

# “Upscaling” Nanoscale Thermoelectrics: The Mesoscale Design Challenge for Real-World Energy Needs

## Opportunity

**Next-generation high-efficiency thermoelectrics (TEs) can solve ‘Waste Heat’ and ‘Heat Management’ problems**

- E.g., Dramatic impact on energy utilization/security challenges
- E.g., Enabling-technology for microelectronics/solid-state lighting
- Also: radioisotope TE generators for interplanetary/deep-space exploration; rapid-response thermocouples; detector energy control

**Materials efficiency driver: TE ‘Figure-of-Merit’, ZT**

- Semiconductor nanowires can be tailored at the nanoscale to achieve optimized ZT ( $ZT = S^2\sigma/\kappa$ )

**Device efficiency driver: High ZT coupled with large  $\Delta T$**

- Bulk material advantage: ‘thick’ devices are required

## Meso Challenge

**How can nanoscale TE functionality be translated across the mesoscale gap to macroscale utility?**

- Nanoscale: 1D NW and junction/interface opportunities & challenges
- Mesoscale: Fractional dimensionality of nanomaterial network (1-2D) affords new degrees of complexity/disorder
- Macroscale: Percolation effects in bulk assemblies of nanomaterial networks and matrix integration challenges for maximal ZT/ $\Delta T$  combinations

**How can we best take advantage of the mesoscale opportunity for emergent functionality at the interfaces between nano and meso or meso and macro?**

## Approach

**Establish new methodology for interconnecting and integrating nanomaterial building blocks**

- ZT-optimized semiconductor nanowires as fundamental units
- Thermally insulating support matrix
- Hierarchy of controlled complexity by directed assembly
- Macroscale “addressable”

**Probe/understand effects of transition from simple nano-structures to complex networks via advanced characterization tools and new theoretical/modeling approaches**

- Interplay of  $S$ ,  $\sigma$ ,  $\kappa$  across scales: feedback to materials design

## Impact

**Path forward for functional integration of optimized TE nanomaterials across mesoscale gap for real-world device performance**

- New understanding of effects of junction formation, extreme anisotropies of scale, percolation processes, & matrix integration on ZT parameters –  $S$ ,  $\sigma$ ,  $\kappa$
- New tools for materials predictive design ranging from nano/meso-scale to macroscopic device-level modeling

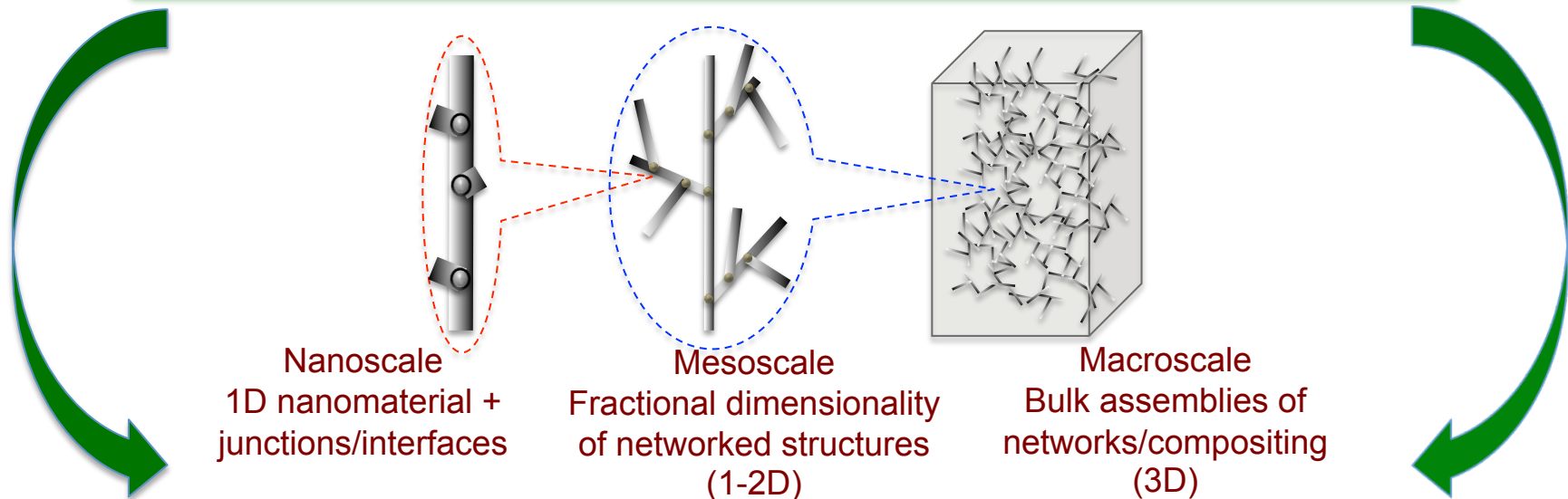
**Realize TE’s potential to impact wide-ranging technological applications in energy (heat) harvesting, utilization and management**

- Bridge mesoscale gap to achieve nano-enabled *and optimized* ‘bulk’ TE devices



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Understanding, Optimizing and Exploiting New Physics of Scale



Unprecedented opportunity to solve waste heat utilization & thermal management challenges

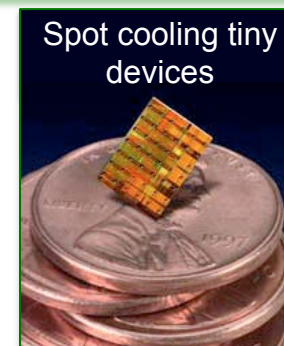
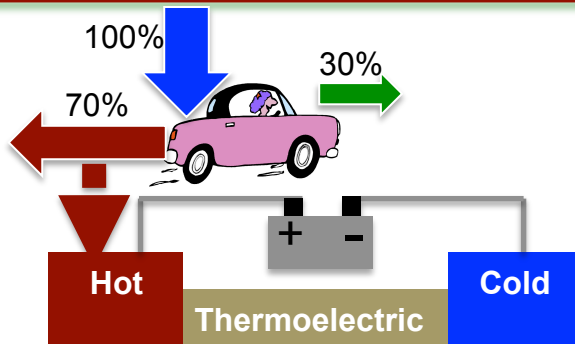


Image: from *How Stuff Works*



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