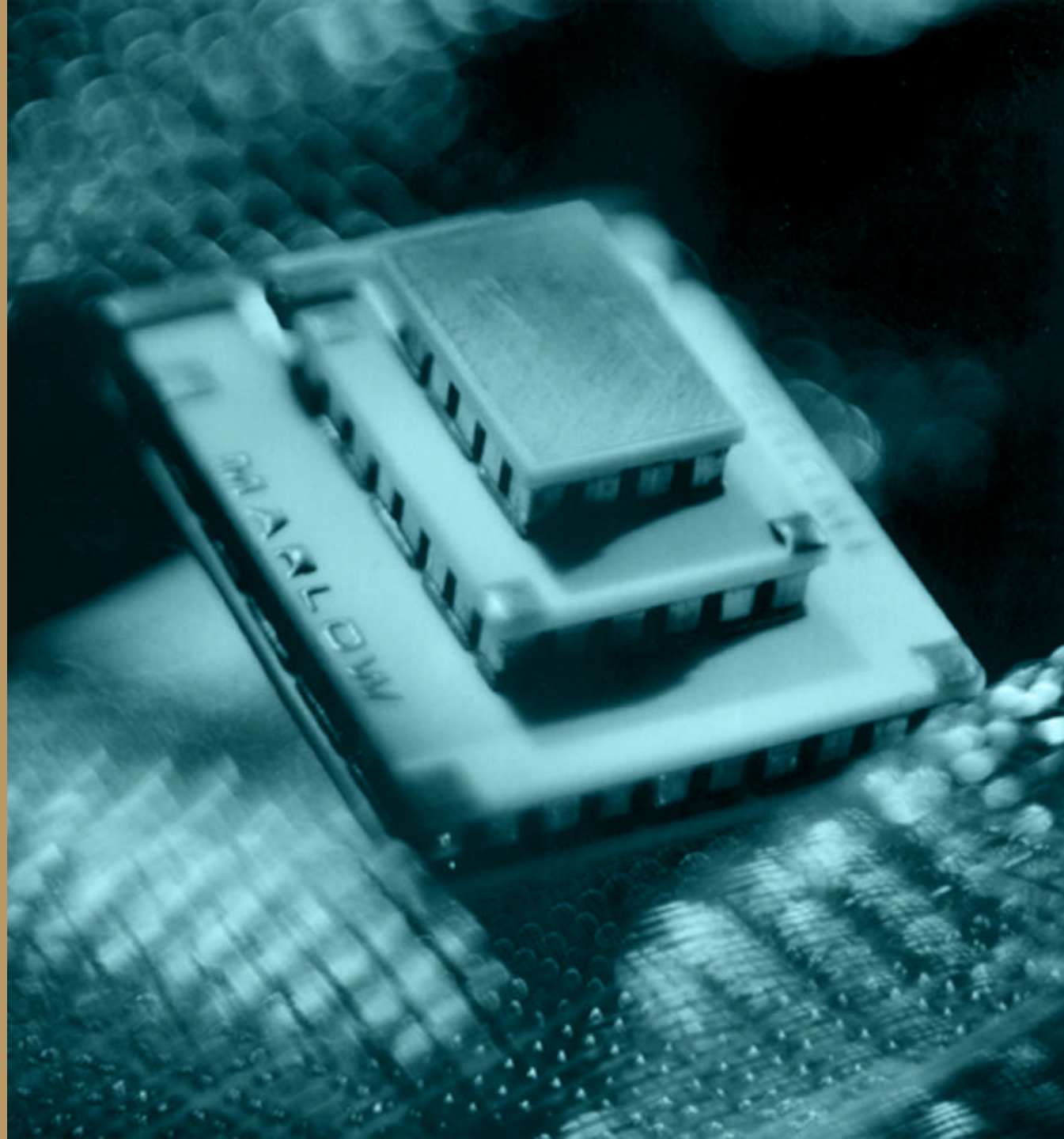
marlow
industries, inc.

The Rest of the Story

Hylan B. Lyon Jr.



Agenda

- The initial demand.
- The characterization of intrinsic material properties.
- Factors that determine the performance of a device for cooling.
- The users perspective – A case study
- The character of demand for thermoelectrics – past, present and future

The Initial Cooling Demand

Altenkirch
1911

Ioffe
Peoples
Tech.
1920's
Semi-Cond

Ioffe
Sci. Am
63
firms.
1958 - 1963

Defense
Space
Telecom
Medical

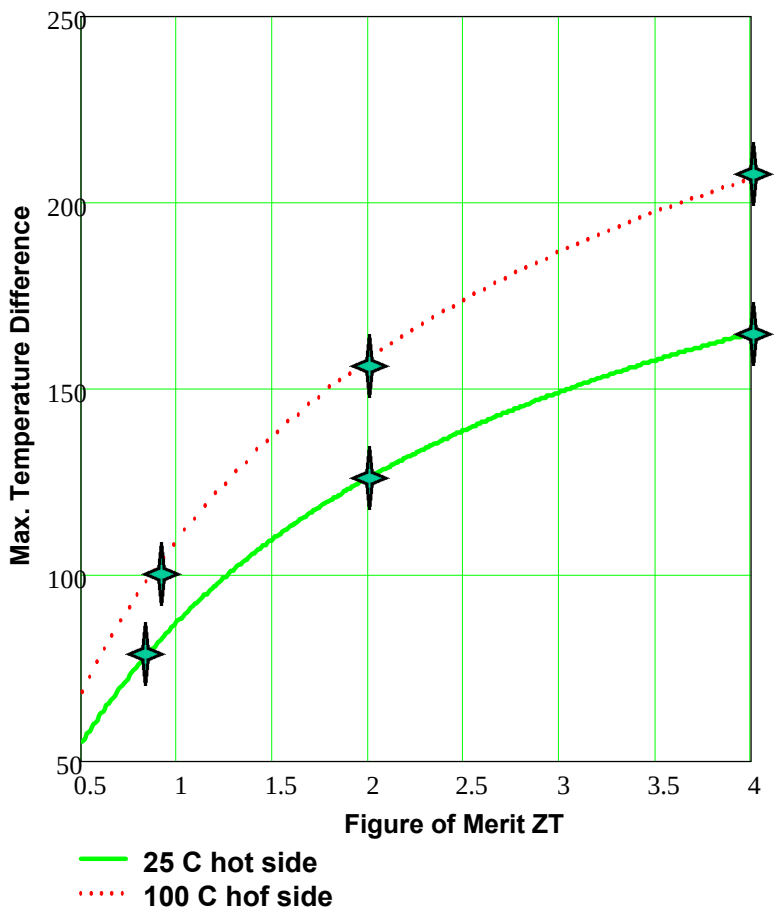
and hundreds
of dead ends

Commodity
Devices

- Cooling at the point of need
- Provide unique form factor.
- Gravity independent.
- Change from cooling to heating.
- Temperature cycling with controlled rates of change.
- Accurate temperature stabilization.
- Lack of vibration.
- Lower acquisition costs.
- Lower maintenance costs.
- Freedom from contamination

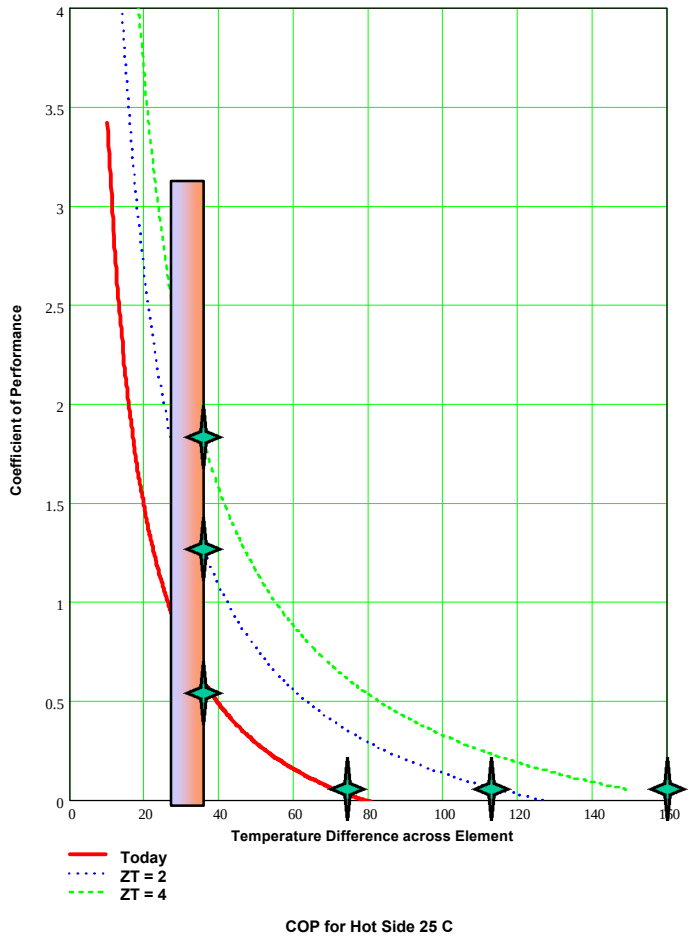
(Clean Room and Manned Space Flight Operations).

Intrinsic Material Properties



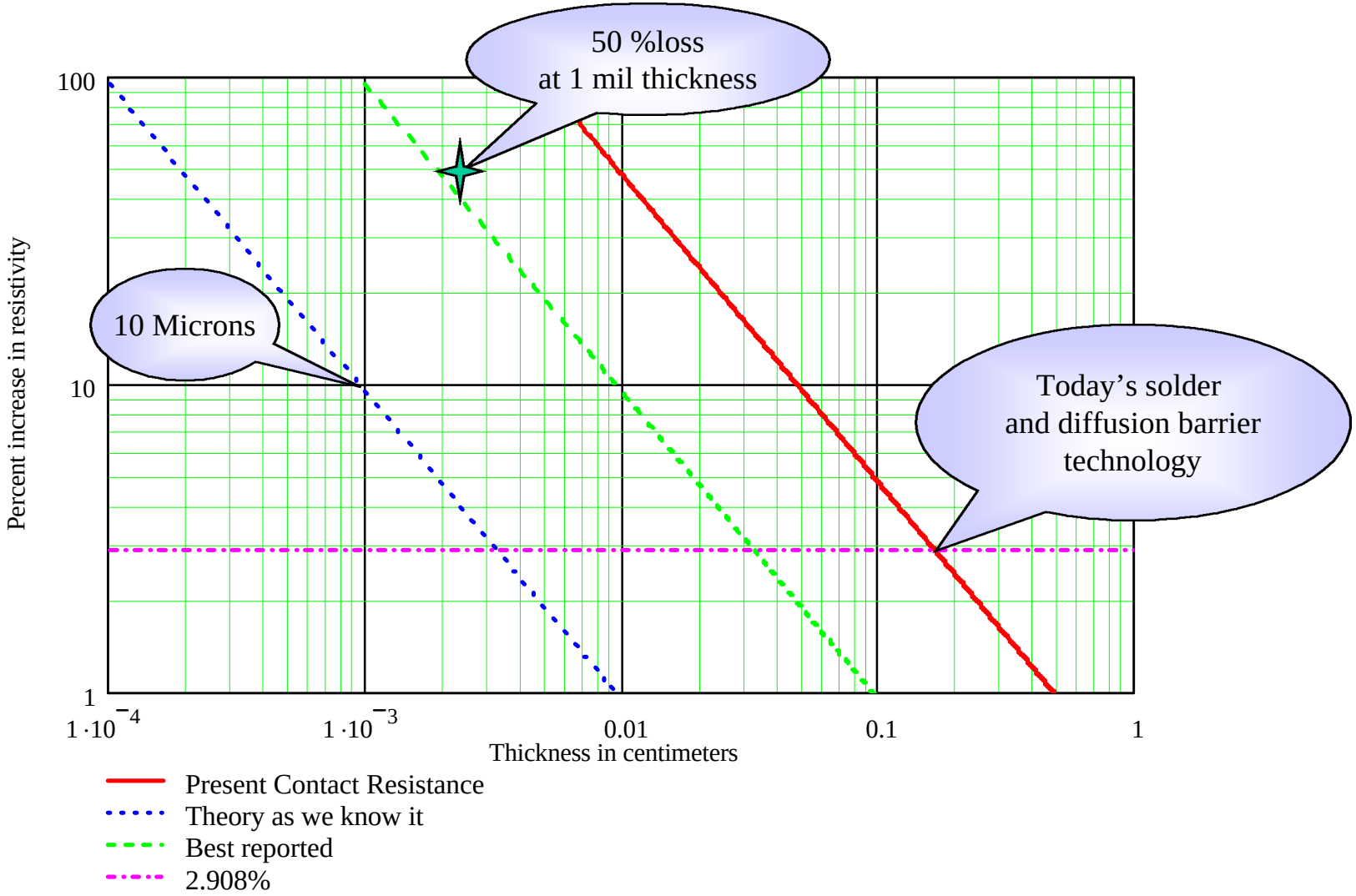
- The Figure of Merit Z or ZT
  - Can be derived to optimize the maximum temperature difference
- The State of the Art in cooling (2002)
  - @ Hot Side 25 ^{o} C ~ 70
  - @ Hot side 100 ^{o} C ~ 100
- One key parameter to document an improved ZT should be demonstration of maximum temperature differences in excess of bulk materials
- Why?

Coefficient of Performance



- The reason why the maximum temperature difference is important is because it determines COP.
  - Heat Pumped/Work Required
- The temperature difference across the element has to include the thermal resistance of the heat sink.
- The contribution of the Heat Sink Resistance to COP begins to demonstrate the difference between a device ZT and the material ZT

Contact Resistance example with Bi_2Te_3



Device Considerations

- Heat Pumping Capacity
  - Current
    - defined by material properties

      { i_{max} f(resistivity, Seebeck) }
    - design

      { interconnect thickness, etc }
  - Number of elements
    - Set by Coefficient of Thermal Expansion (CTE) of substrates
      - constrained by fragility of material
      - picnic box w/Bridgman material limit is 245 elements.
    - Power Conditioning

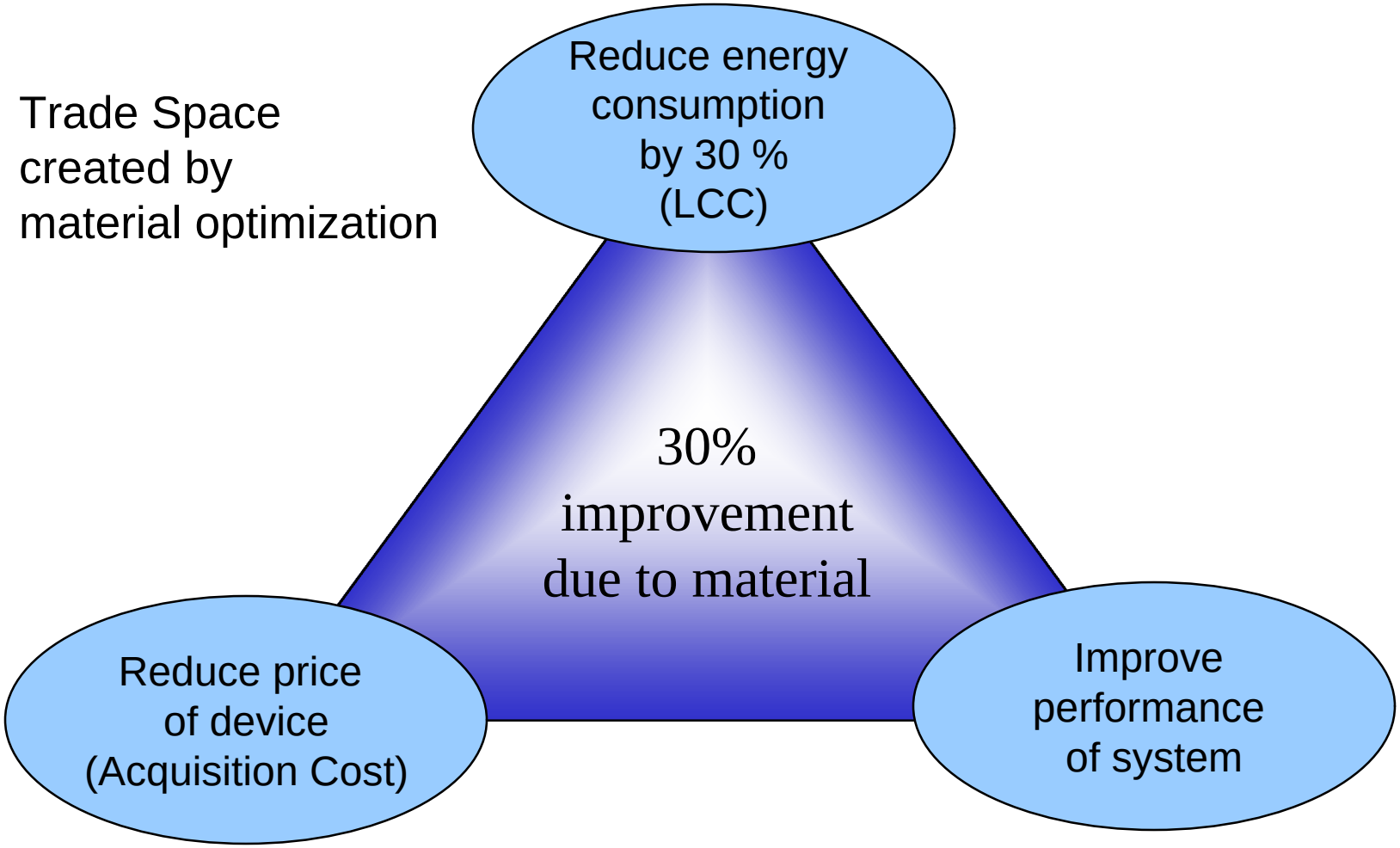
- **Additions to the Altenkirch Equation**
  - Thermal conduction by air between the hot and cold side
  - Contact resistance between the thermoelectric material and the interconnects of the assembled device.
  - The resistance of the interconnects.
  - The thermal resistance of the substrate.
  - Thermal convection of the air between the substrates and the surrounding air.
  - Stephan Boltzman radiation between the hot and cold side.
- **Other factors in addition to Altenkirch inclusions**
  - Any inefficiency due to heat concentration or spreading in the thermal path.
  - Any imperfections in the bonding process
  - Stress induced in final testing.
  - Tolerance of downstream thermal environments in customers line.
  - Dimensional control which exceeds that of the process today.
  - Precision placement of bonding agents.
  - Any anisotropy's in mechanical fracture, particularly perpendicular to the direction of current flow.
  - Lead wires

Device Considerations

- Testing prior to release
  - Mechanical strength
    - Shear strength
  - Thermal cycling
    - Requirements are market specific.
  - Life time testing
    - Requirements are market specific.
  - Uniformity in electrical properties
    - AC resistance
- Present status
  - Large dimension of commodity products
    - All factors contribute to 3 - 5% of loss of material ZT in device ZT.
- Future
  - With length dimensions of 100's of microns
    - Factors can combine to contribute to 50% of loss of ZT in device.

Example

Trade Space created by material optimization



The Past as Prolog?

- The starting point
  - *Customers of today*
    - *Price reduction*
    - *Price reduction of 20% per year*
    - *Performance increases with no price increases.*
    - *You pay the non-recurring costs of device design and manufacturing set up.*
  - *Niche markets*
    - *All transitioning to commodity*
  - *New entrants !!!*
    - *Non-US*

- After proof of concept
  - *How to assure sponsors and supporters that "the rest of the story" will not destroy the intrinsic improvements of the laboratory?*
  - *Focus on the non-transport property aspects of the material science.*
  - *Requirements*
    - *not established because of TE improvements*
    - *but competing technology price/value sets the requirements.*

A comment

A significant amount of "good science" brings us to this juncture.
- the Scientists in the room should be congratulated.

Customers (end users) will have to be engaged in the transition to device feasibility providing explicit device design constraints and objectives.

This will be a cultural change for all of us.

We need

- *an honest assessment of what critical criteria have to be proven.*
- *a rough assessment of whether laboratory results take us:*
  - *to the critical design constraints*
  - *or through these critical design constraints.*
- *an estimate of the difference between laboratory ZT and device ZT for reduced dimension materials.*

A whole new set of skills will be involved