



RDECOM

Review of Interests and Activities in Thermoelectrics



DoE Thermoelectrics Applications Workshop: Jan 3-6, 2011

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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- Army Rationale
- Thermoelectric Power Generation
 - Soldier power
 - UAV power
- Materials Research
 - Bulk
- Thermoelectric Cooling
 - DARPA/MTO: ACM
 - NEA device idea
 - Where would these help?
- Summary

- 3×10^5 barrels per Day!
- JP-8:
 - Base cost \$3/Gallon
 - “Fully burdened cost” \$42/Gallon
 - Human cost 1 US casualty per 24 trips

- 3×10^5 barrels per Day!
- JP-8:
 - Base cost \$3/Gallon
 - “Fully burdened cost” \$42/Gallon
 - Human cost **1 US casualty per 24 trips**

Batteries require more supply trips!

POINT: Power-Generation opportunities that ARL is looking at:

1. reduce batteries (soldier power)
2. reduce demand (UAV)



AN/PVS 14 (Night Vision)
(2) AA
.106 lbs/.04 watts*



Mark VII
(1) 3.9 V lithium
.256 lbs/.167 watts*



MBITR
(8) BB 521
6.4 lbs/5.33 watts*



Sure Fire Light
(6) CR-123A
.222 lbs/.219 watts*



Mag Lite
(2) AA
.106 lbs/.019 watts*



DAGR
(24) AA & (1) ½ AA
1.3 lbs/.729 watts*



**Base Approach Load = 77 lbs
Max Approach Load = 170 lbs**

Head Set
(2) AA
.106 lbs/.019 watts*



PEQ-2A
(2) AA
.106 lbs/.011 Watts*



HTWS (Night)
(12) AA Lithium
384 lbs/.68 watts*



M68 CCO (Day)
(1) DL 1/3N
.007 lbs/.00006 watts*



LMR
(8) 3600 mAh NIMH
6.4 lbs/1.51 watts*



P-Beacon
(1) 9V
.1 lbs/.049 watts*



Total: 7 types of batteries, 70 batteries, 16 lbs; 9.17 watts

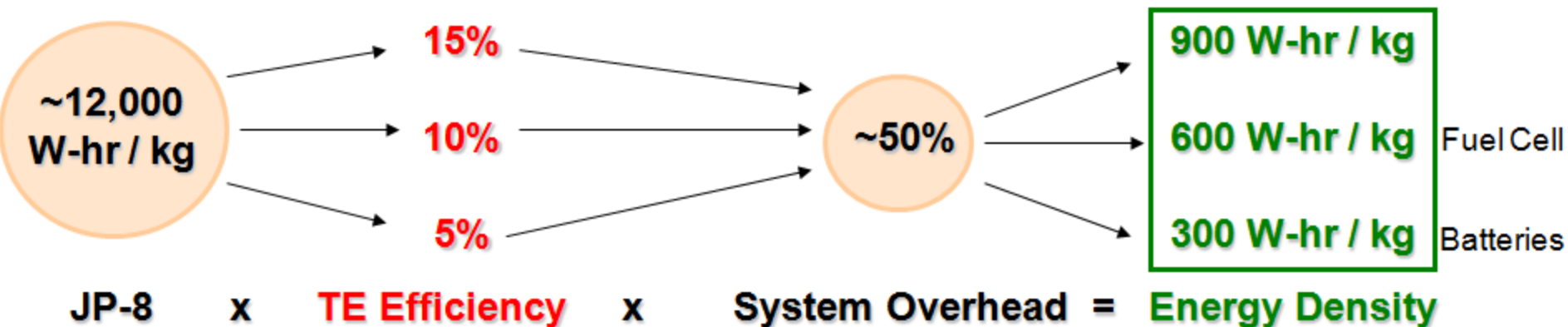
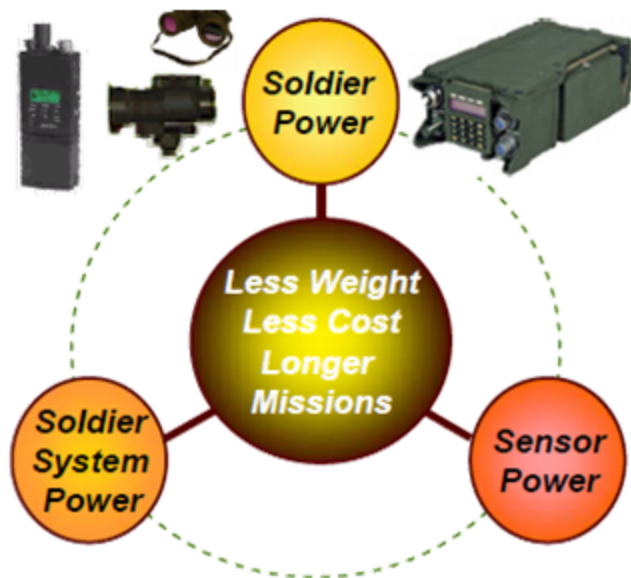
CREDIT: Brian Morgan/Ivan Lee

Goal:

- Develop small light weight power sources for the Warfighter that maximize specific energy for Soldier systems and sensors.
- High efficiency thermoelectrics could compete with fuel cells, while likely using logistic fuels

Research Areas:

- Burner development
- TE materials
- TE packaging / interconnects
- Thermal management
- Balance of plant (pumps, valves, etc)





Total weight (14.2 kg)
 Main payload is imaging pod (intel)
 UEL AR 741 Wankel (air-cooled)
 -28 kW power, 50 kW max (* 1:1)
 28 Volt/900-1500 W_e generator (3.5 kg)



Say...only 1/3 goes to heat...

@28 kW, then 10 kW heat

-5% TE	then 500 W _e
-10% TE	then 1000 W _e
-15% TE	then 1500 W _e

@50 kW, then 16 kW heat

-5% TE	then 800 W _e
-10% TE	then 1600 W _e
-15% TE	then 2400 W _e

Opportunity? weight, cost, reliability, performance

BULK

Basic theory:

➤ Efficiency $\propto f(1/\kappa)$

.....as $\kappa \downarrow$...efficiency $\uparrow$

Credit: N.B. Singh/Team at Northrop Grumman

Low κ bulk (450° C)

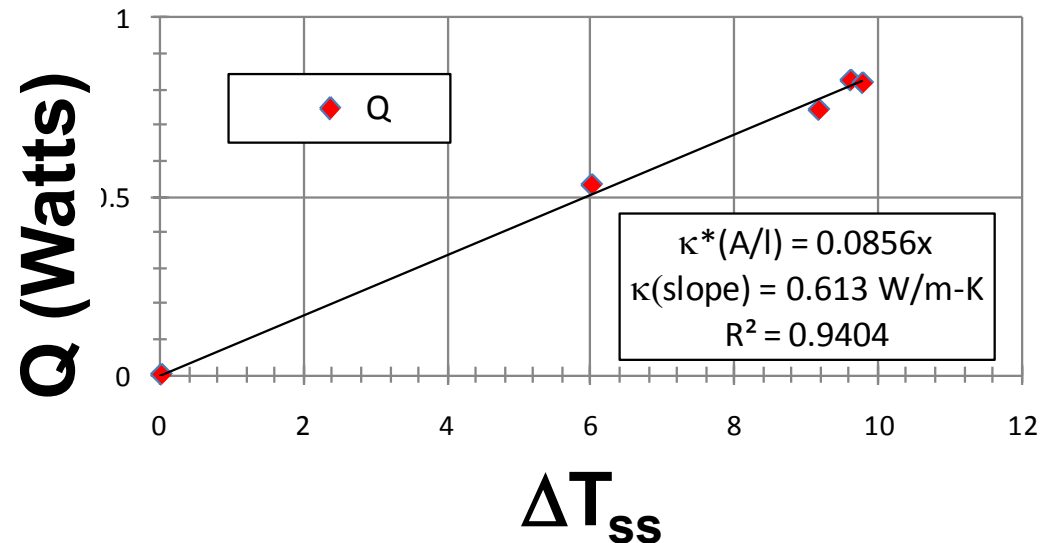
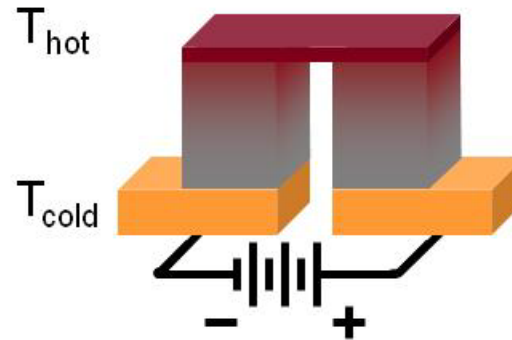
➤ (Tl,Bi)Te₂ ~ PbTe

“Pseudo-PbTe”

J. Jensen, R. Burke, D. Ernst, R. Allgaier,
Phys. Rev. B, Vol. 6(2), p. 319 (1972).

$$Q_{\kappa} = \kappa \left(\frac{A}{\ell} \right) (\Delta T_{ss})$$

➤ **Room-Temp.** $\kappa \sim 0.6$ W/m-K....3X better than PbTe

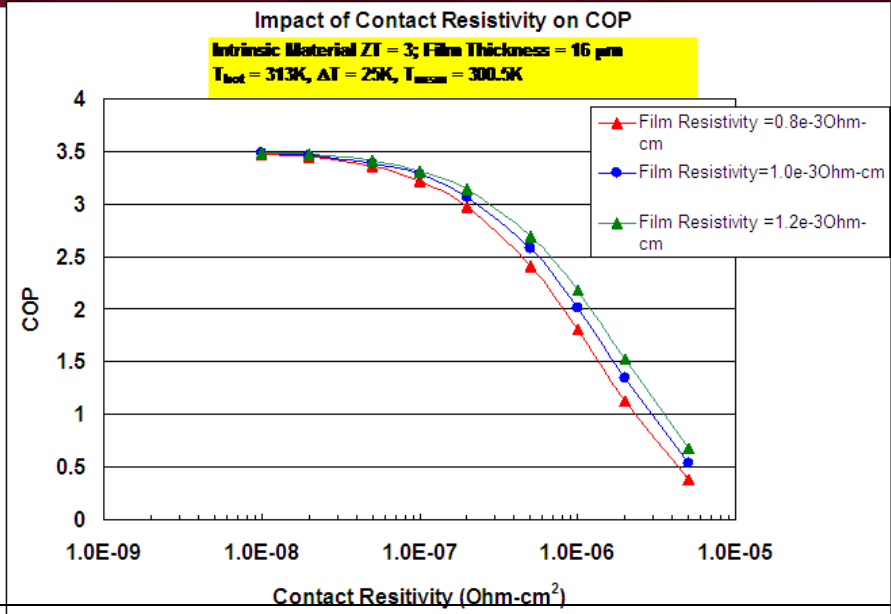
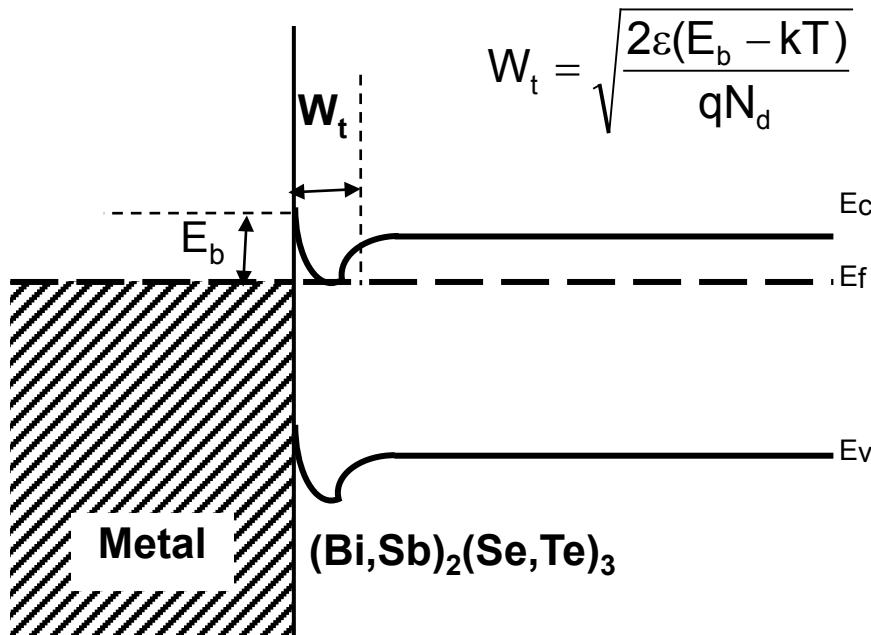


TE Cooling

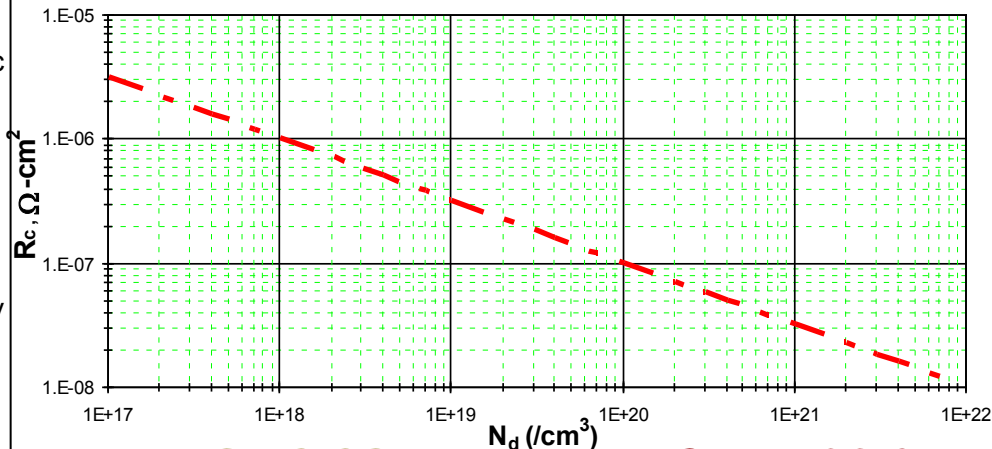


DARPA/MTO: ACM (Kenny → Bar-Cohen)

PROG: *Develop high-COP devices*
ARL: *Revolutionary Improvement in Contact Resistivity*

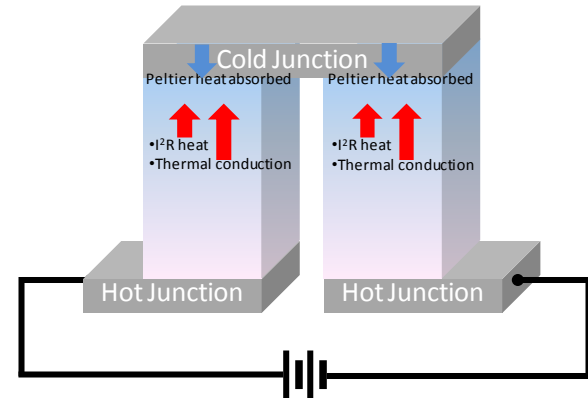


$$W_t \propto R_c \propto \frac{1}{\sqrt{N_d}}$$



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Thermodynamics:



$$Q_c = -(\alpha_n + \alpha_p)TI + (\kappa_n + \kappa_p)\Delta T(A/l) + \frac{1}{2}I^2(\rho_n + \rho_p)(l/A)$$

$$\Delta T_{\max} = \frac{1}{2} ZT^2$$

$$Z = \alpha^2 / \rho \kappa$$

Anything else that can be done?

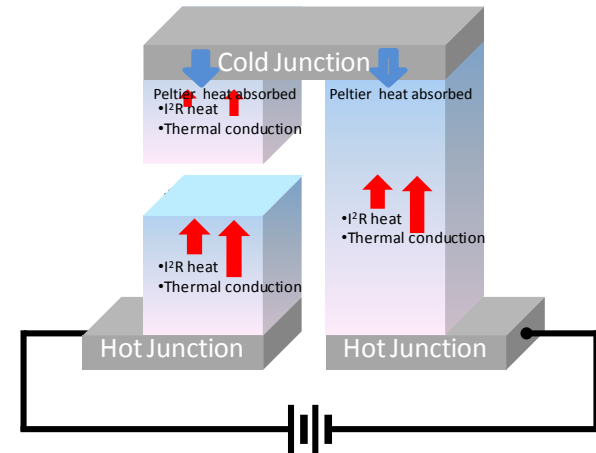
“What if....”

- we incorporate a gap

1. Heat cannot be conducted



2. Current cannot flow

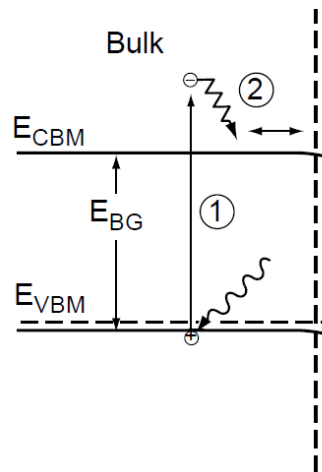


Is there something that we can do
to induce the electrical current to cross?

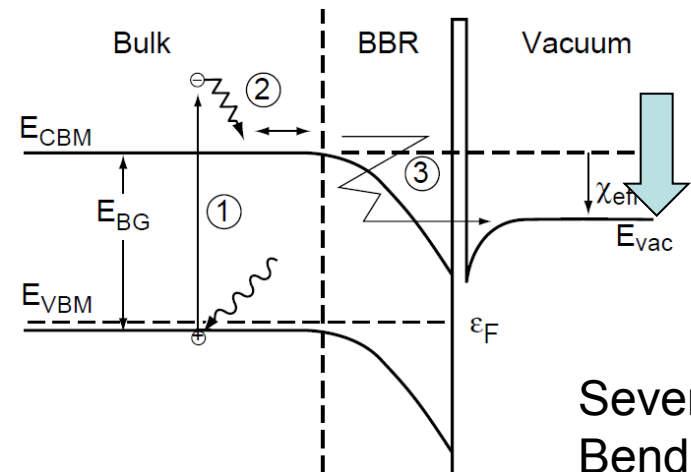
“Negative Electron Affinity”

- Phenomenon in p-GaAs
- Surface treatment → severe band-bending
- e^- source at Stanford Linear Accelerator (SLAC)

Key: Cs metal on GaAs



Surface States,
Some Band
Bending

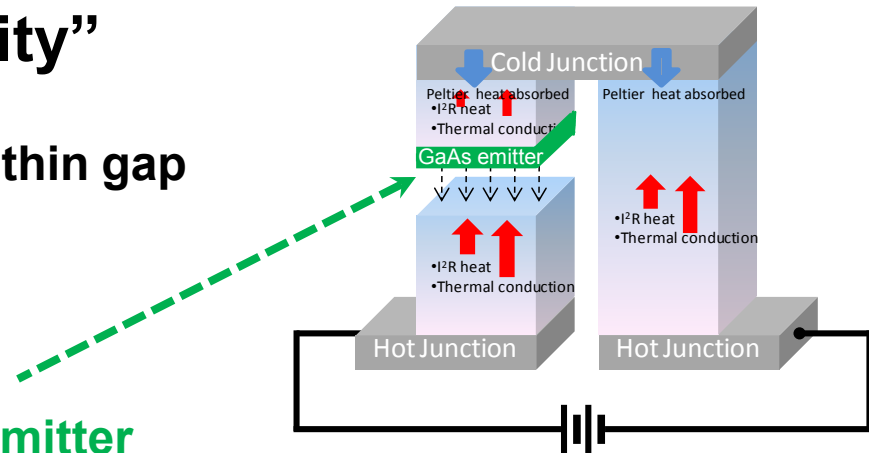


Severe Band
Bending

“Negative Electron Affinity”

- How would this work?
- Incorporate GaAs e⁻ emitter within gap

GaAs e⁻ emitter



▪Physics:

Child's Law: current density across gap:

$$J = K V_d^{3/2} / d^2$$

where

J = current density

d = gap spacing

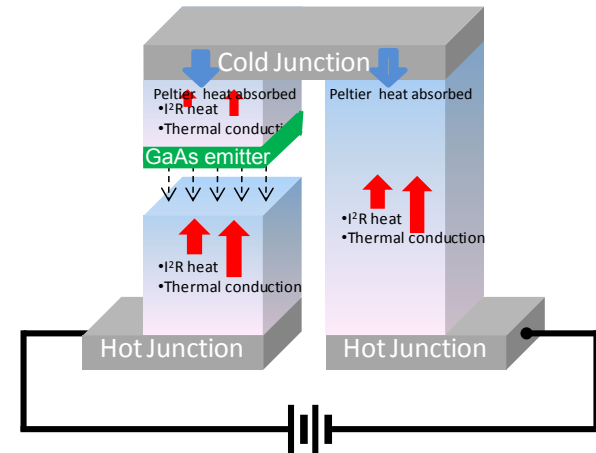
V_d = Potential across d

K is a constant = $(4/9) \epsilon_0 (-2q/m)^{1/2}$

10 V ~ “d” in mm range

“Negative Electron Affinity”

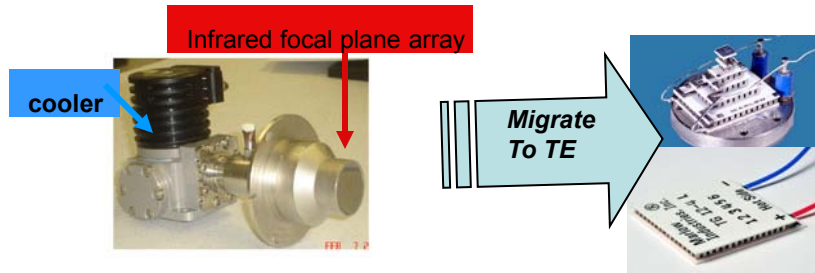
- Role for thin-film TE in practical devices
- Maybe:
 - $(\text{Bi,Sb})_2(\text{Se,Te})_3/\text{GaAs}$ NEA Cooler
 - PbTe/GaAs NEA Power



At this stage:
Form Analysis
Risk is OK

Unmanned Assets (UAV/UGV):

- High-performance IR would be nice
- High-performance IR needs coolers
- SADA is...



Attribute	TE 6-stage	SADA (Stir.)
Volume	7 cm ³	986 cm ³
Weight	100 g	2500 g
Cost	\$800	\$10,000
$\Delta T_{\max}$	133 K	235 K
Input Power	22.7 Watts	20 W (60 W _{max})
Heat Load	0.58 Watts	1.5 Watts
MTTF	unlimited	~ 10,000 Hrs.

Funding:



ACM



MDA:



Army I²WD:

Passive infrared threat warning

Collaboration:

RTI

Brimrose

Northrop-Grumman

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