 = IS_{p\text{-}n,\text{eff}}(T_1 - T_2) - 2I^2R_{e,\text{eff}} \quad (3.127)$$

$$R_{t,\text{cond,mod}} = \frac{L}{NA_{c,s}k_s}$$

- q_1 and q_2 dependent on surface temperature of TEG
- S_p-n,eff-Effective seeback effect of n and p type semiconductor
- R_eff-Internal resistance of TEG
- q_1 and q_2 dependent on surface temperature of TEG

Heat Transfer Analysis

- <u>Current conclusion</u>
  - Combining all previous equation leaves the model indeterminate in EES.
  - The interface temperature between the TEG and heat sink is needed.
  - Model has too many unknowns to solve without guessing.

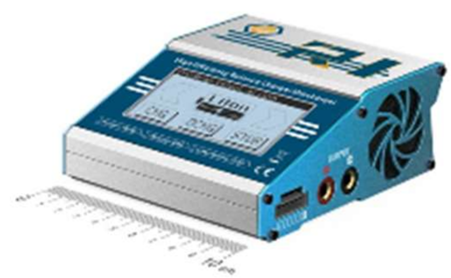
Cooling

- Flared: Has space constraints
  - Thermal Resistance = 0.57°C/W
  - Dimensions: 5” x 5” x 2.5”

Picturesfrom coolinovations.com

Using the Power

- Charges all types of batteries
- Variable DC input range



Picture from http://www.getfpv.com

Cooling options

- If natural convections fails after testing
  - Forced convections
  - Liquid cooling
  - Heat pipes

Power Uses

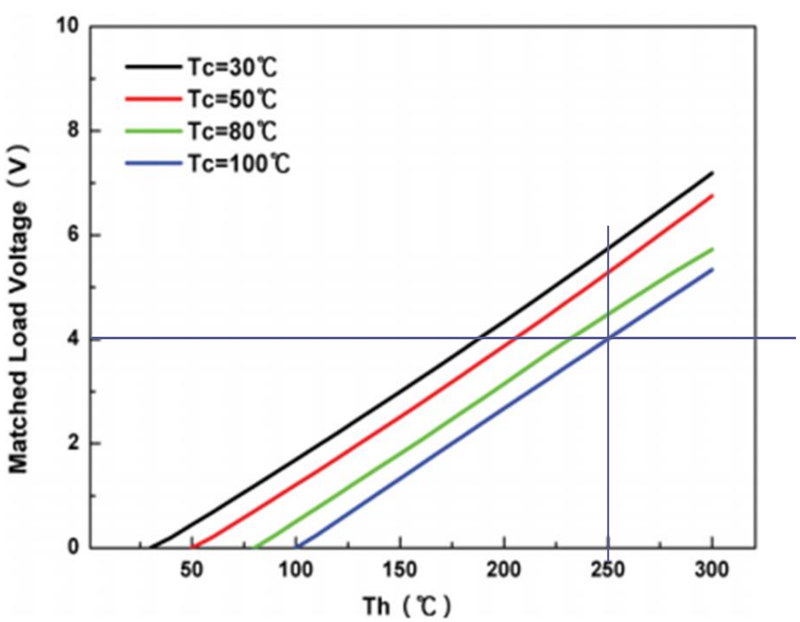
- Pros
  - Charges all types of batteries
  - Variable DC input range
  - Only one needed
- Cons
  - Has fan that could fail
  - Uses some power
  - Operation is unknown

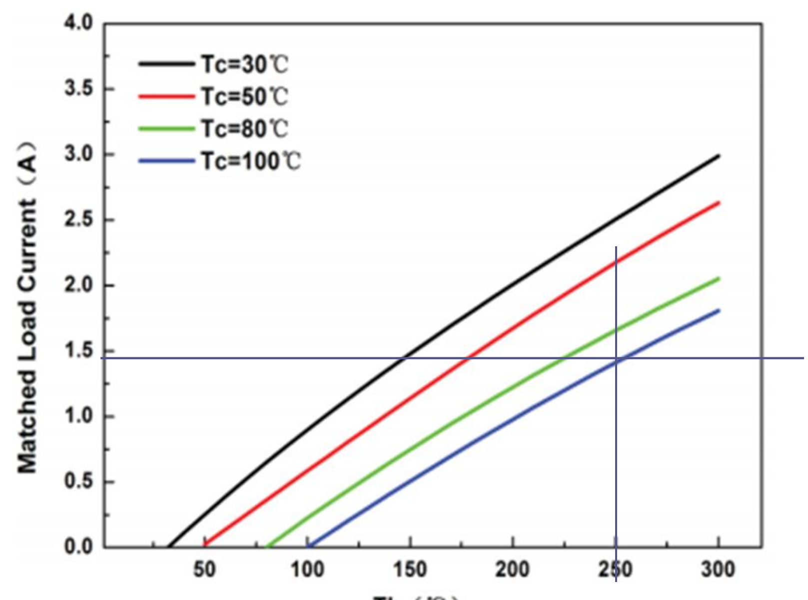
- Pros
  - Simple operation
  - No moving parts
  - Does not use power
  - High DC input range
- Cons
  - One charger need for each device
  - Only charges Li-Ion

*Data sheets available as handouts

Modular Option 1

- Looking for V_{out} = 16-18V and I_{out} = 1.5A
  - 1st option 22 Watt TEG
    - Dimensions: 2.2" x 2.2" x 0.2"



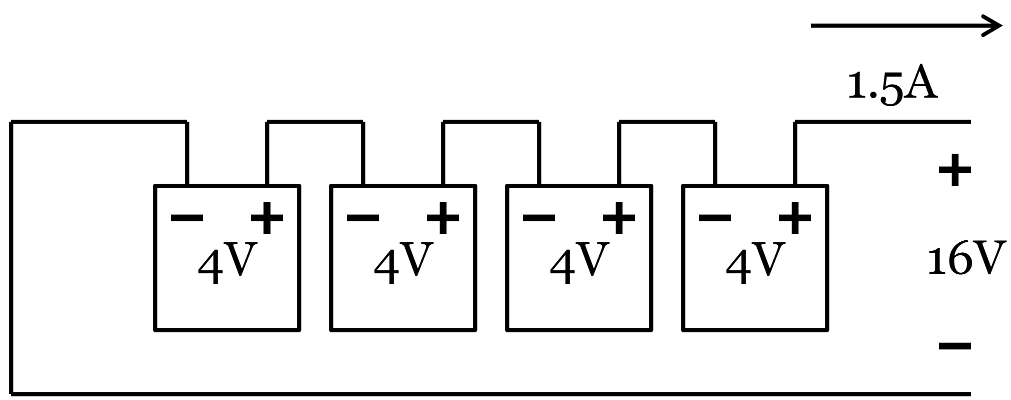


Graphs from tegmart.com

1st option 22 Watt TEG

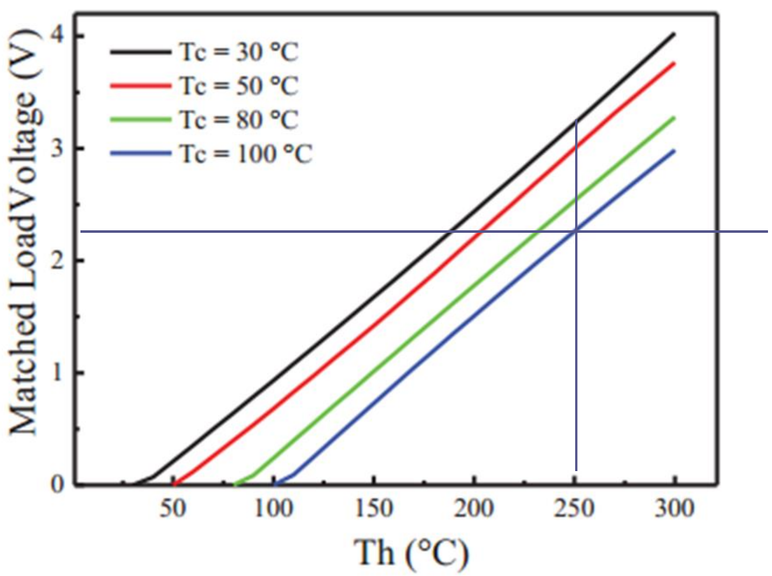
Price using 4 TEGs	
TEGs (57.50 each)	230
Heat Sinks	20
Misc. Hardware	20
Misc. Wiring	20
Total Price with Option 1 battery charger($70)	360
Total Price with Option 2 battery charger($26 each)	316

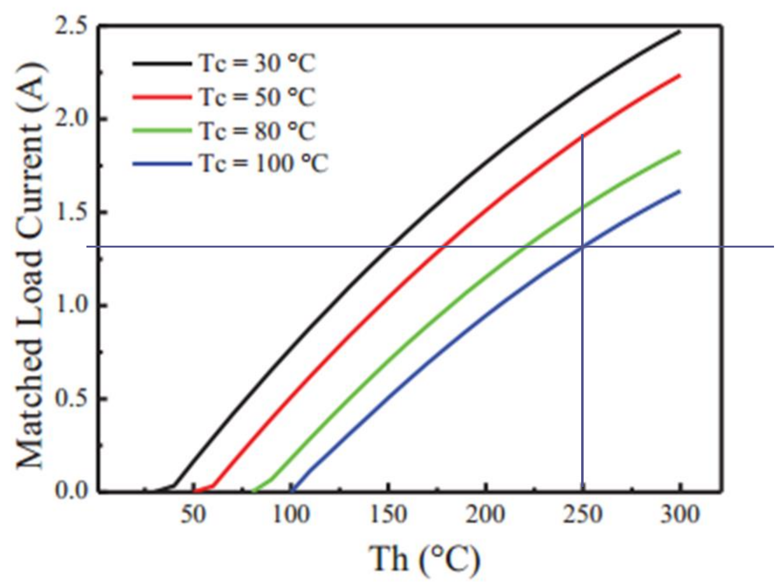
- T_H = 250°C (490°F)
- T_c = 100°C (212°F)



Modular Option 2

- Looking for Vout = 16-18V and Iout = 1.5A
  - 2nd option 10 Watt TEG
    - Dimensions: 1.6" x 1.6" x 0.2"



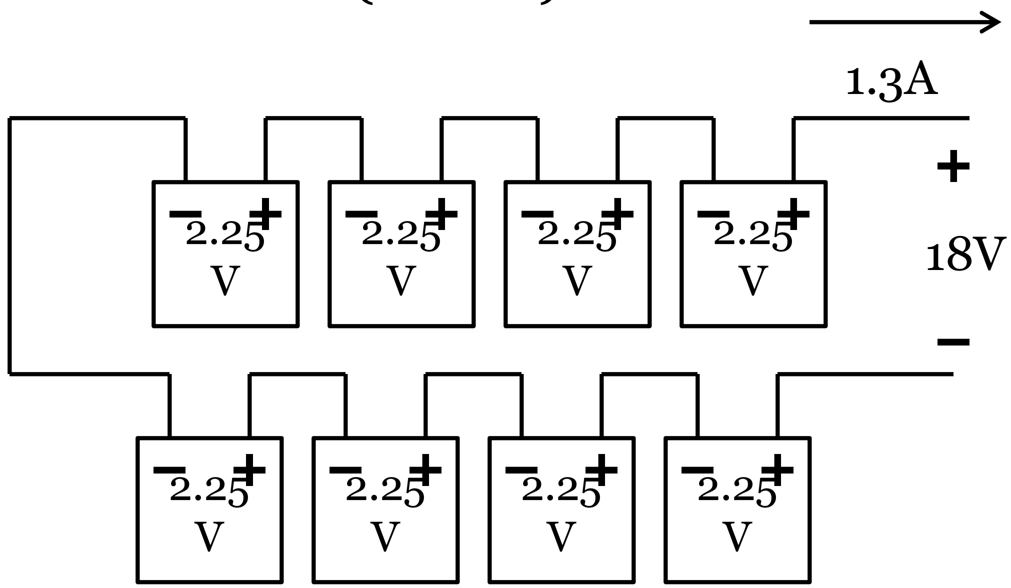


Graphs from tegmart.com

2st option 10 Watt TEG

Price using 8 TEGs	
TEGs (25.50 each)	204
Heat Sinks	20
Misc. Hardware	20
Misc. Wiring	20
Total Price with Option 1 battery charger($70)	334
Total Price with Option 2 battery charger($26 each)	290

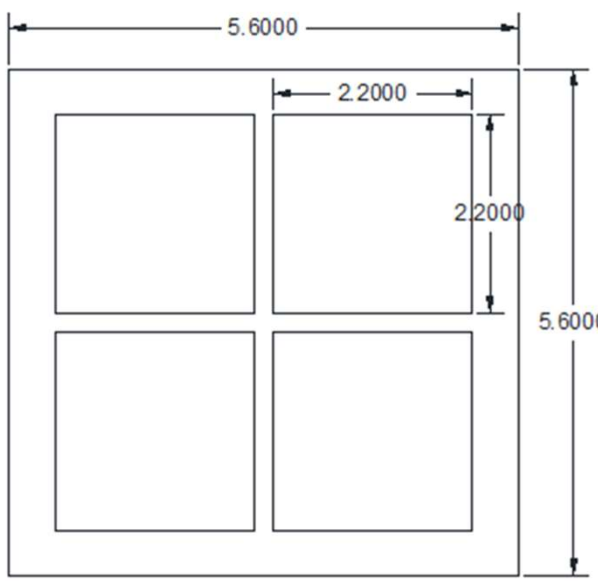
- At T_H = 250°C (490°F)
  - T_c = 100°C (212°F)

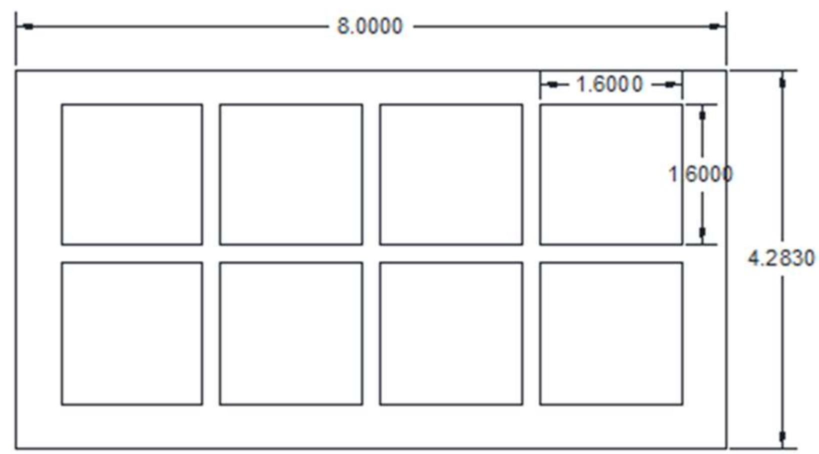


Price Comparison of Options

Price using 4 TEGs		Charing 5 Radios
TEGs (57.50 each)	230	1150
Heat Sinks	20	100
Misc. Hardware	20	100
Misc. Wiring	20	100
Total Price with Option 1 battery charger($70)	360	1520
Total Price with Option 2 battery charger($26 each)	316	1710

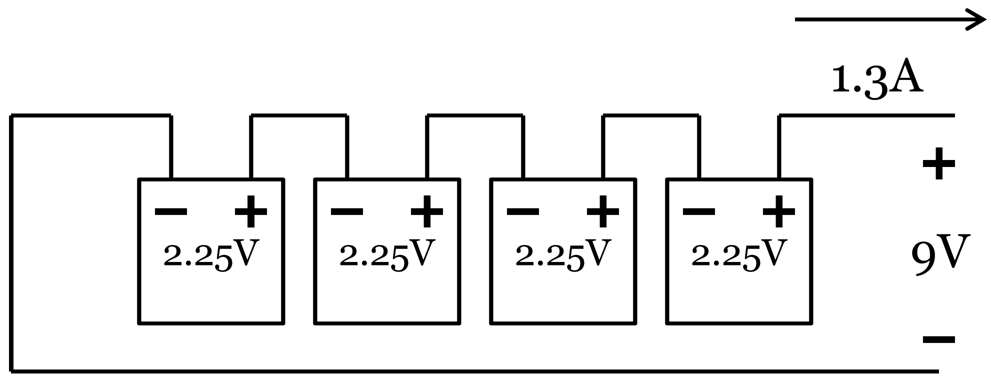
Price using 8 TEGs		Charing 5 Radios
TEGs (25.50 each)	204	1020
Heat Sinks	20	100
Misc. Hardware	20	100
Misc. Wiring	20	100
Total Price with Option 1 battery charger($70)	334	1390
Total Price with Option 2 battery charger($26 each)	290	1580

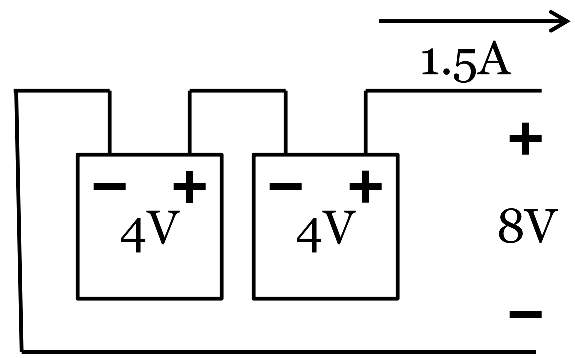




3rd option for power use

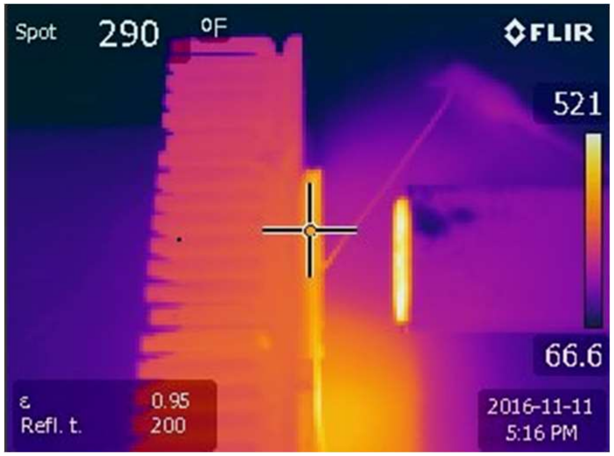
- Flue Gas Stack Analyzer
  - $V_{in} = 7.5V$
  - $I_{in} = 14A$

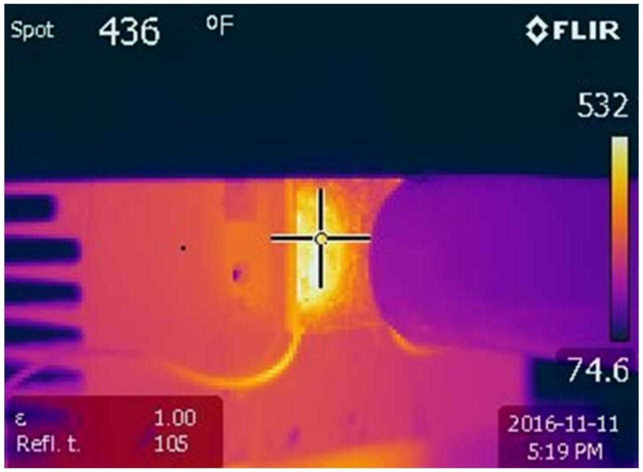


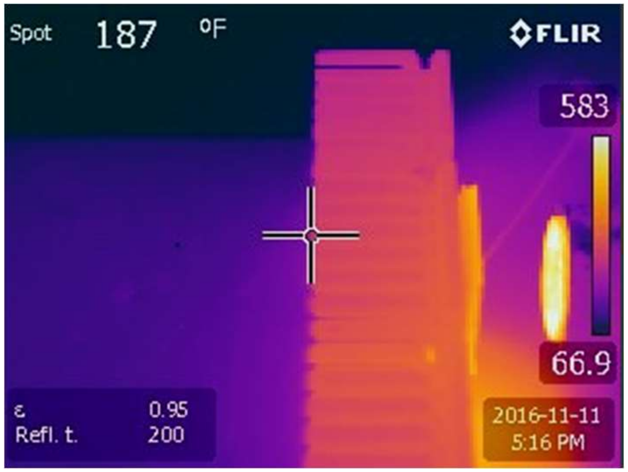


Proof of concept

- 1^{st} test
  - T_h = 436°F
  - T_c = 290°F
  - T_{fin} = 187°F
  - V_{out} = 0.87V

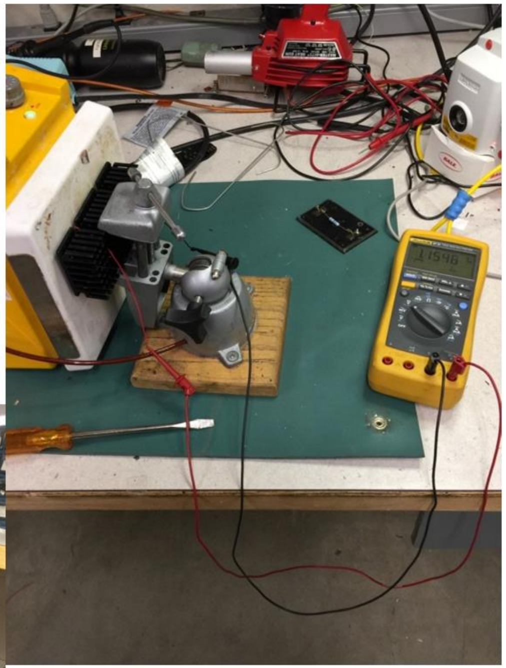


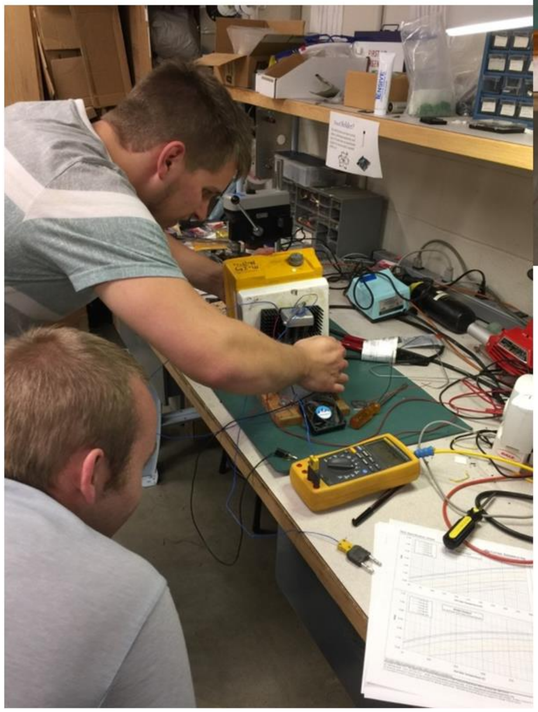




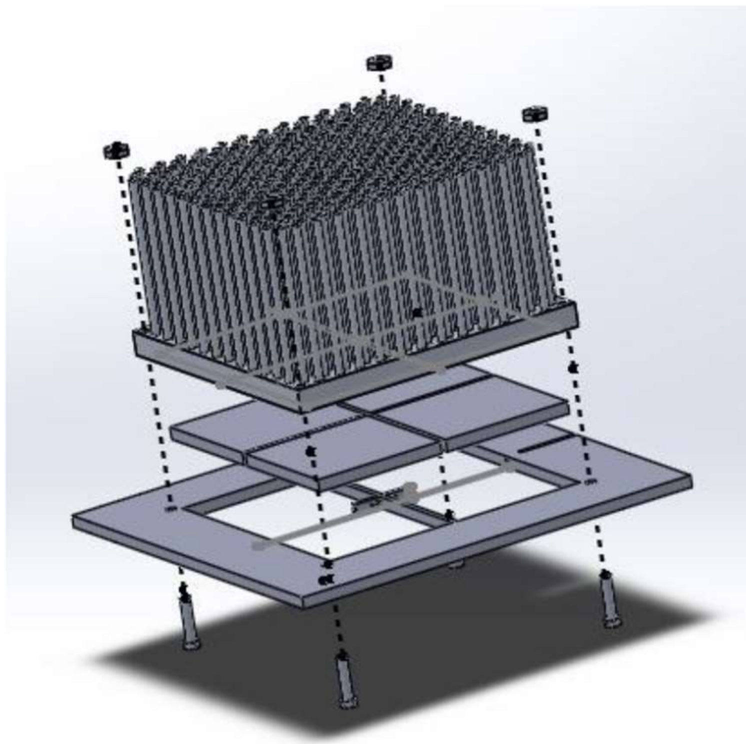
Testing

- 2^{nd} Test
  - $T_h = 410°F$
  - $T_c = 266°F$
  - $T_{fin} = 194°F$
  - $V_{out} = 1.22V$





Proposed design



Questions????