Thermoelectricity: From Atoms to Systems

Week 3: Thermoelectric Characterization
Lecture 3.0: Introduction and Motivation

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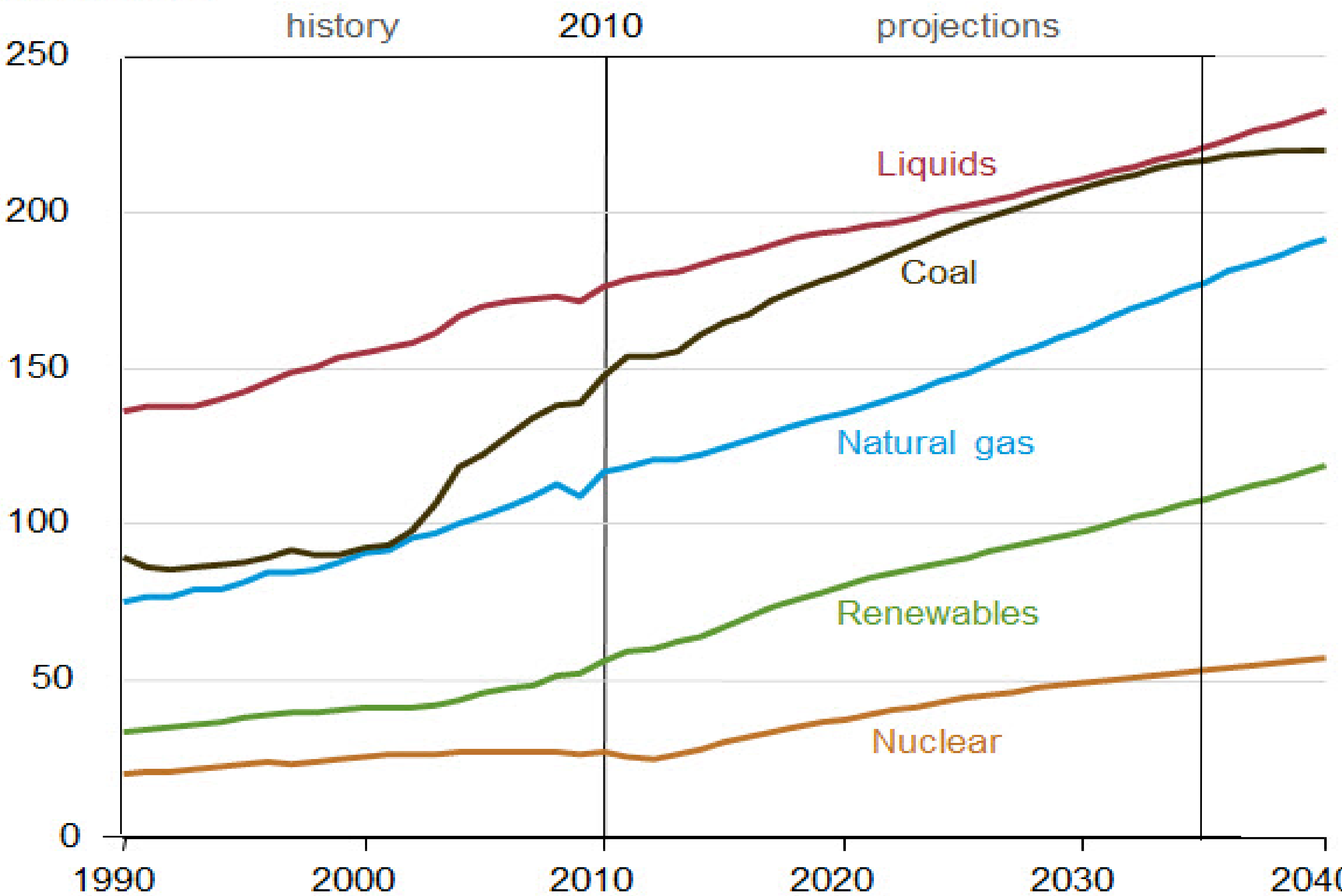
World Marketed Energy Use1990-2035

US Department of Energy; Energy Information Administration (2010, 2013)

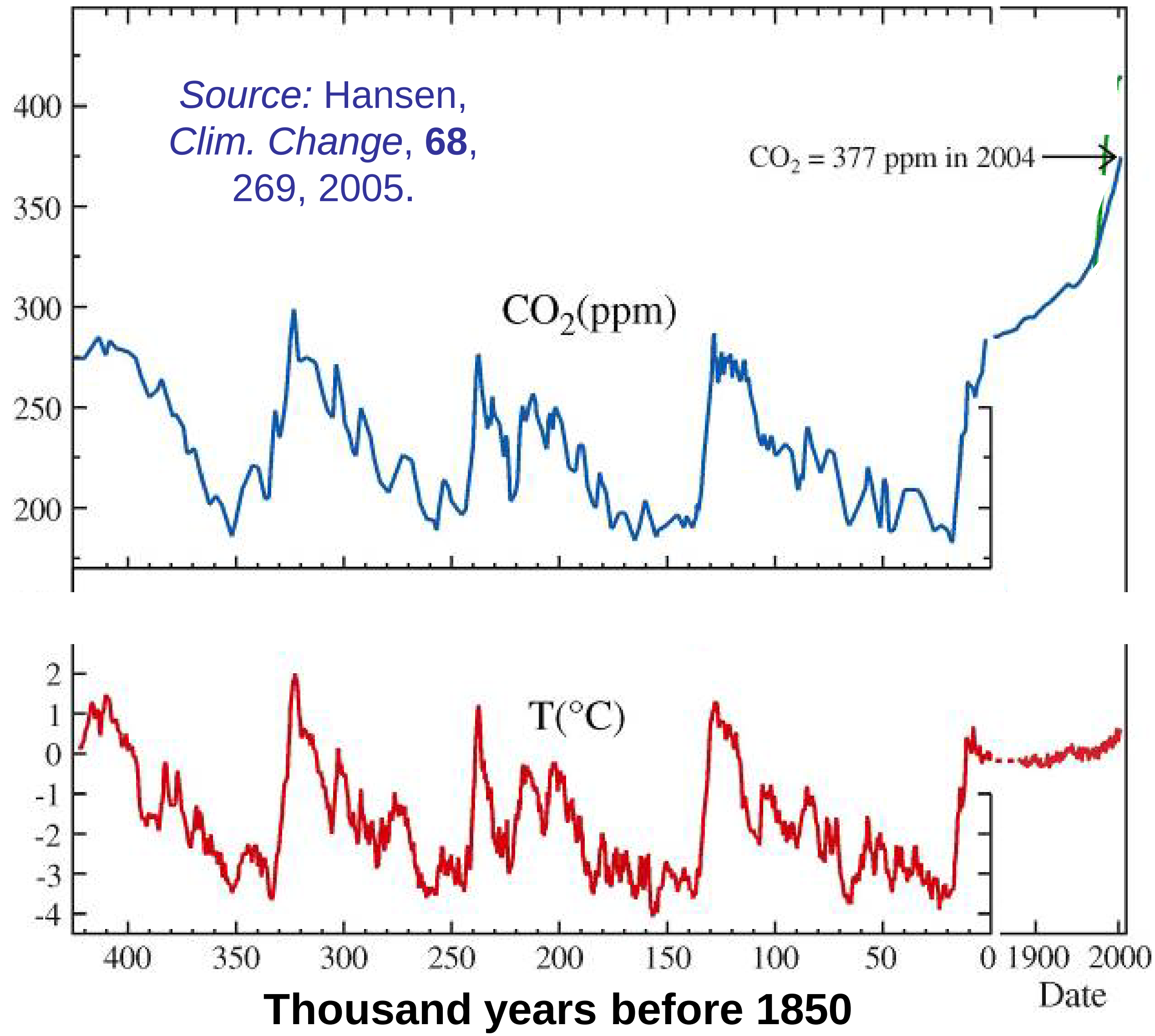
1 Quad = 1.055 x 10^{18}J

13TW

2050: 25-30TW



Climate Change

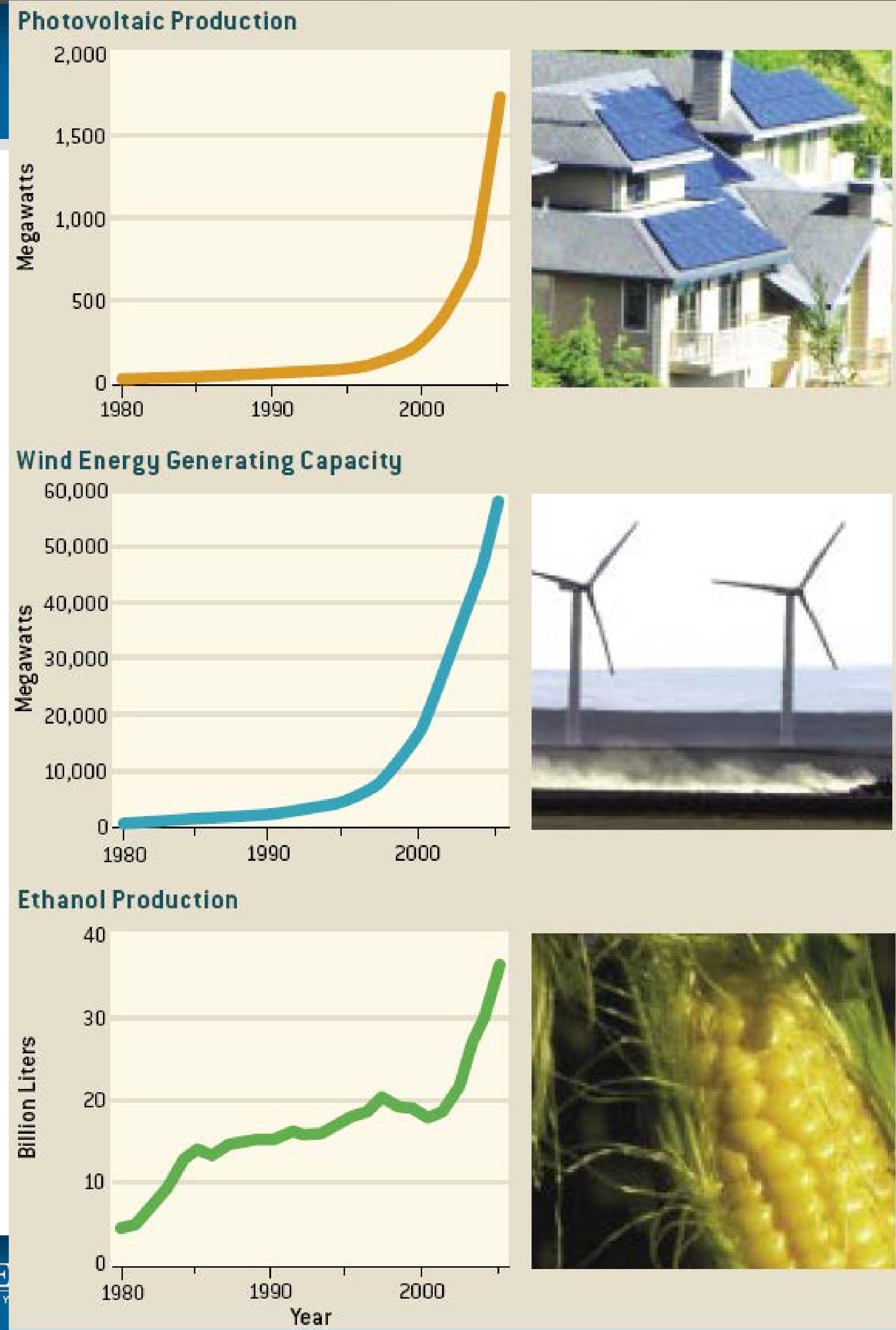


John P. Holdren, 2006

Photovoltaic Production

Wind Energy Generating Capacity

Ethanol Production



2009: 24 GW
2011: 67GW

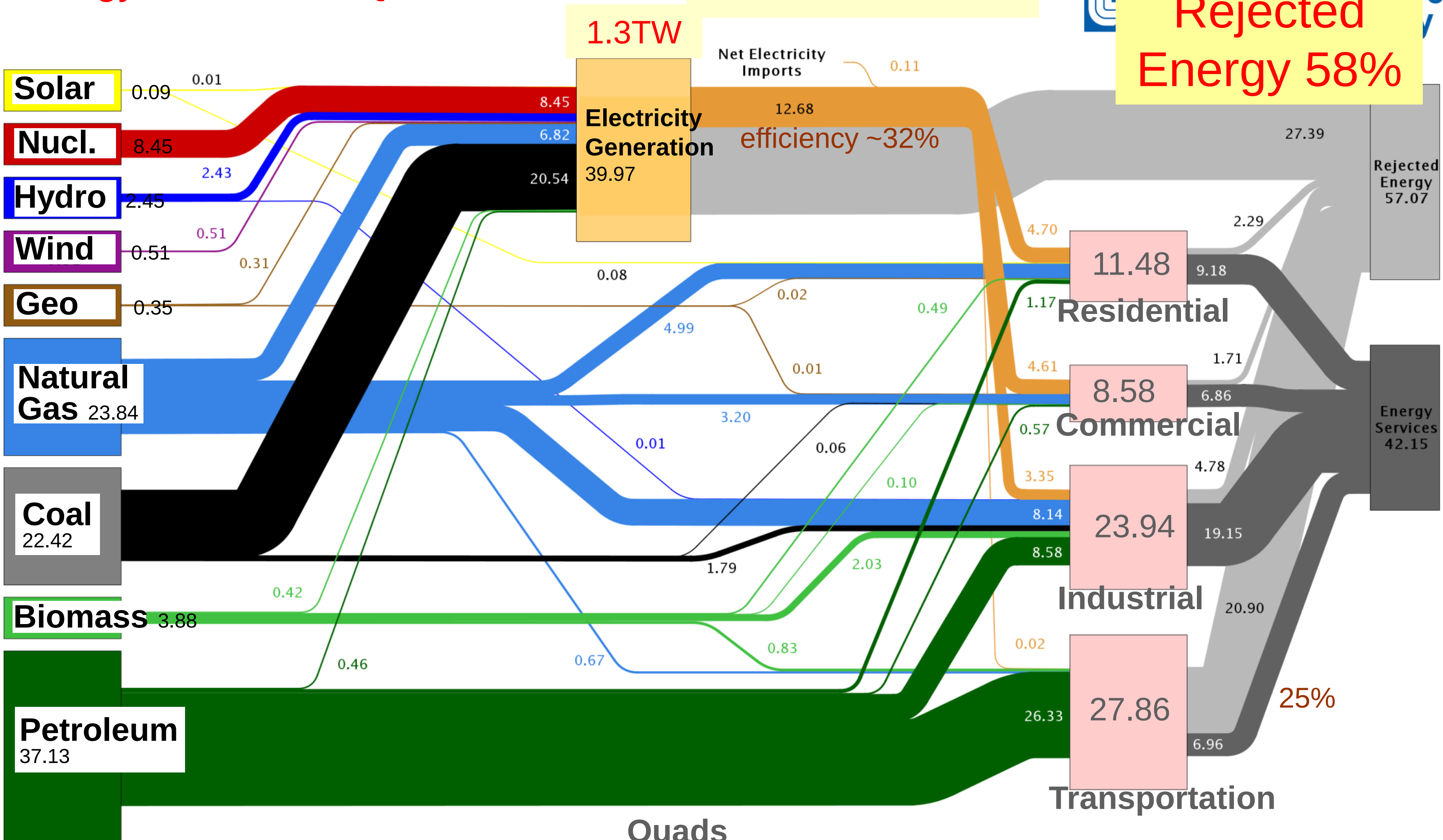
2009: 160 GW
2011: 238GW

2009: 75 B liters
2011: 86 B liters

Dan Kammen
Scientific American
Sept. 2006

US Energy Flow 2008

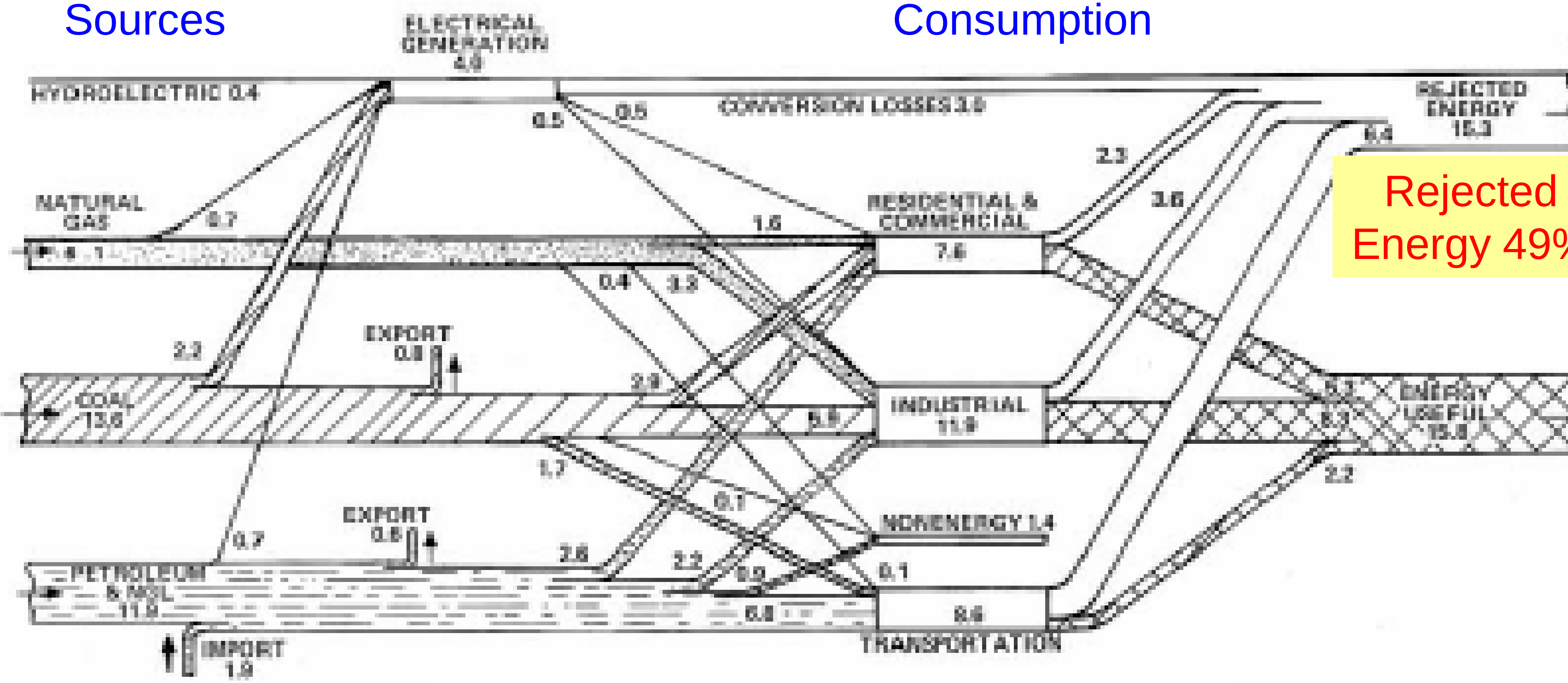
Energy Use = 99.2 Quad = 105 EJ → Power ~3.3 TW



US Energy Flow 1950

Energy Sources

Energy Consumption

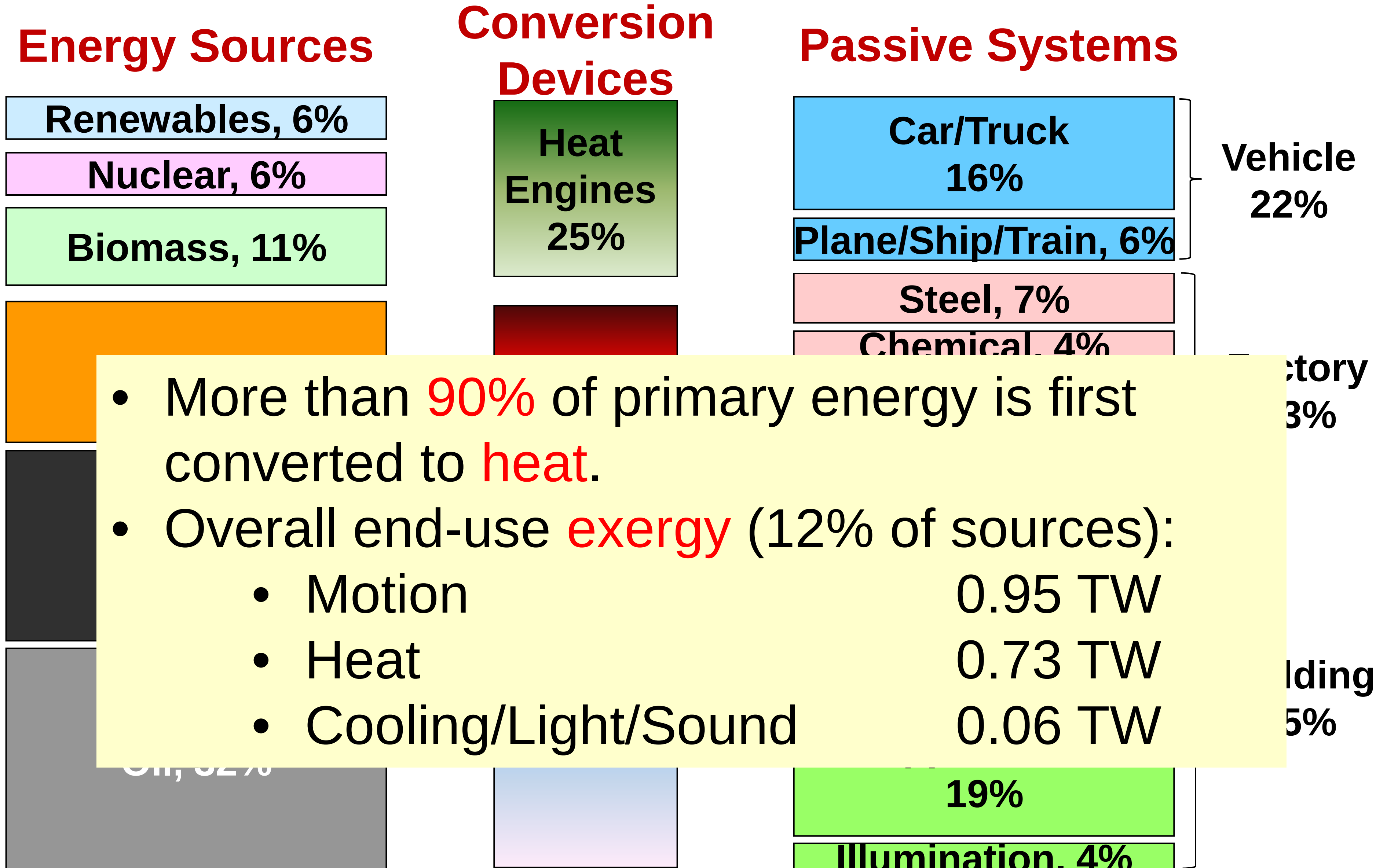


Rejected Energy 49%

LLNL

Total 31.8 Quad
Population: 161M

World Energy Use in 2005 (15TW)



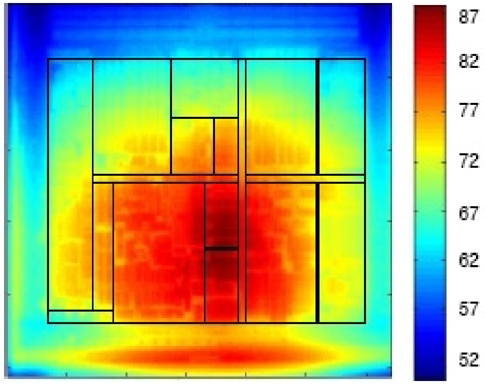
- More than 90% of primary energy is first converted to heat.
- Overall end-use exergy (12% of sources):
  - Motion 0.95 TW
  - Heat 0.73 TW
  - Cooling/Light/Sound 0.06 TW

A. S. 15 August 2012

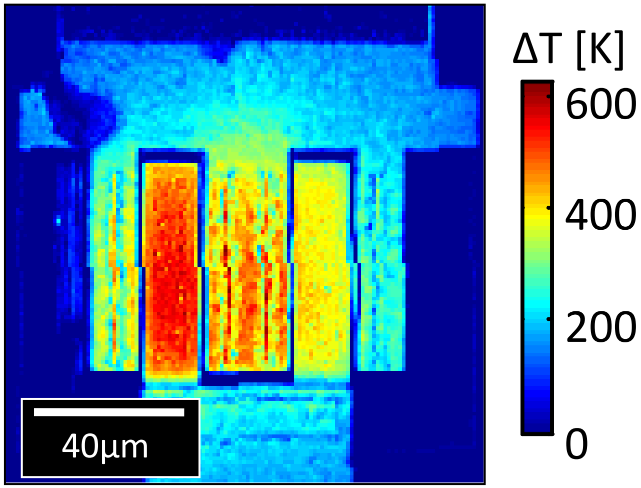
Adapted from Cullen and Allwood, *Energy*, 2010

Localized heating in microelectronics

- Leakage power exponential increase with temperature
  - Potential thermal runaway
- Lifetime exponential decrease with temperature
  - (ΔT= 15C → ¼ lifetime)

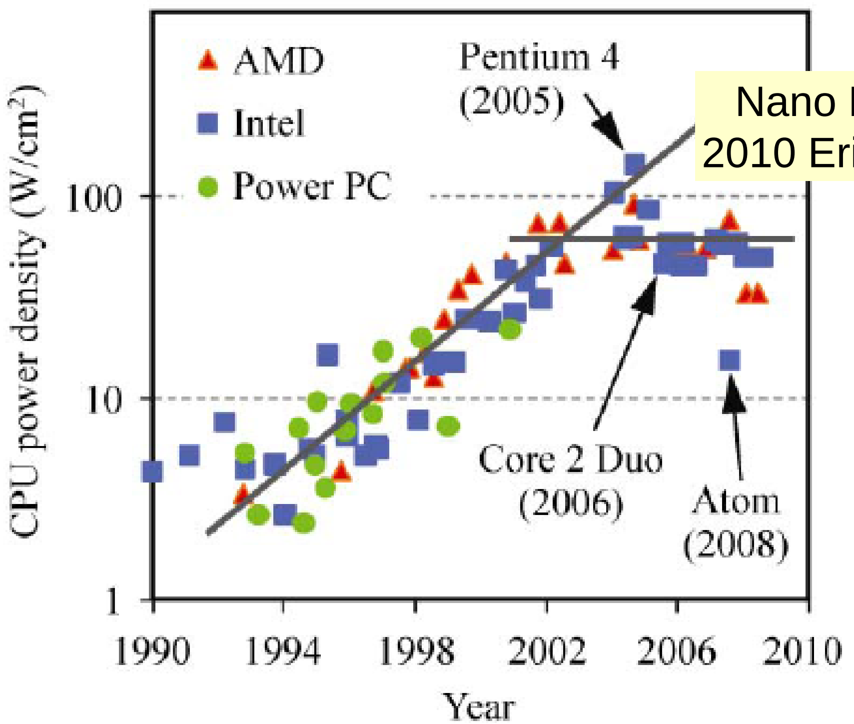


http://masc.cse.ucsc.edu



SCR, I= 1.22A, 170µs

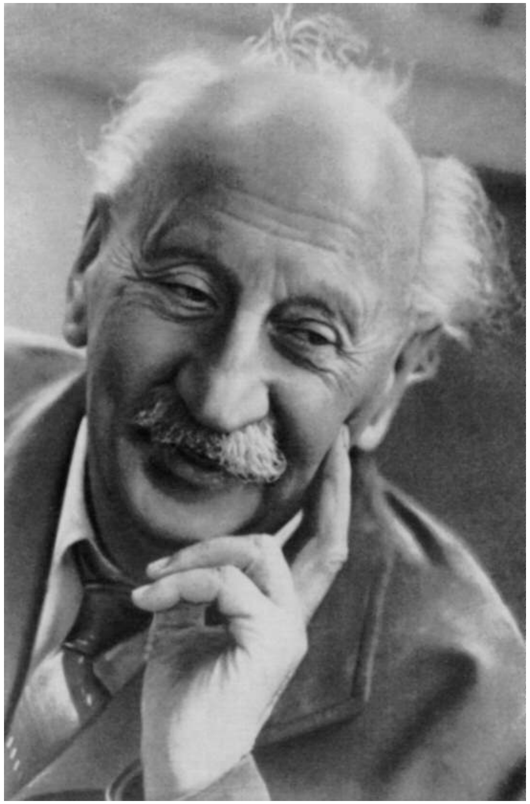
K. Maize, V. Vashchenko et al, *IRPS*, 2011.



Nano Res. 2010 Eric Pop

Early Thermoelectricity

- First practical devices USSR during WWII
  - Tens of thousands built, to power radios from any available heat source.
- In the 1950s-60s many in the US & USSR felt semiconductor thermoelectrics could replace mechanical engines, much as semiconductor electronics were replacing vacuum tube technology.
  - Hint: it didn't happen!



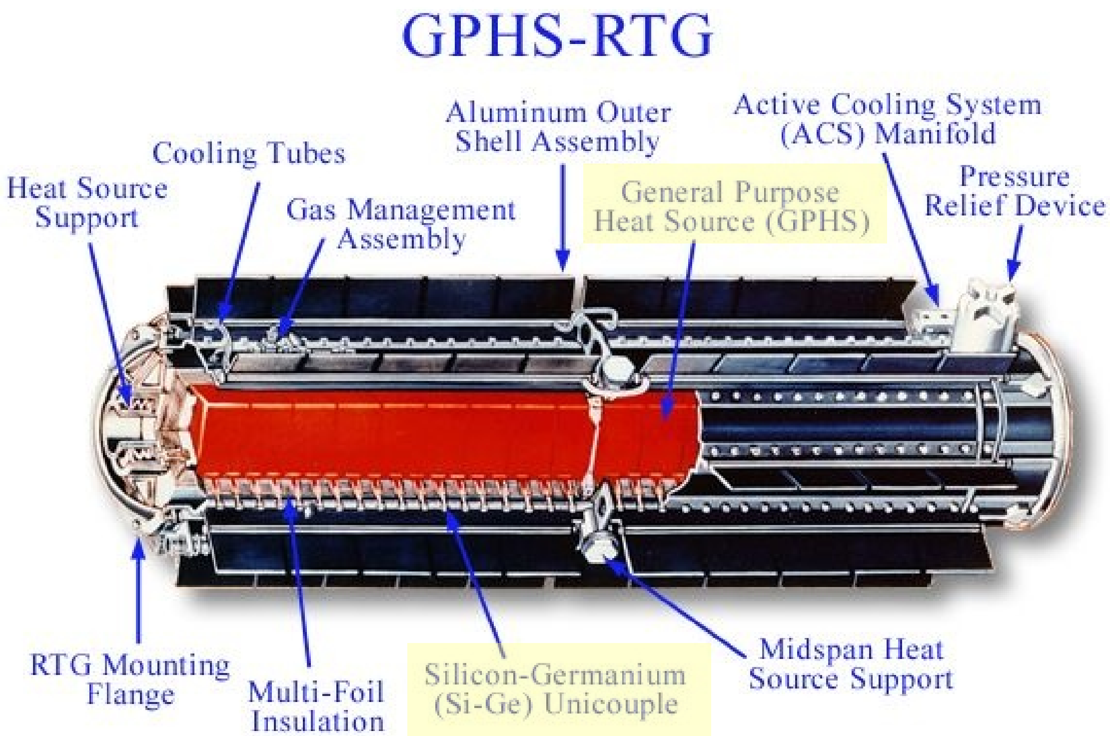
Abram F. Ioffe 1880-1960

Ioffe, A. F. (1957). Semiconductor Thermoelements and Thermoelectric Cooling. London, Infosearch Limited.

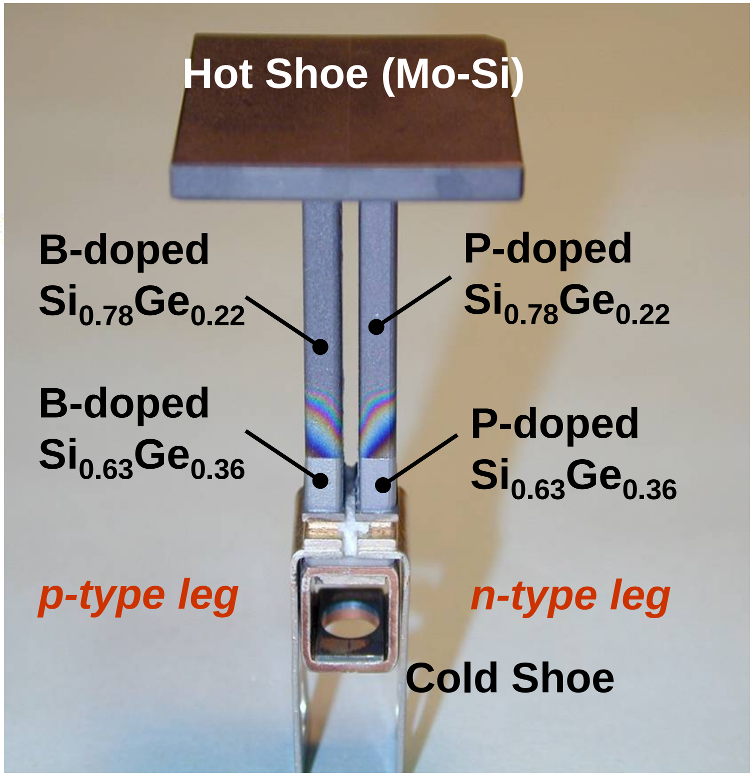
Cronin Vining, ZT Services

Radioisotope Thermoelectric Generators (Voyager, Galileo, Cassini, …)

- 55 kg, 300 W_e, ‘only’ 7 % conversion efficiency
- But > 1,000,000,000,000 device hours without a single failure

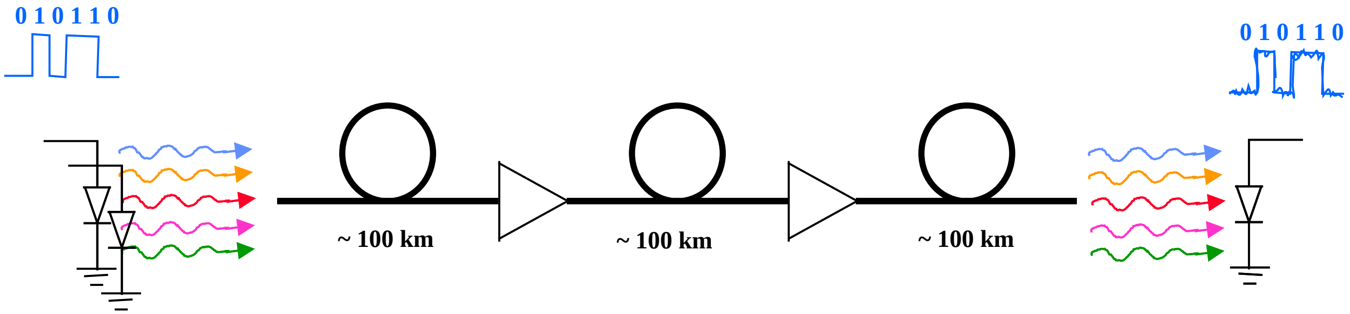


Cronin Vining, ZT Services



SiGe unicouple

Wavelength Division Multiplexing



$\Delta\lambda$ ~ 0.4-0.8 nm

- **Optoelectronic devices generate kW/cm^2 and they need temperature stabilization.**

Typical DFB Laser:

$\Delta\lambda/\Delta T$= 0.1 nm/^{o}C

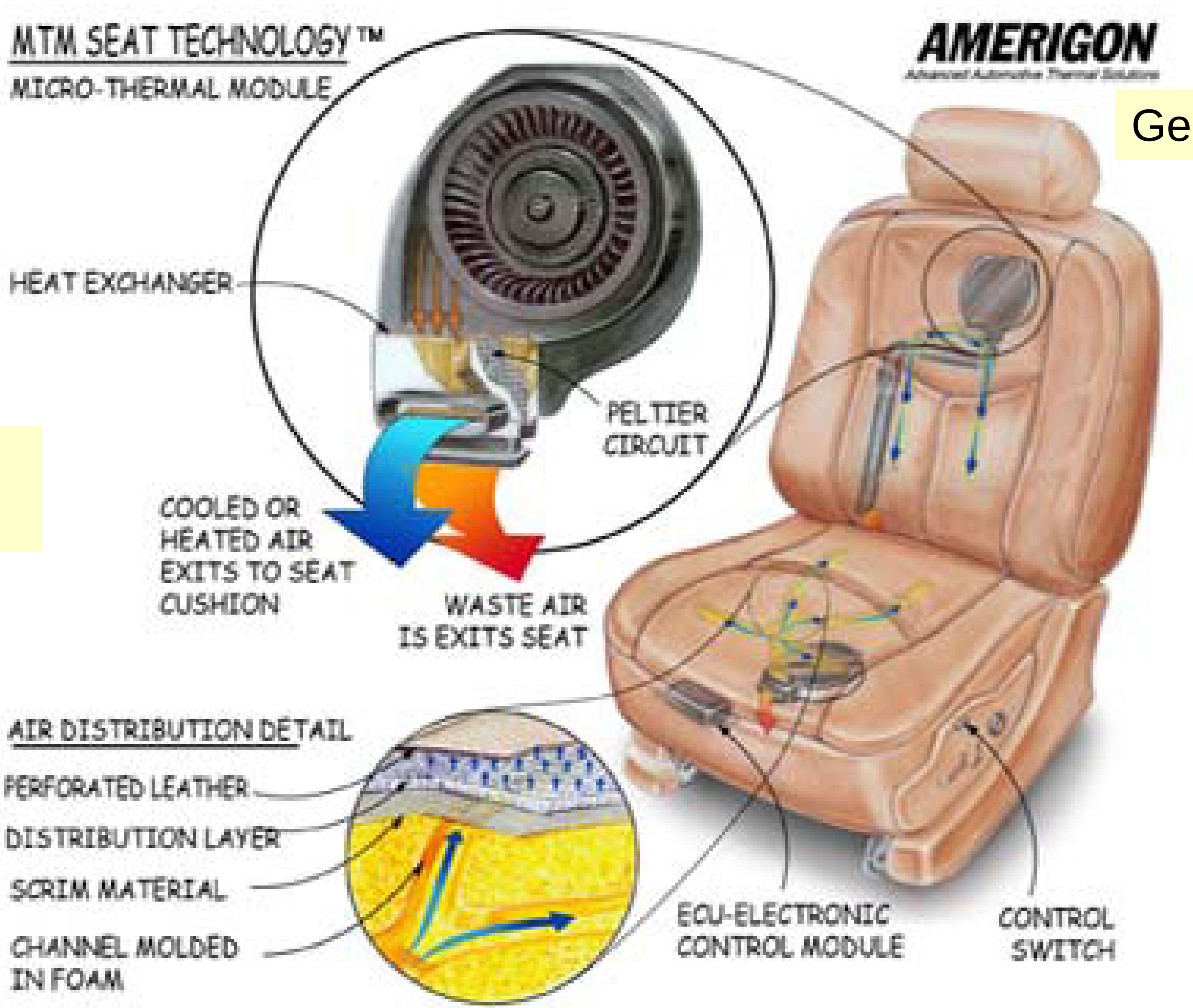
TEs for Telecom Cooling

- Melcor, Marlow and many other TE manufacturers provide coolers specifically designed for Telecom laser-cooling applications

Cronin Vining, ZT Services

Thermoelectrically-Cooled/Heated Car Seat

Lon Bell
BSST



GenTherm

Summary

- Impact in energy systems
  - Waste heat recovery
  - Topping cycle applications
- Thermal management in electronics and optoelectronics
  - Microrefrigeration
- Characterization of electrical and thermoelectric transport in nanocomposites