UiO : Centre for Materials Science and Nanotechnology
University of Oslo

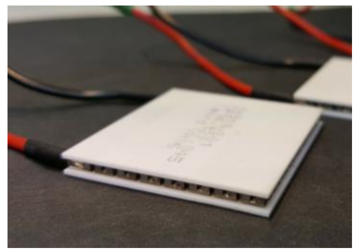
Top-down to know thermoelectrics
Part 1
TE industrial applications

Top-down to know thermoelectrics (TE)

-- From TE applications to Materials

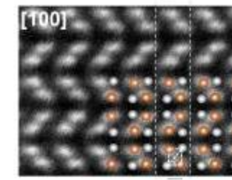
TE industrial applications

TE modules



TE Pairs

TE Materials



Availability and Installation

- Zinc Antimonides

Fabrication

- Conducting Oxide

Legs matching

- Oxide

Material properties

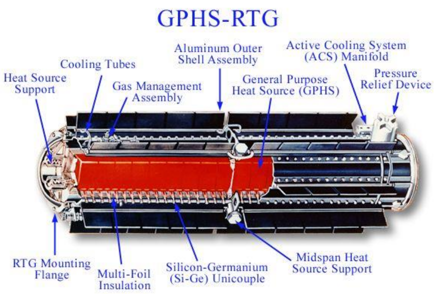
- Silicide

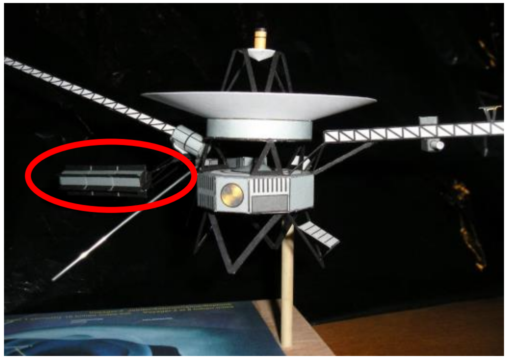
Outline

- TE industrial applications
- Commercially available modules
- ZnSb

Applications of thermoelectrics today

RTG – space probes

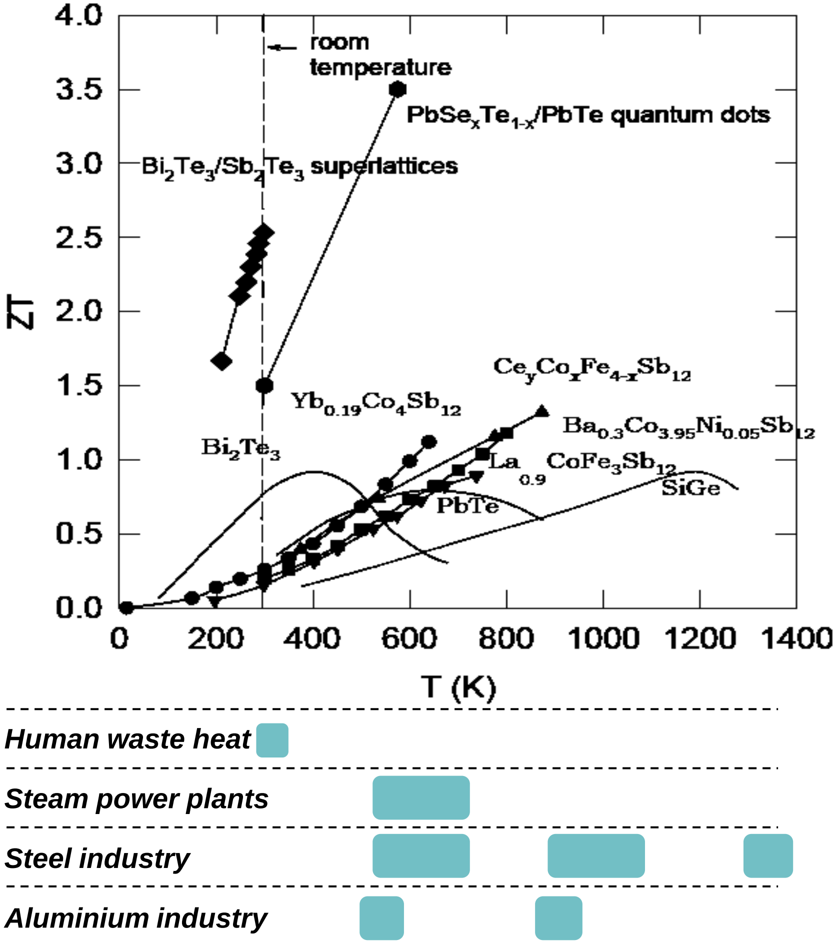




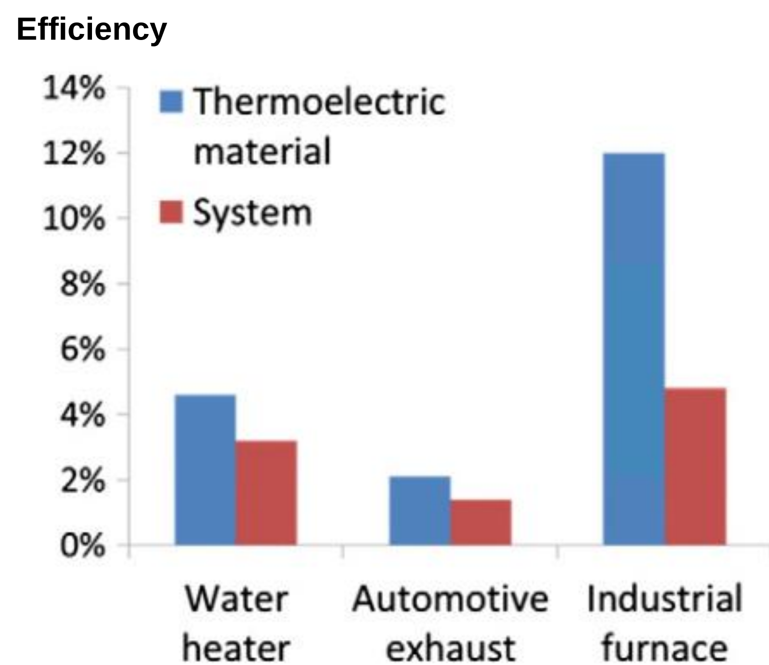
Assorted niche applications

E1 by Alphabet Energy

Different materials



Material vs System



LeBlanc, S. (2014). Thermoelectric generators: Linking material properties and systems engineering for waste heat recovery applications. *Sustainable Materials and Technologies*, *1*, 26–35. http://doi.org/10.1016/j.susmat.2014.11.002

Gaining insight into “real” numbers of modules

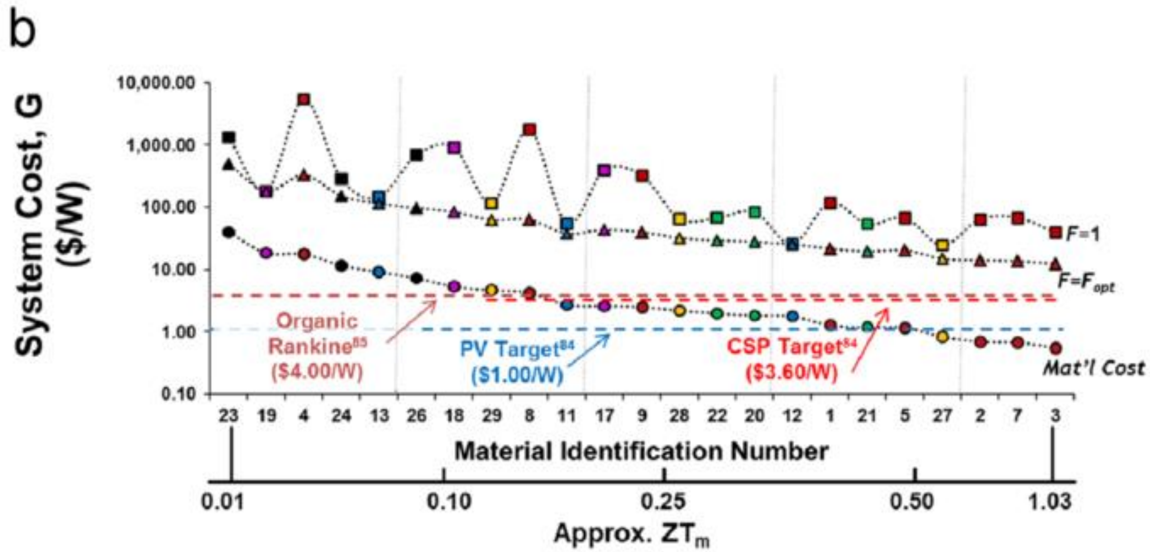
Case example:

Hot side = 250 C

Cold side = 20 C

$$G = \frac{C}{P_{gen}}$$

System cost of different materials



System cost is complex to calculate and requires many assumptions

Leblanc, S., Yee, S. K., Scullin, M. L., Dames, C., & Goodson, K. E. (2014). Material and manufacturing cost considerations for thermoelectrics. *Renewable and Sustainable Energy Reviews*, *32*, 313–327.

Calculating the desired efficiency from temperature difference

Want 6% efficiency

Case example:

Hot side = 250 C

Cold side = 20 C

+

$$\eta = \frac{T_h - T_c}{T_h} \frac{\sqrt{1 + ZT_{avg}} - 1}{\sqrt{1 + ZT_{avg}} + T_c/T_h}$$

Need system ZT of 0.16

Outline

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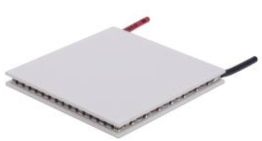
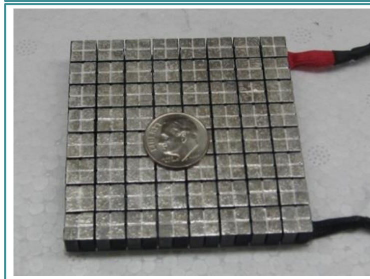
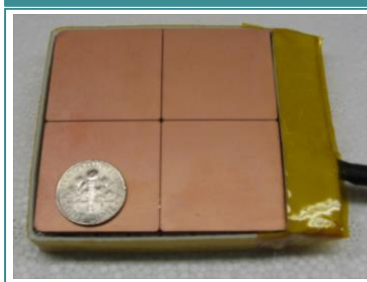
Low- Mid temperature modules

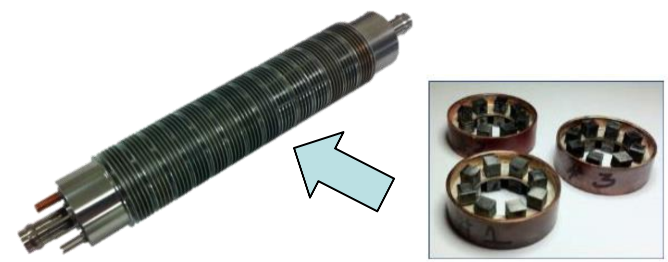
Module	Max T (C)	ΔT	Output	Efficiency
	210	110	3,6	~5%
	150	60	0,03	-
	160	140	1,5	-
	80	72	77	-

High temperature modules

Tubular designs

Pure CMO	
	Max T: 800C

CMO + Bi2Te3	
	Max T: 600C Claimed efficiency of 6%



Crane, D. T. (2012). Thermoelectric waste heat recovery program for passenger vehicles. *US Department Energy Efficiency & Renewable Energy (EERE)*, 114-121.
Schmitz, A., Stiewe, C., & Müller, E. (2013). Preparation of ring-shaped thermoelectric legs from PbTe powders for tubular thermoelectric modules. *Journal of electronic materials*, *42*(7), 1702.

Outline

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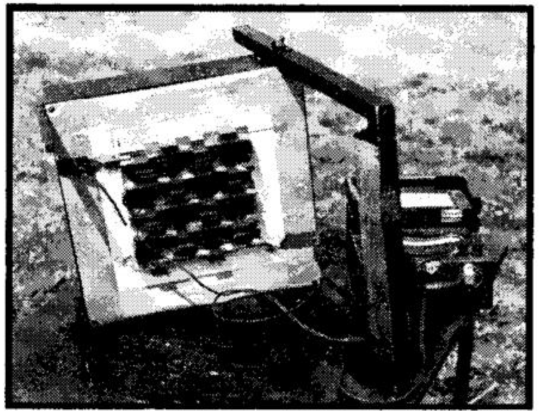
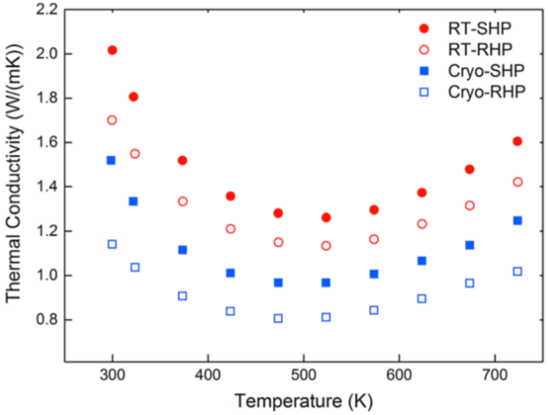
ZnSb: History and UiO research

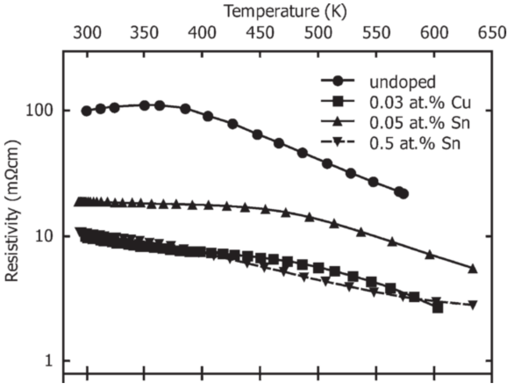
Solar thermoelectric generator (1950s)



Nanostructuring



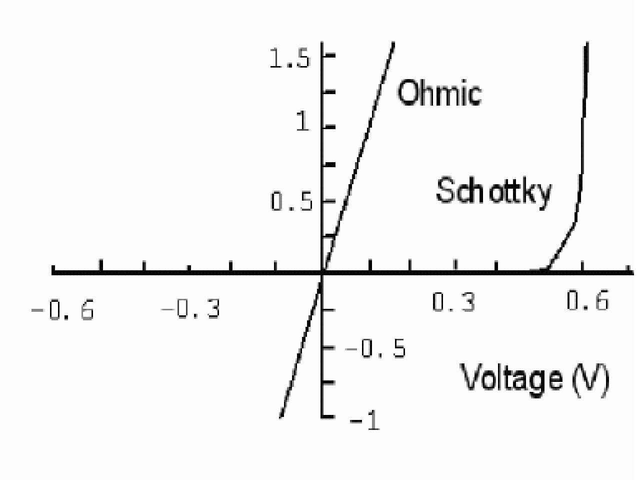
Doping



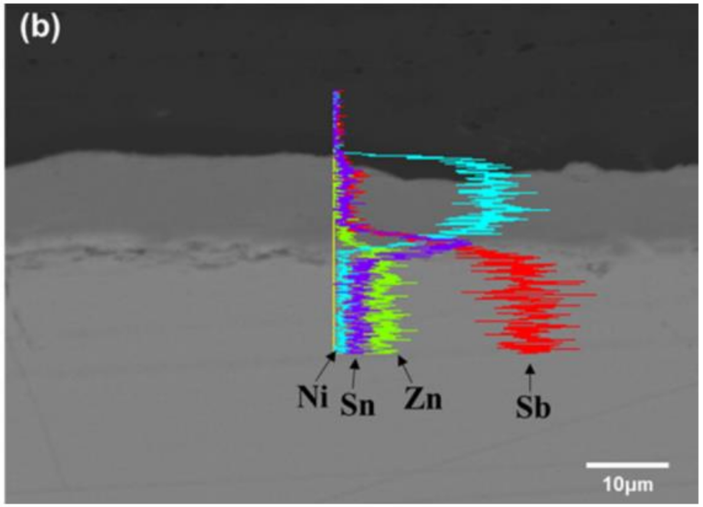
Telkes, M. (1954). Solar thermoelectric generators. *Journal of Applied Physics*, *25*(6), 765–77.
Songet al. (2015). Nanostructuring of Undoped ZnSb by Cryo-Milling. *Journal of Electronic Materials*, *44*(8), 1–7.
Böttger et al.(2011). Doping of p-type ZnSb: Single parabolic band model and impurity band conduction. *Physica Status Solidi (A) Applications and Materials Science*, *208*(12), 2753–2759.

ZnSb challenges: Optimization of contact interface

Electrical behavior



Diffusion



Lin, Y. C., Lee, K. T., Hwang, J. D., Chu, H. S., Hsu, C. C., Chen, S. C., & Chuang, T. H. (2016). Solid Liquid Interdiffusion Bonding of Zn4Sb3 Thermoelectric Material with Cu Electrode. *Journal of Electronic Materials*, *45*(10), 4935–4942.