Thermoelectricity:
From Atoms to Systems

Week 4: Thermoelectric Systems

Lecture 4.1: Thermoelectric Cooling and Power Generation Applications

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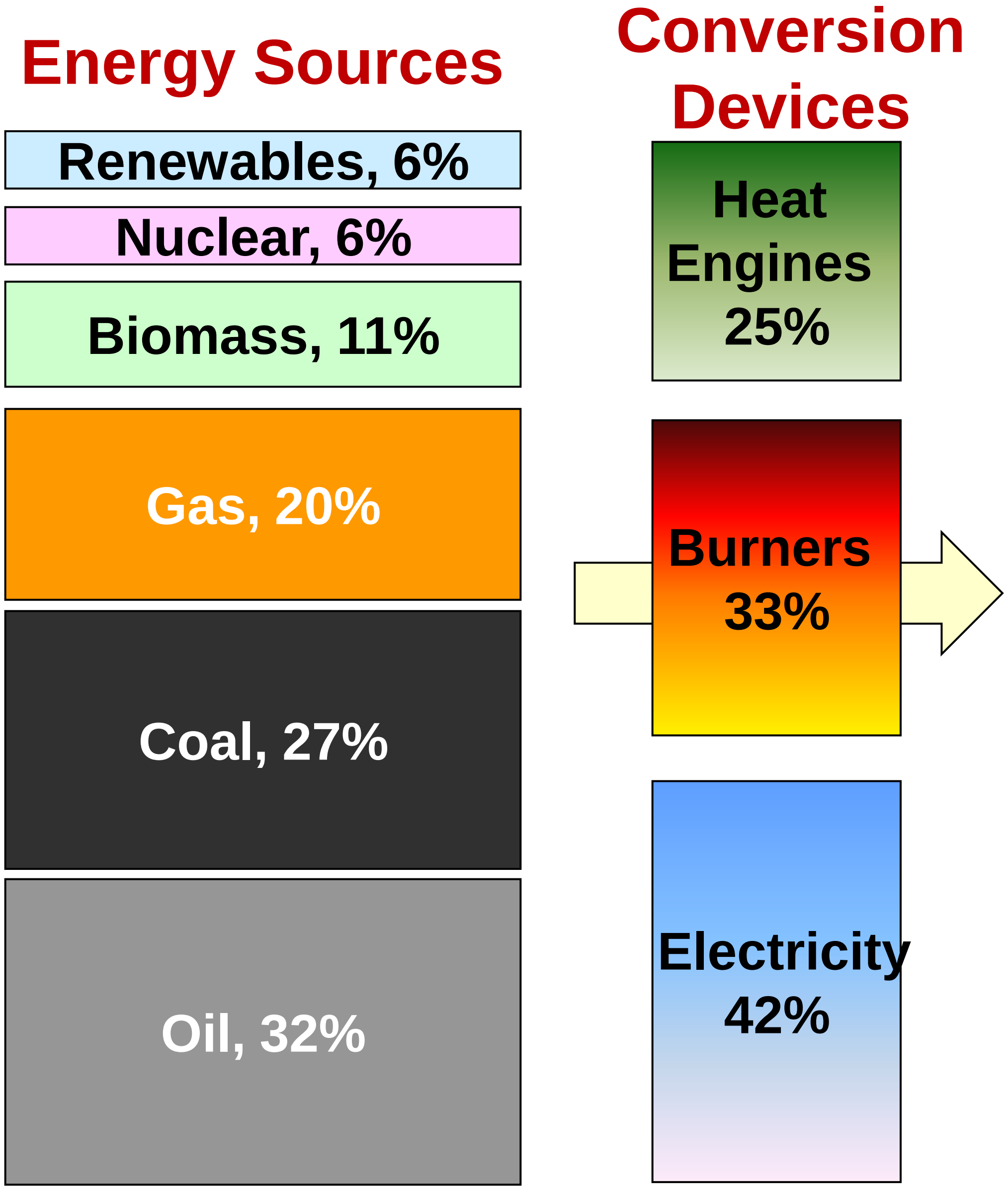
World Energy Use in 2005 (15TW)



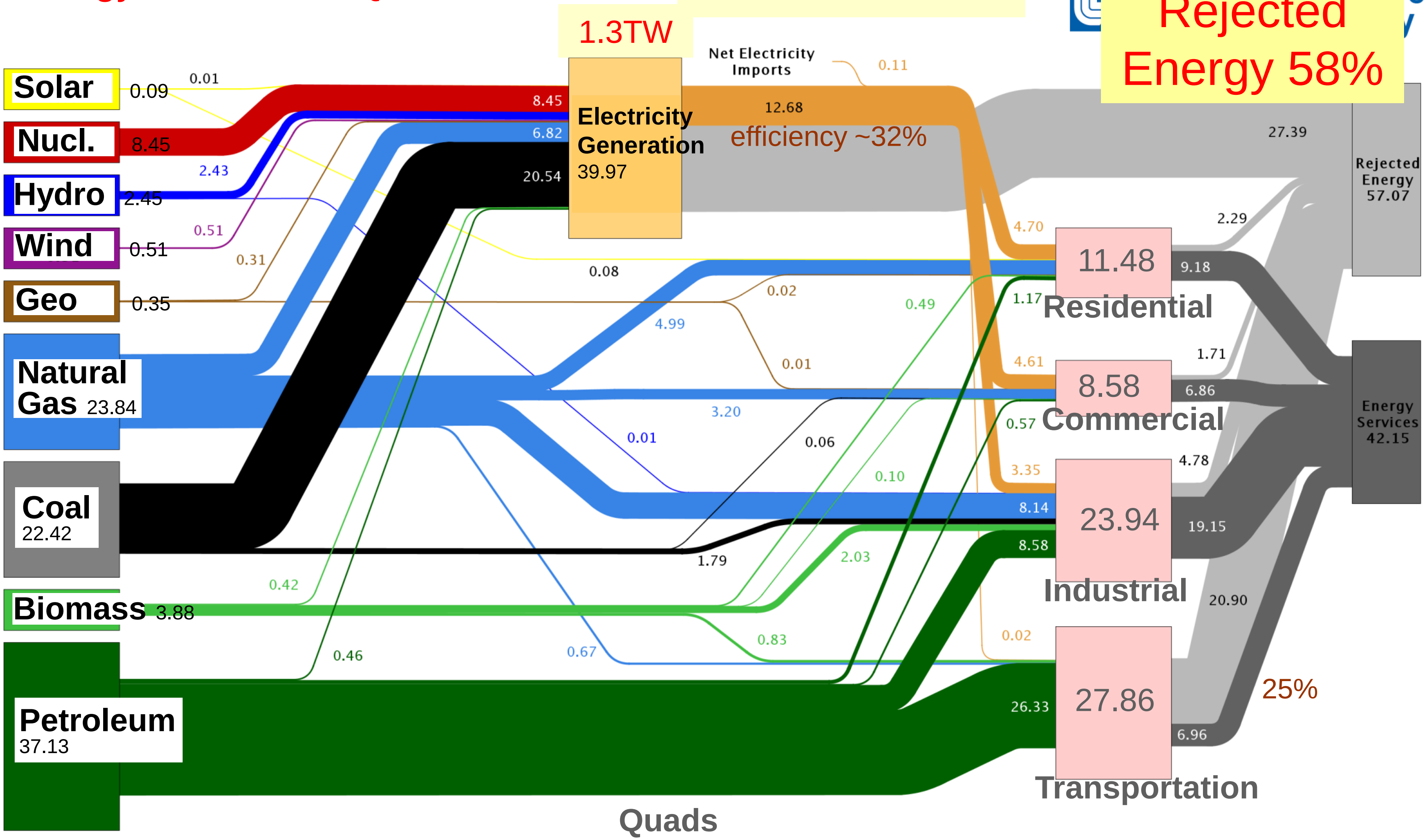
- More than 90% of primary energy is first converted to heat.
- Overall end-use exergy (12% of sources):
  - Motion 0.95 TW
  - Heat 0.73 TW
  - Cooling/Light/ Sound 0.06 TW

A. S. 15 August 2012

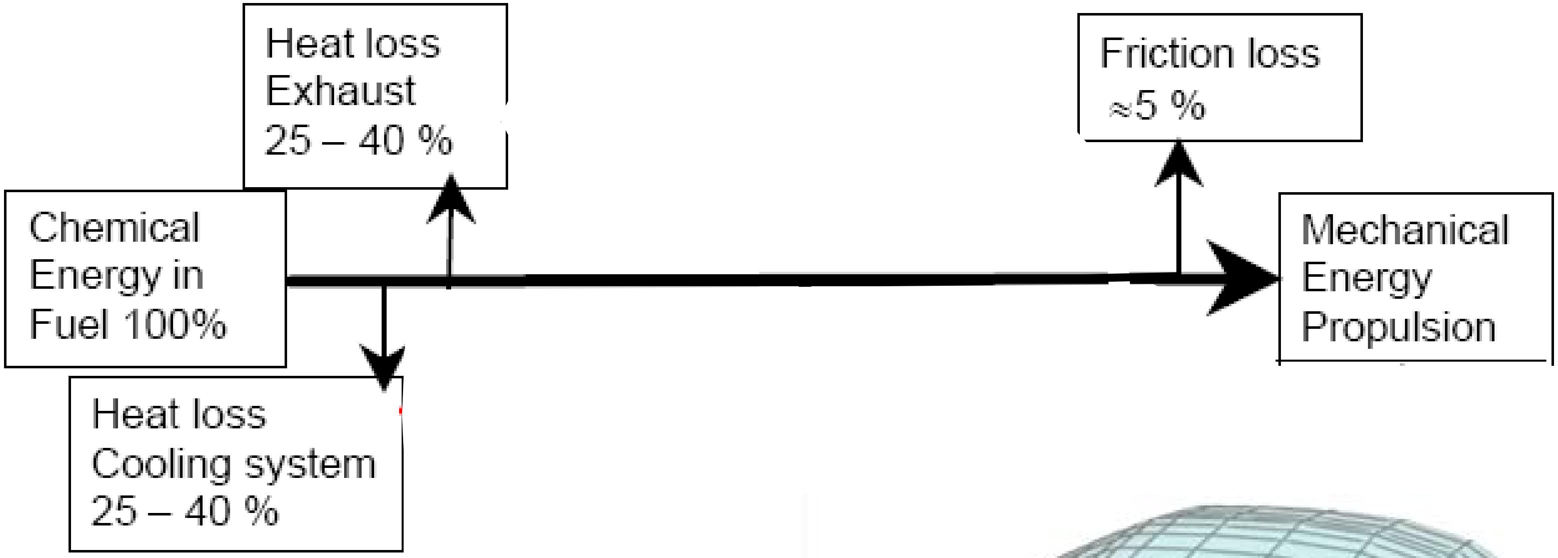
Adapted from Cullen and Allwood, *Energy*, 2010

US Energy Flow 2008

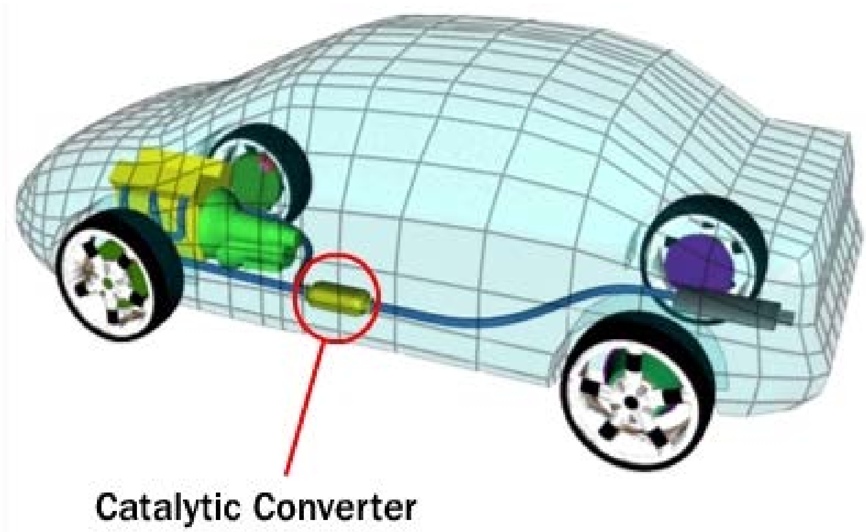
Energy Use = 99.2 Quad = 105 EJ → Power ~3.3 TW



Energy Waste in Cars

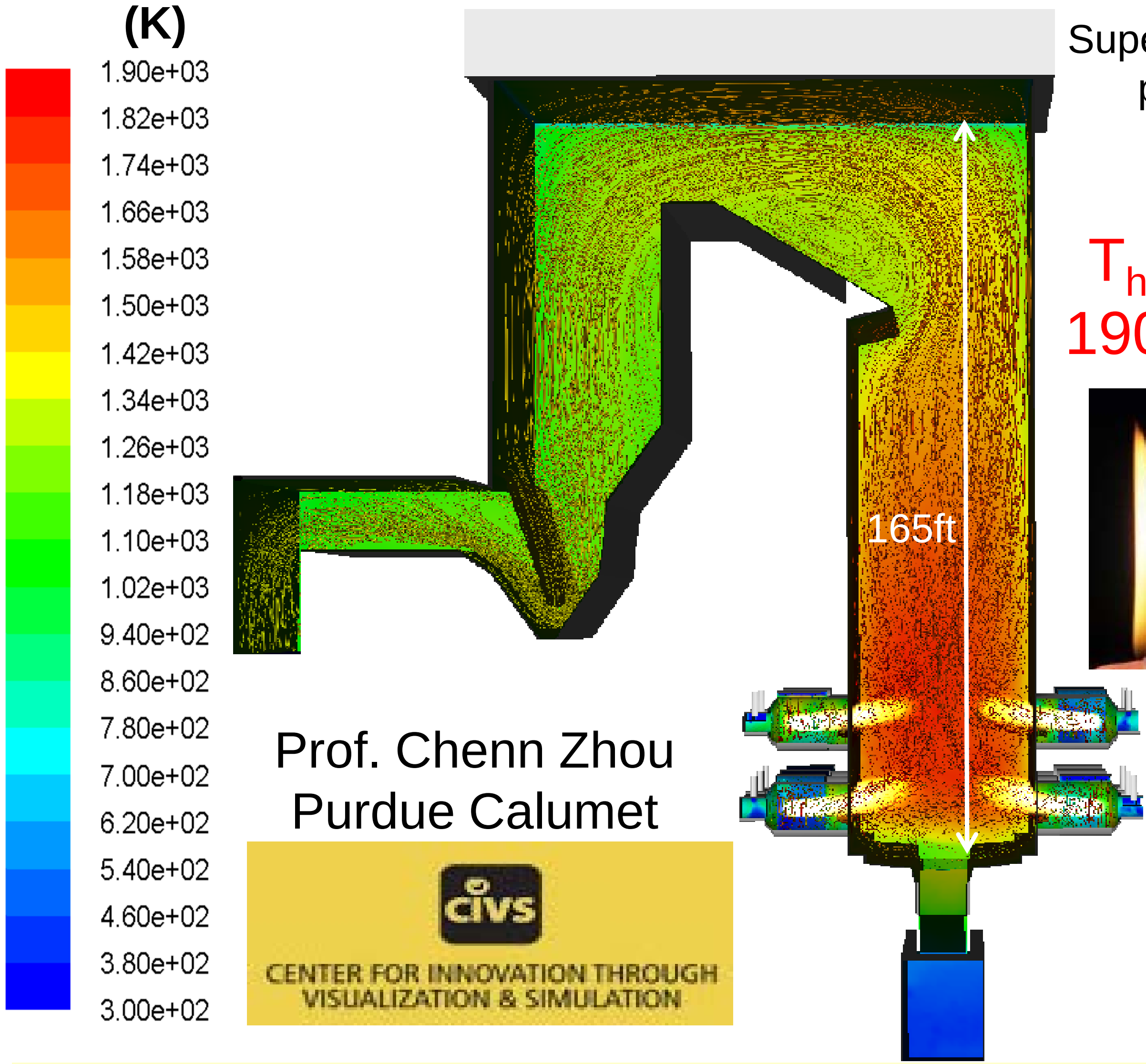


2/3 of the power in cars is dissipated (heat in the engine and in the catalytic converter)



T. Hendricks, PNNL

Coal Fired Power Plant



Prof. Chenn Zhou
Purdue Calumet

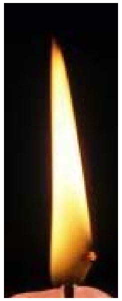
CENTER FOR INNOVATION THROUGH VISUALIZATION & SIMULATION

Supercritical steam turbine with 520 MW_e power output, efficiency ~40-42%

T_{hot}= 1900K

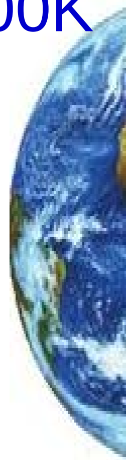
$T_{working\ fluid}$= 813K

$T_{ambient}$= 300K



TE

Rankine cycle

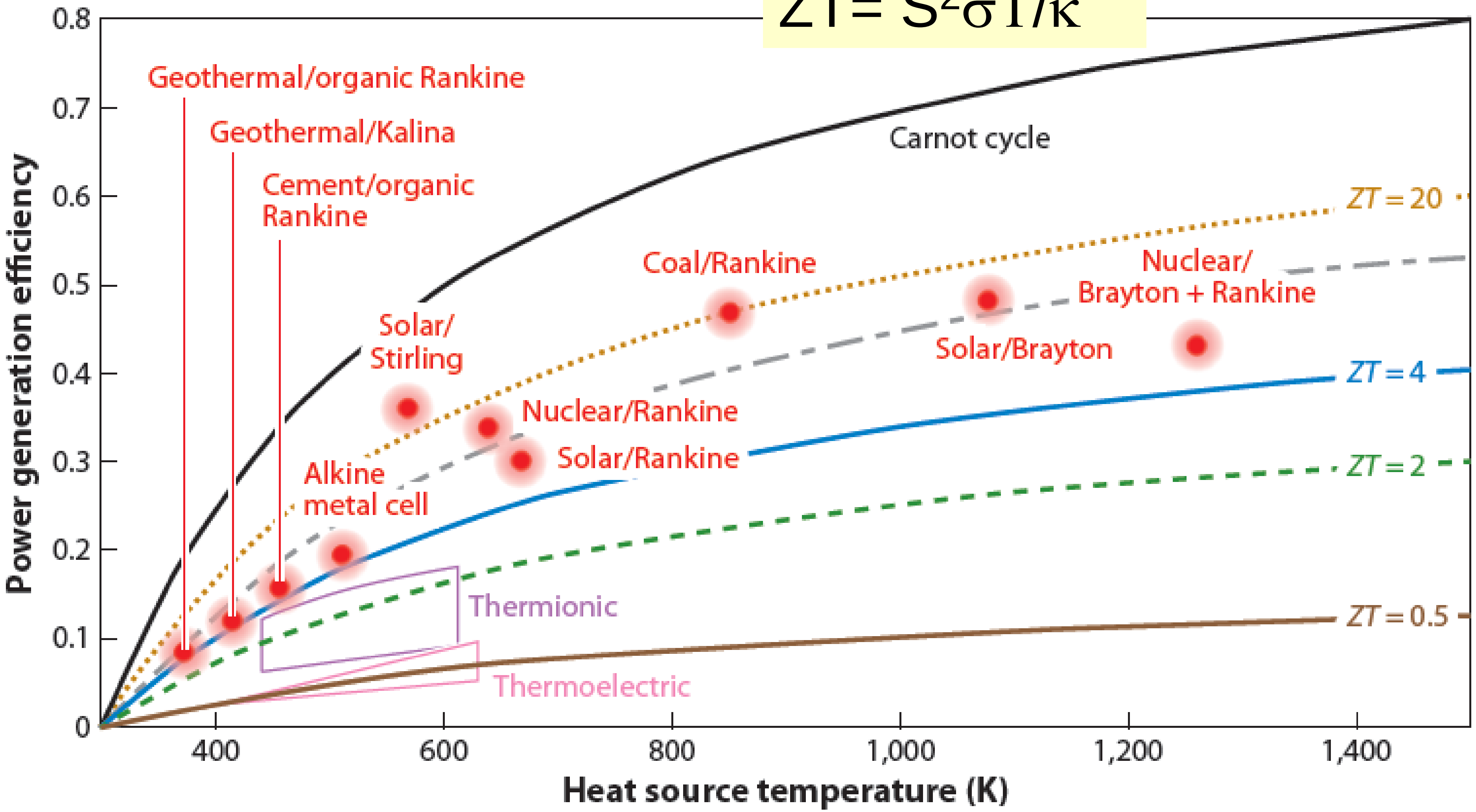


Thermoelectric generator for topping cycle application

- Highest exergy lost is between the flame and the working fluid (steam).
- Highest steam temperatures/pressures are limited by the turbine materials.

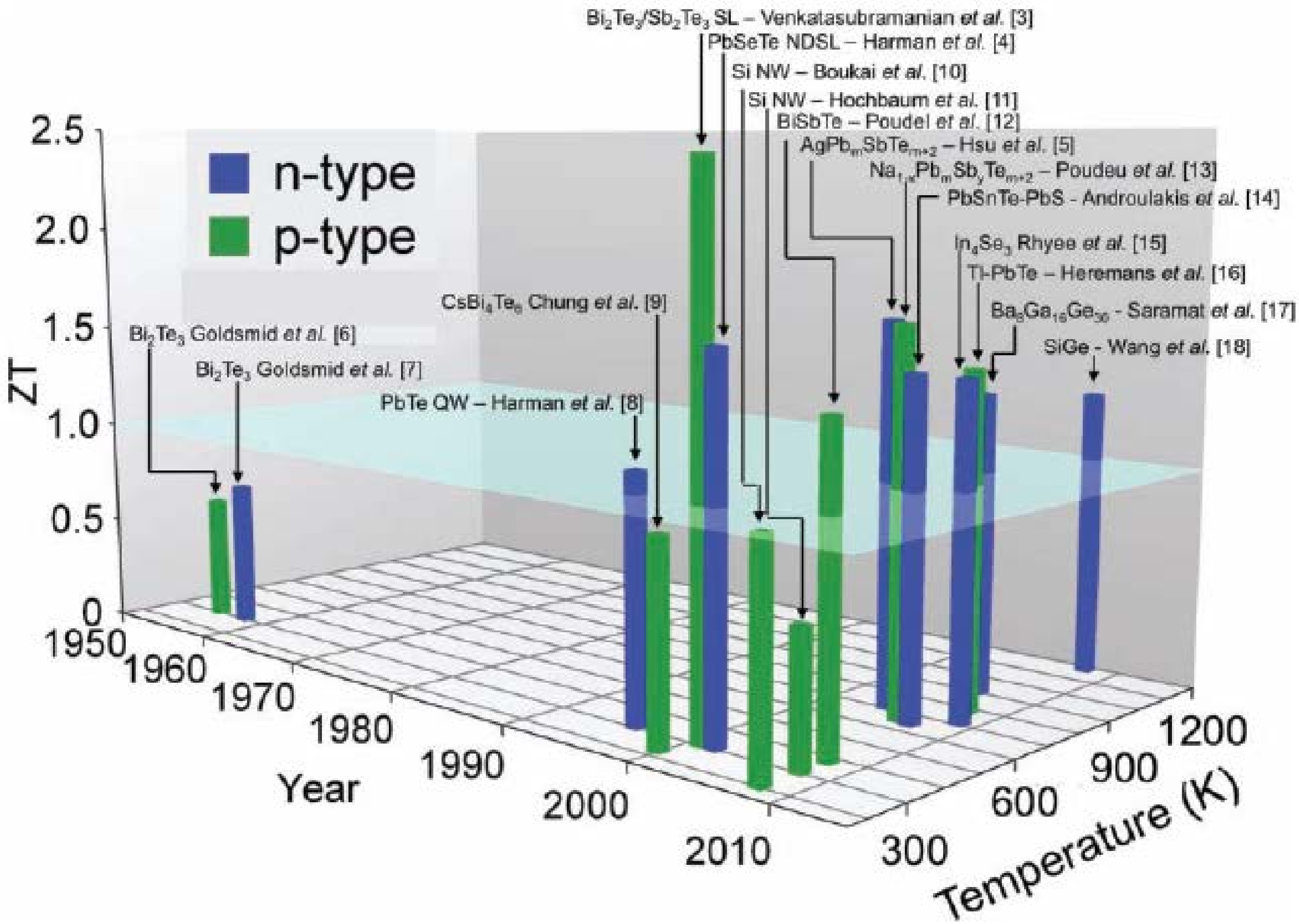
Power Generation Efficiencies

$ZT = S^2\sigma T/\kappa$



Adapted from Cronin Vining, Nature Materials 2009

Recent Advances in ZT



Some record ZT's are not independently verified

Nanostructured Thermoelectrics: Big Efficiency Gains from Small Features, *Vineis et al*. **Advanced Materials, 22,** 2010

An inconvenient truth about Organic Solar Cells

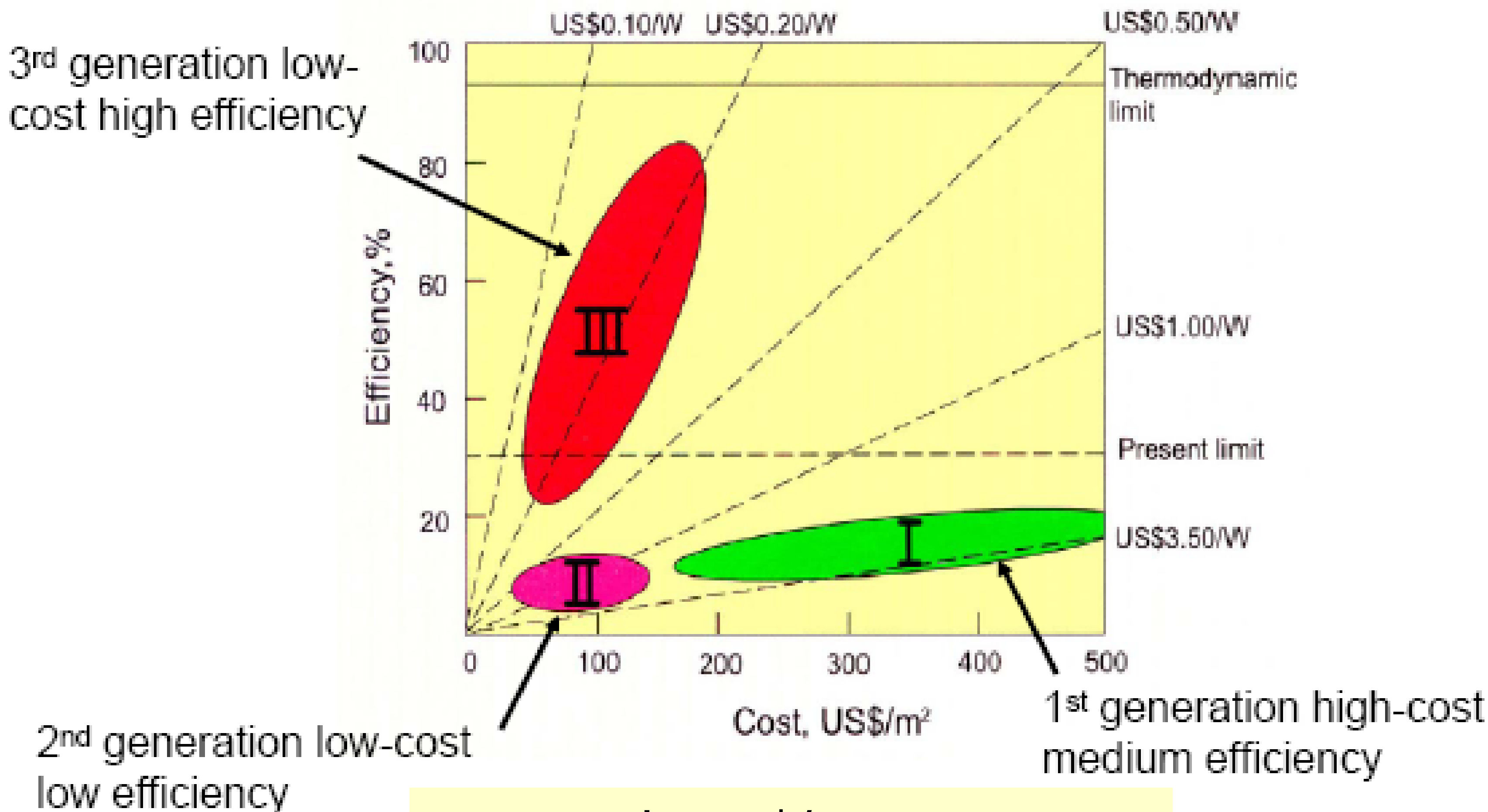
Cronin B. Vining

Despite recent advances, Organic Solar Cells will never be as efficient as multi junction cryst. That means Org. Solar Cells will remain limited to applications served poorly or not at all by existing technology. Bad news for Organic Solar Cells, but the climate crisis requires that we face bad news head on.

NATURE MATERIALS | VOL 8 | FEBRUARY 2009 |

Solar Cells

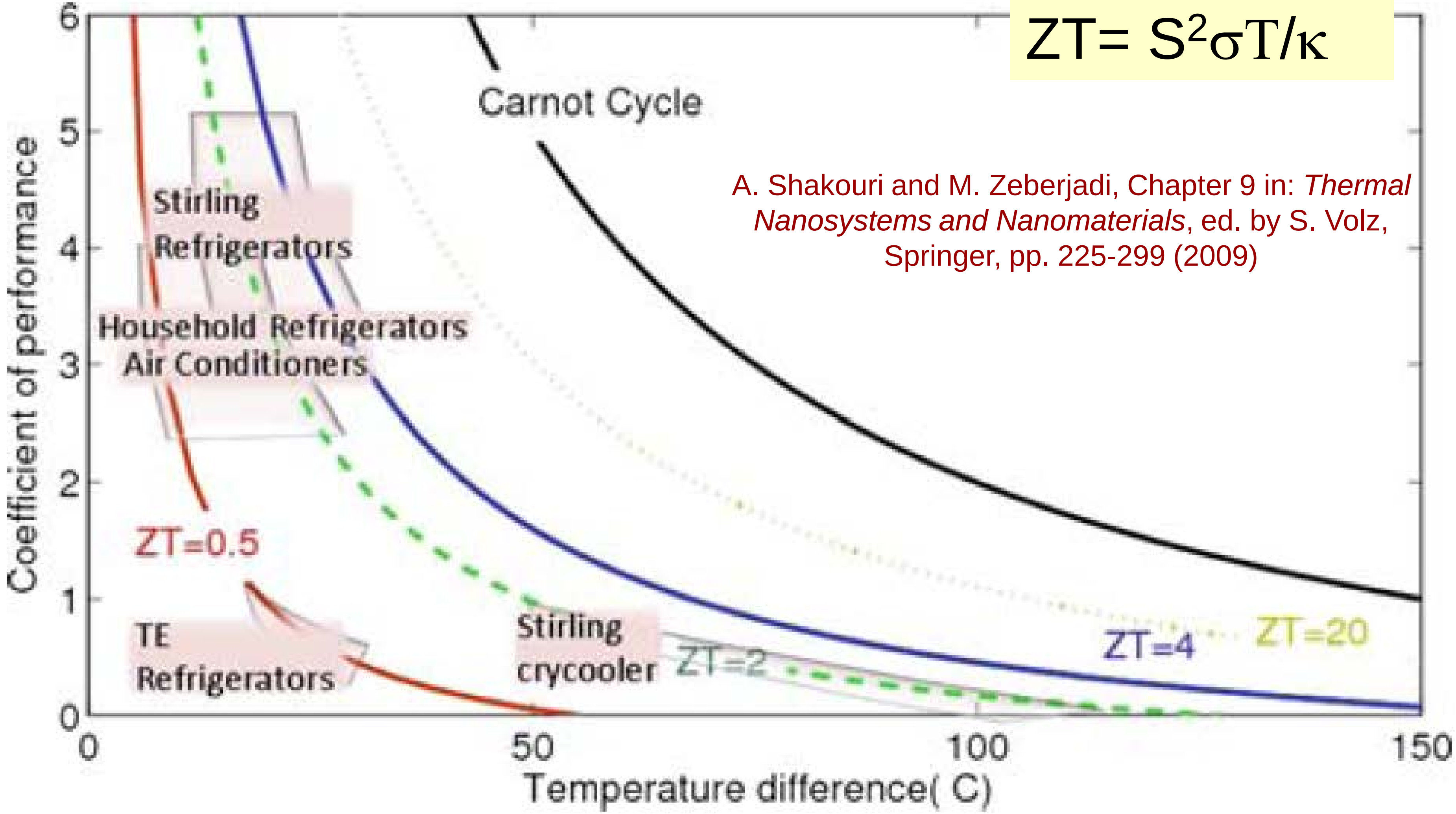
(Efficiency+ Cost → $/W)



How about $/W versusTE material performance (ZT)?

Coefficient of Performance of Refrigerators

$ZT = S^2\sigma T/\kappa$



A. Shakouri and M. Zeberjadi, Chapter 9 in: *Thermal Nanosystems and Nanomaterials*, ed. by S. Volz, Springer, pp. 225-299 (2009)

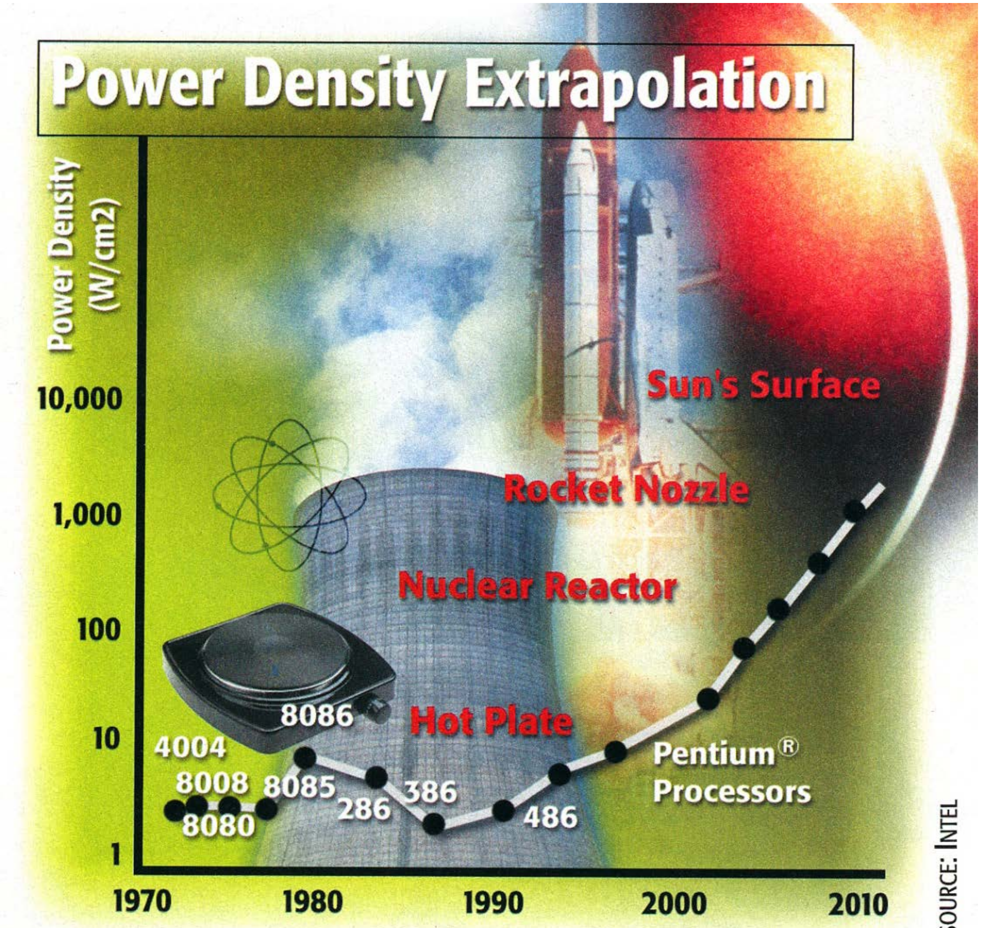
TEs for Telecom Cooling

- TE manufacturers provide coolers specifically designed for Telecom laser-cooling and low noise detector/sensor applications

Cronin Vining, ZT Services

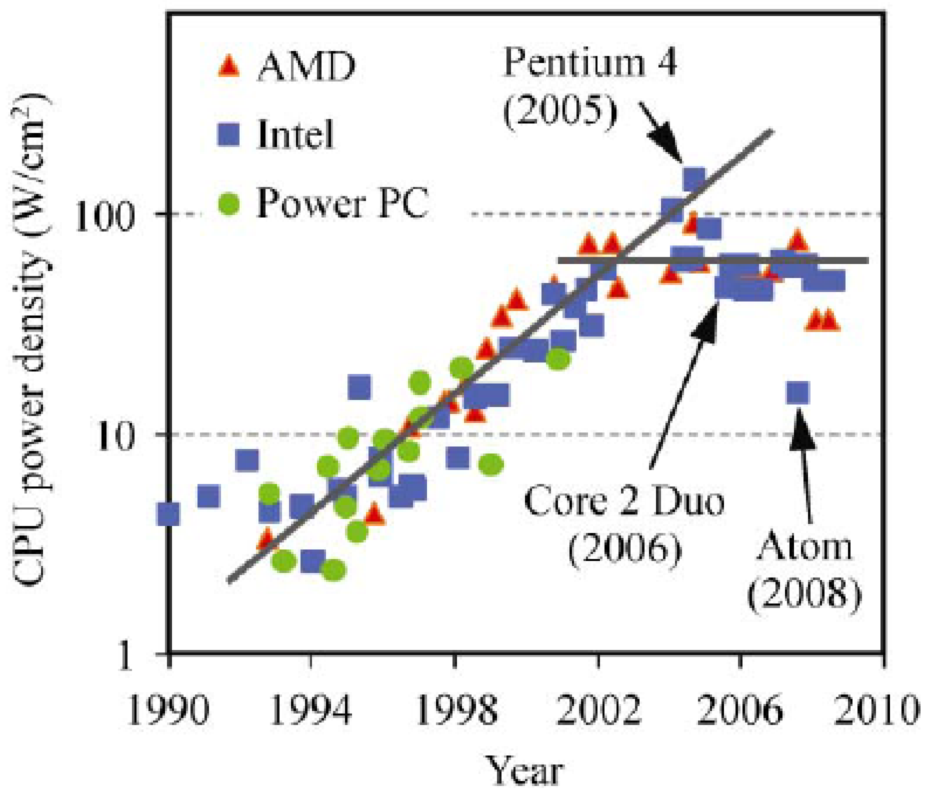
Microprocessor Cooling Requirement

Predictions around 2000-2002



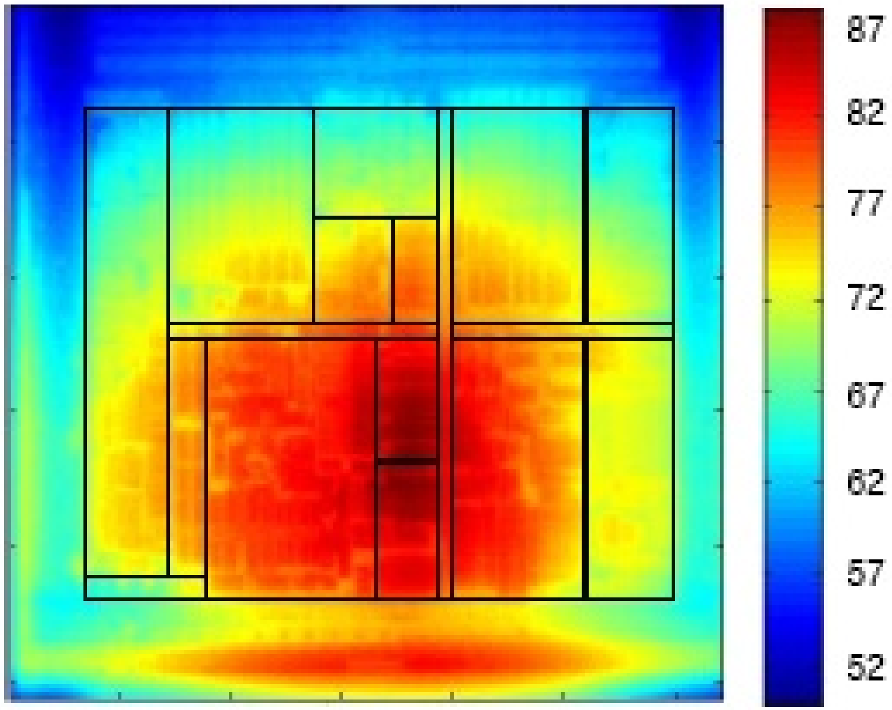
CPU - Computer Power User Magazine

Nano Res.
2010 Eric Pop



Localized heating in microelectronics

- Leakage power exponential increase with temperature
  - Potential thermal runaway
- Lifetime exponential decrease with temperature – e.g. electromigration, oxide breakdown
  - (ΔT= 15C → ¼ lifetime)
- Interconnect delay
- Crosstalk noise



http://masc.cse.ucsc.edu

Thermal integrity: a must for low-power-IC digital design, EDN 15 Sept. 2005

Lectrure 4.1: Summary

- A significant fraction of energy from chemical and nuclear sources is wasted in the form of heat
  - Waste heat recovery in cars and trucks
  - Thermoelectric topping cycle in power plants
- Peltier coolers can provide localized, high speed, high power density cooling for electronics and optoelectronics
- Thermoelectric cooling and power generation should be evaluated in terms of efficiency, cost, size, material use, noise, …