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Adaptable Nanotechnology for Cleaner, Energy-Efficient Products

Multi-physics modeling of thermoelectric generators for waste heat recovery applications

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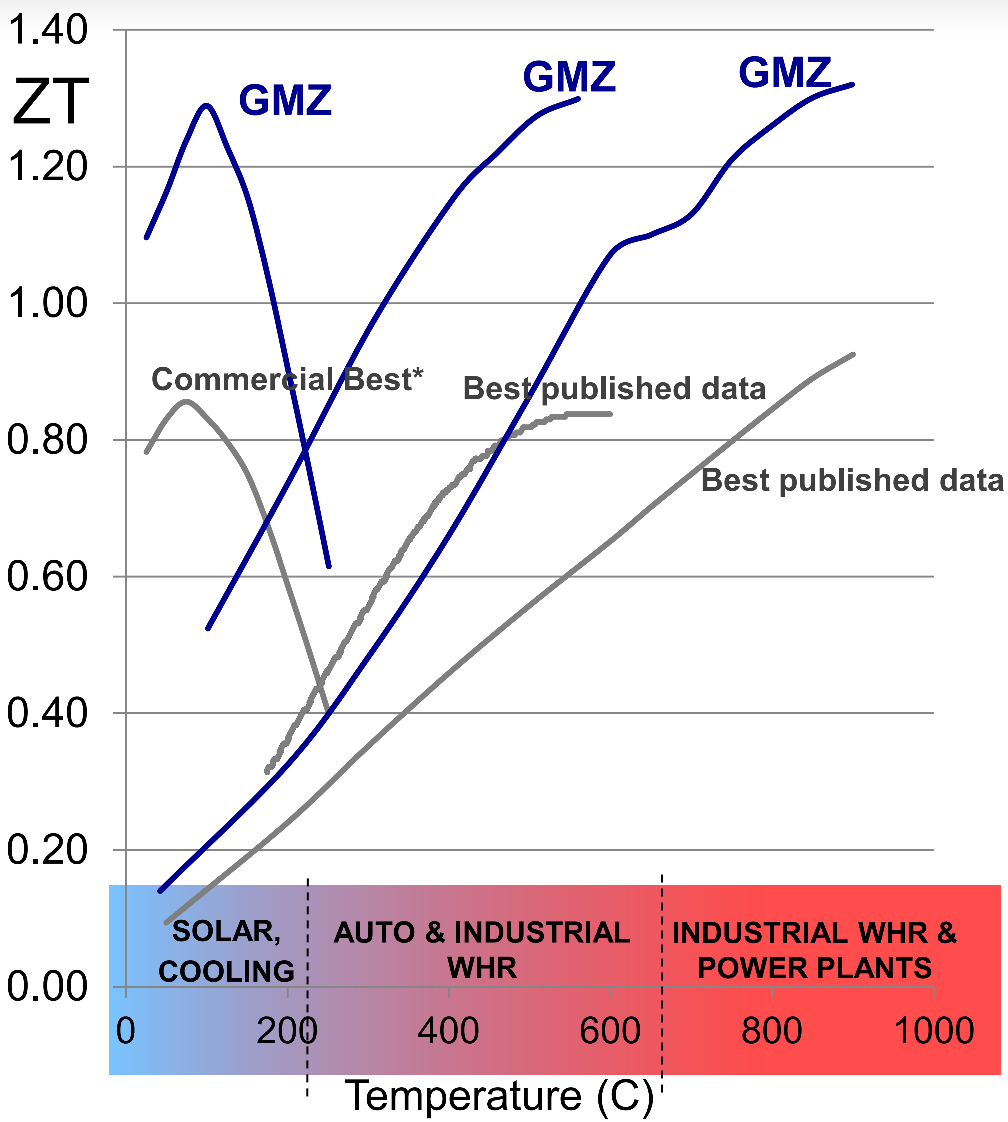
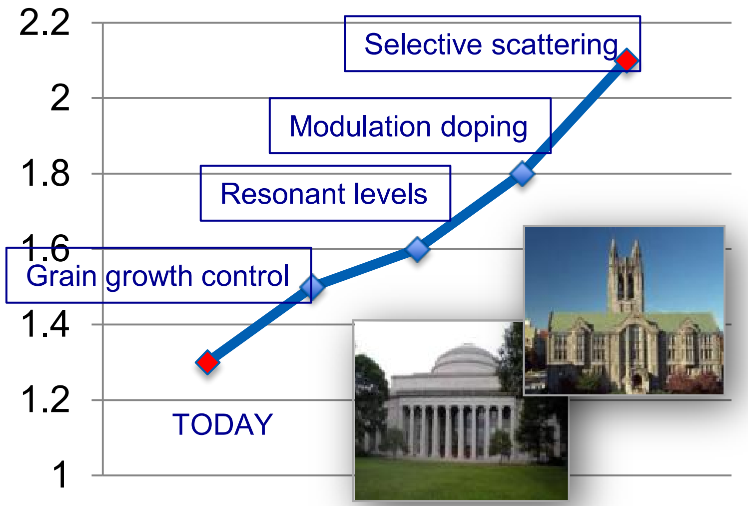
GMZ TE LEADERSHIP: Across all Markets



ZT Roadmap: Achieving 2.0

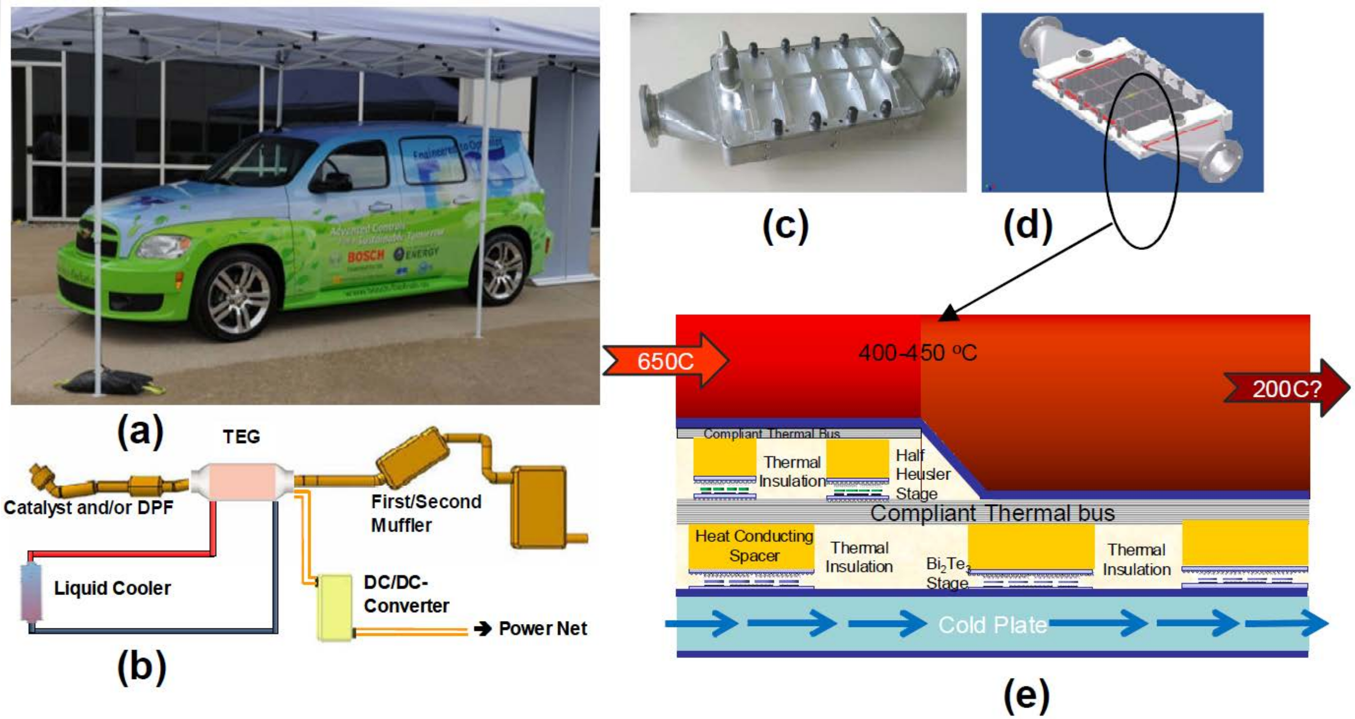


Powerful Technology

- Independent of material family
- Covers all applications & markets
- Sustaining performance advantage

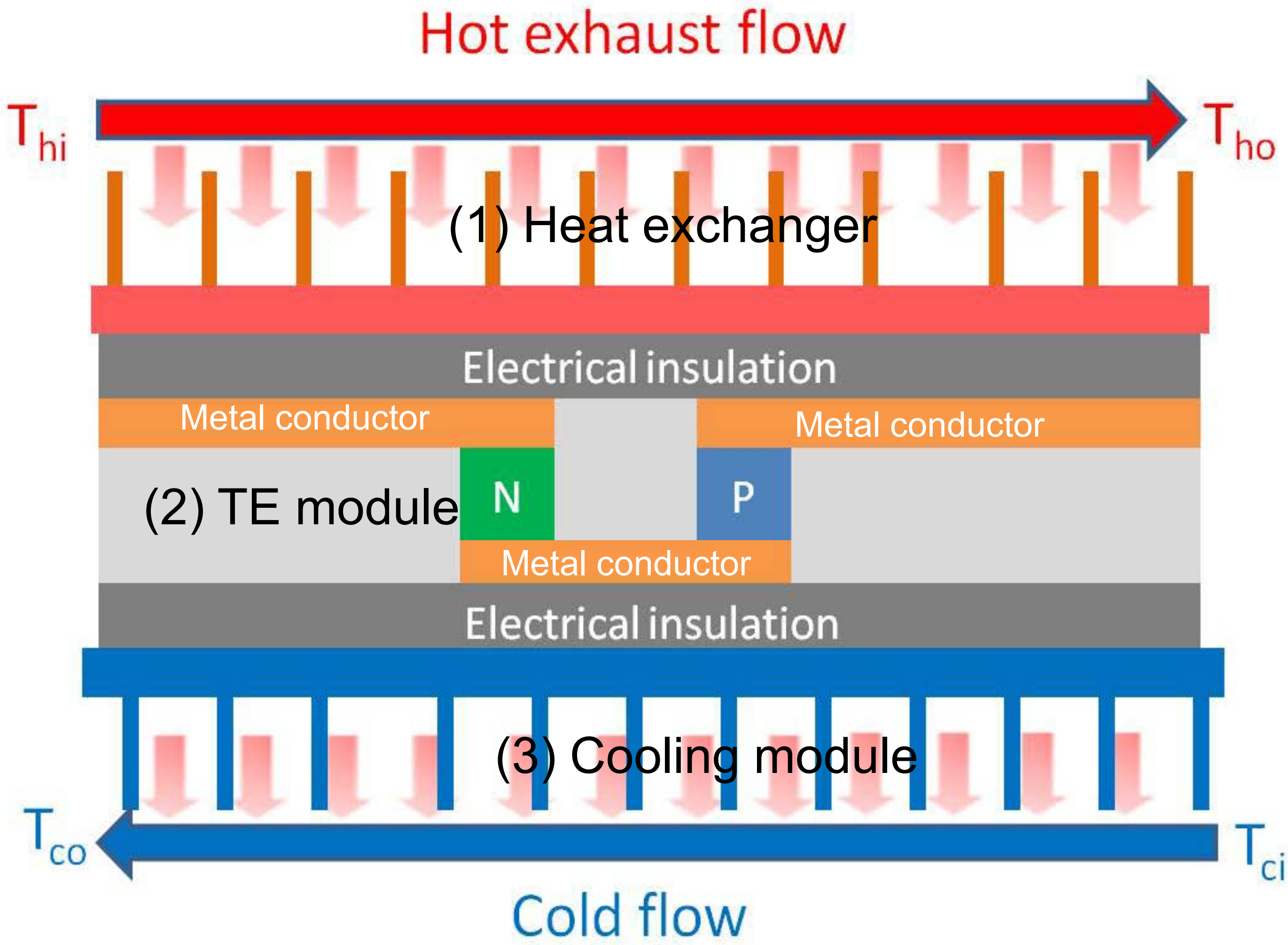
*it is possible to acquire specialty non-commercial material with ZT~1 for 5x cost.

DOE Program Overview

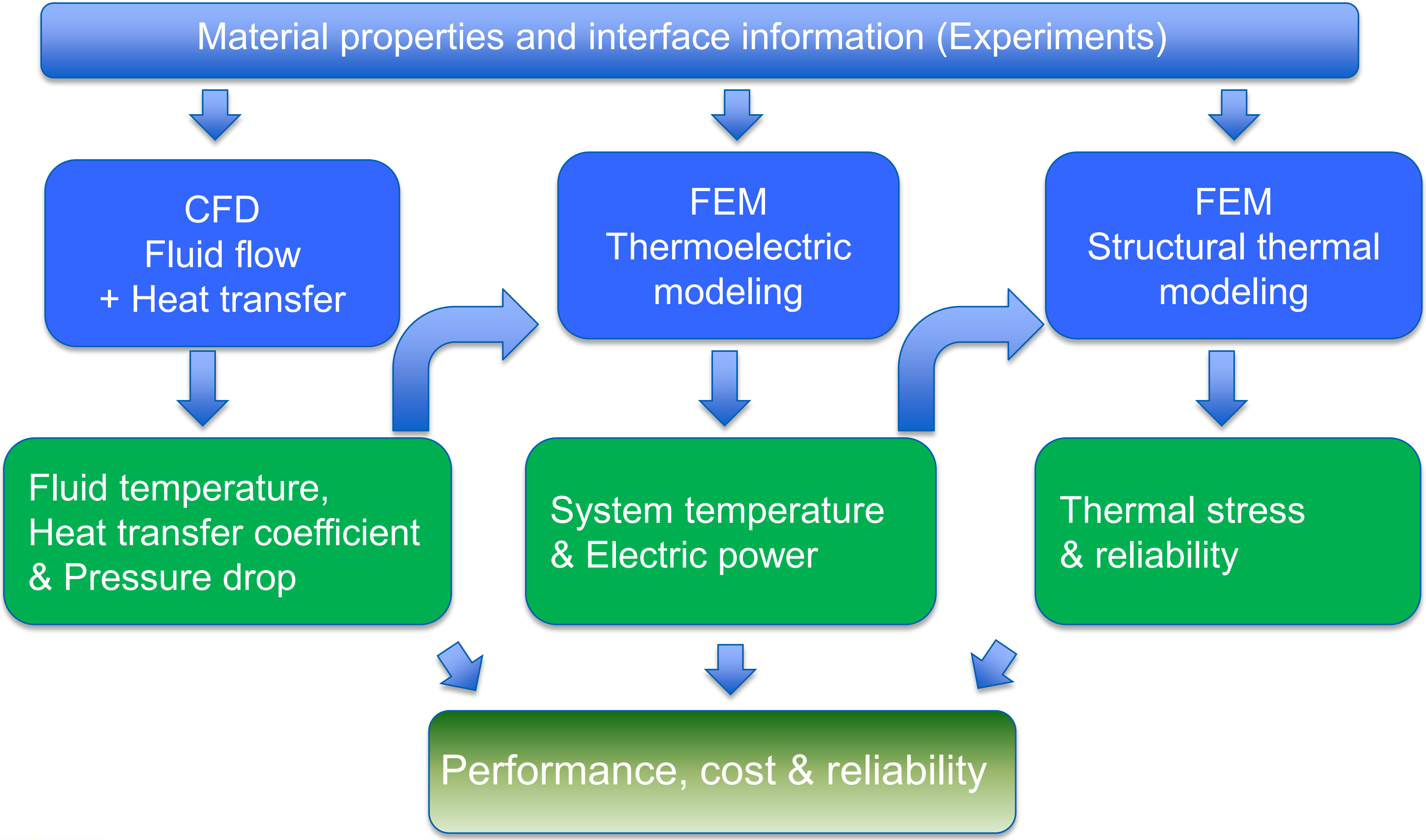


- Proposed two-stage TEG system with half-heusler as the first stage, and Bi_2Te_3 as the low temperature stage. Thermal buses and high thermal conductivity spacers, together with thermal insulation are used to concentrate heat to low-profile generators, significantly reducing the amount of materials used for the TEGs.
- 5% fuel efficiency improvement with TE generator integrated and tested in vehicle platform under US06 drive cycle
- (a) Chevrolet HHR vehicle, (b) exhaust system, (c) a prototype built at Bosch, (d) and (e) illustration of the two-stage cascade design

An overview of TEG system

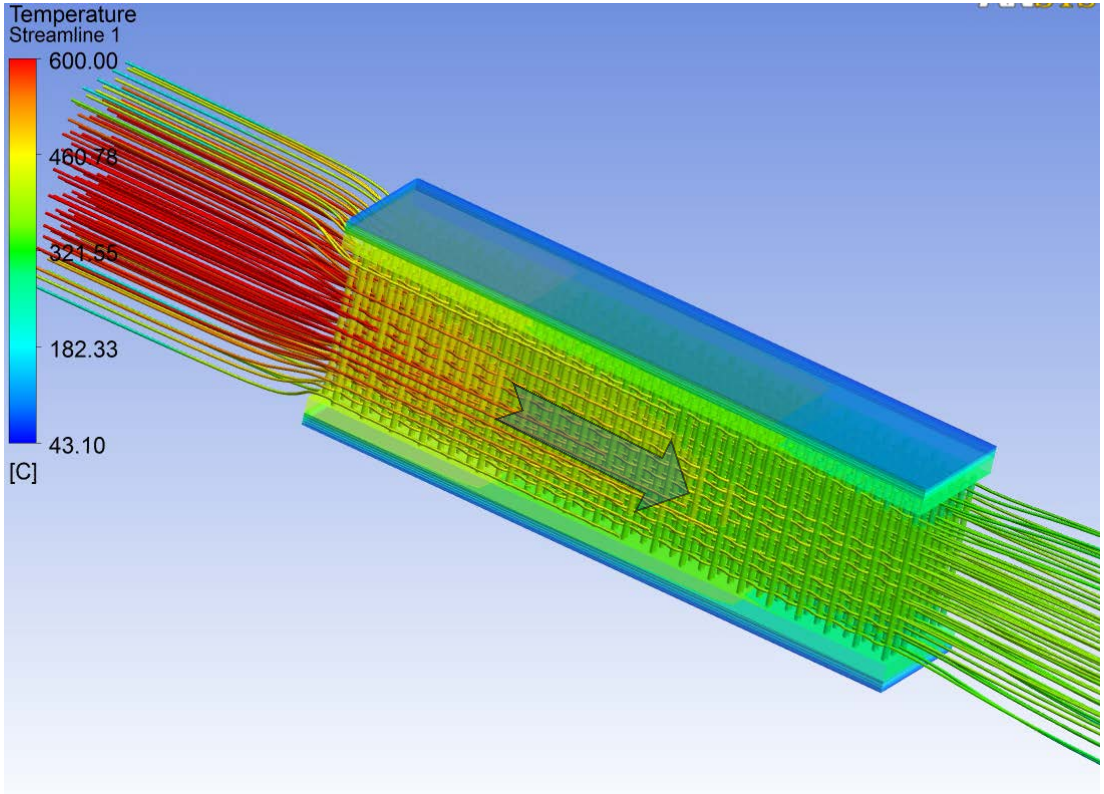


3-D multi-physics model of TEG system



CFD simulation of heat exchanger

Heat exchanger is the lead component, dictating heat flow in TEG



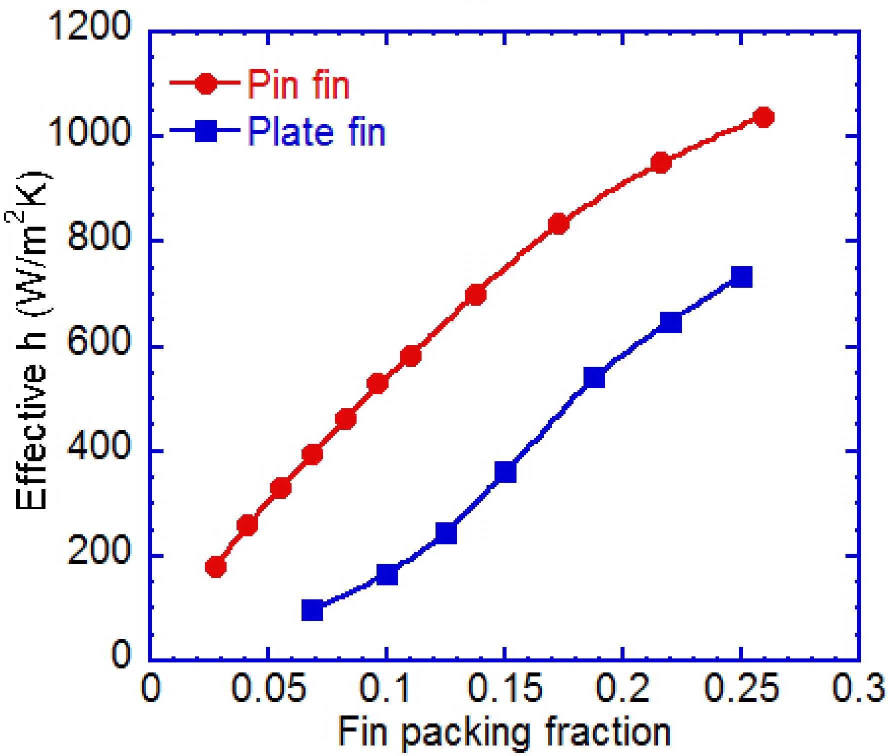
CFD simulation of exhaust flow through heat exchanger

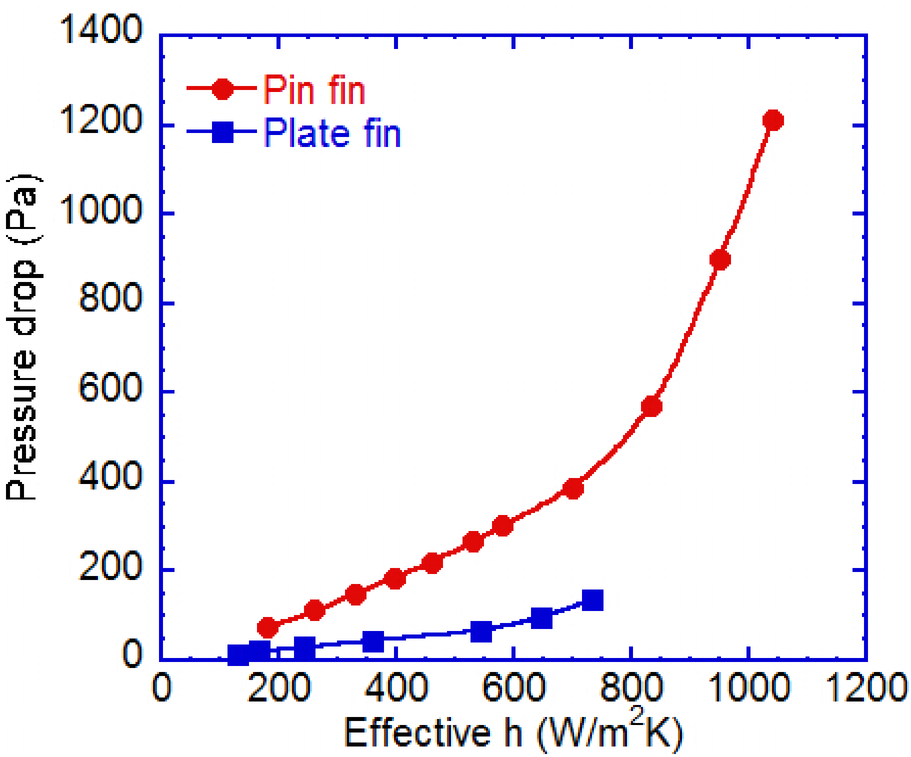
- Fin material selection
- Fin geometry and size
- Fin packing fraction
- Fin arrangement

↓

- Heat transfer performance
- Pressure drop

Heat transfer performance and pressure drop

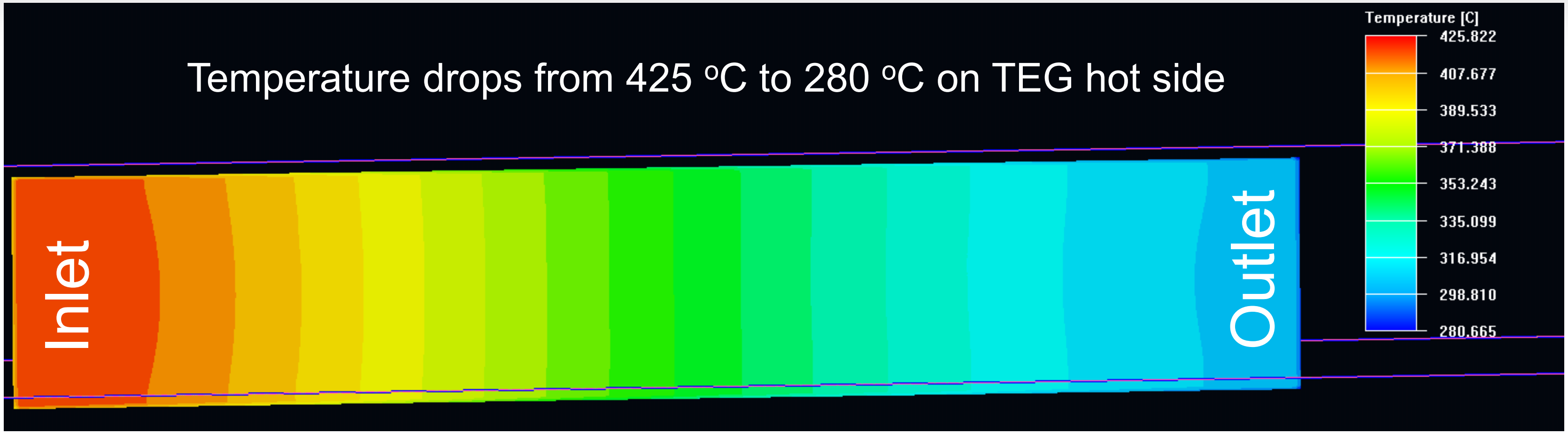


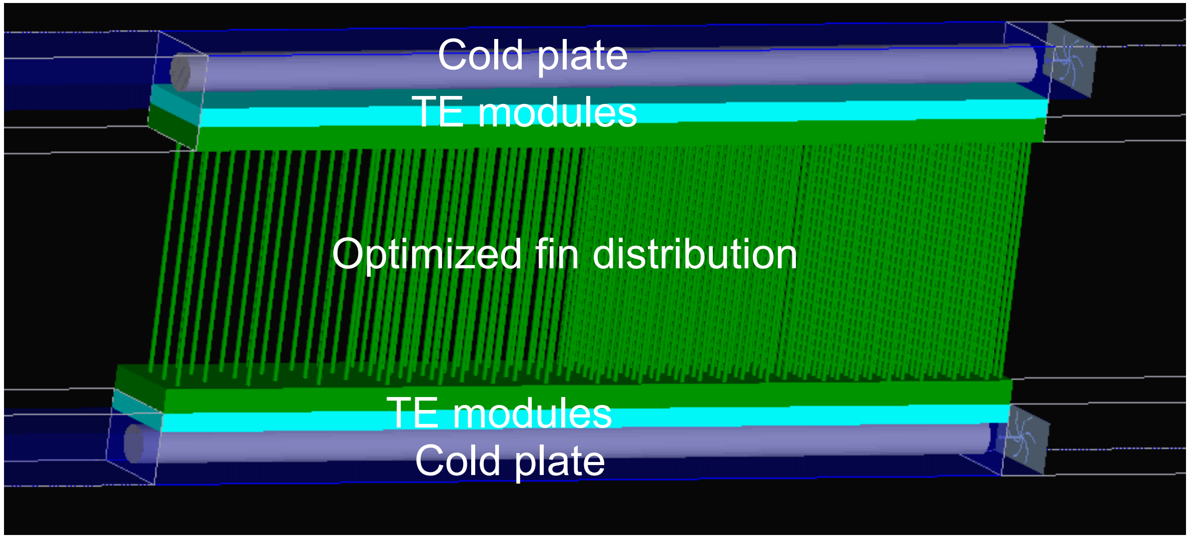


- Pin-fin HEX has higher heat transfer performances due to enhanced surface area and flow turbulence;

- Plate-fin has less pressure drop at the same heat transfer performances.

Temperature drop on TE module across the flow





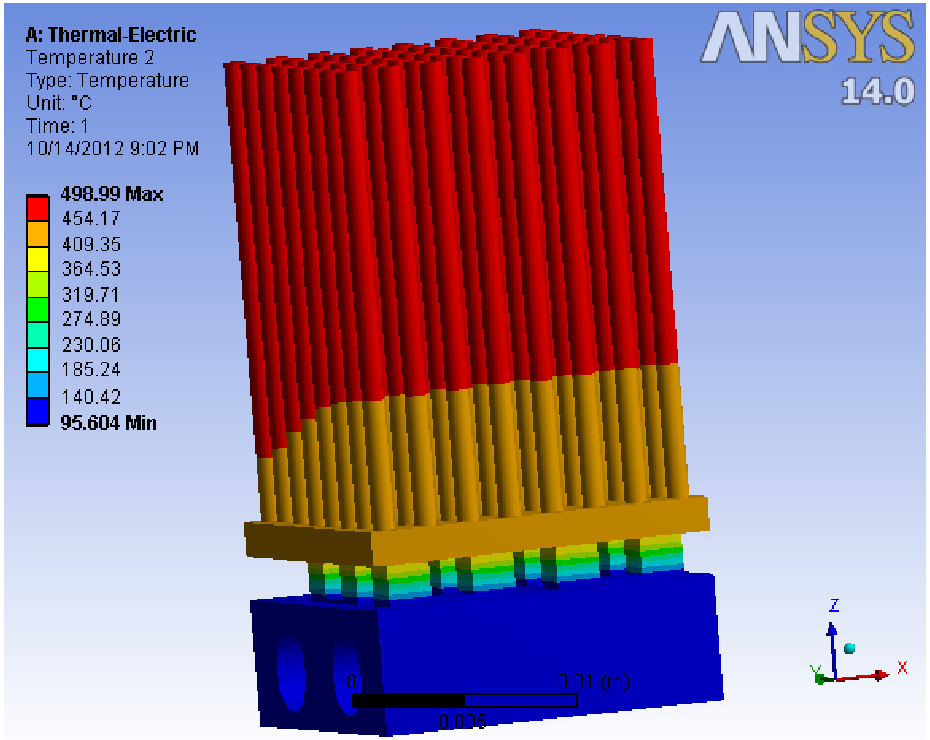
Temperature uniformity can be improved by optimizing fin distributions.

Comparison between regular and gradient heat exchangers

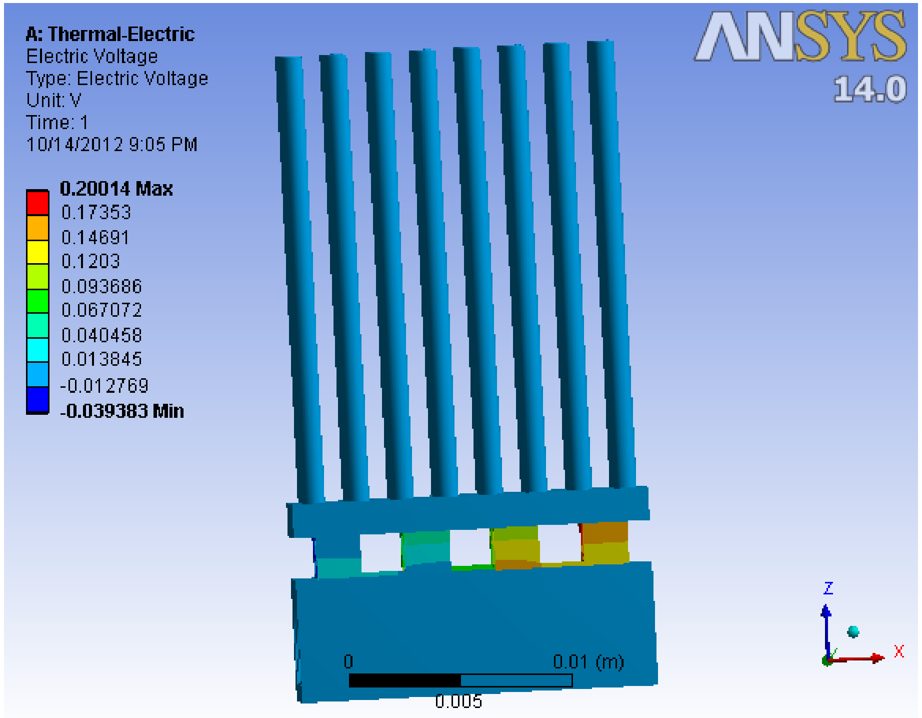
	TEG-in (^oC)	TEG-out (^oC)	ΔT (^oC)	Heat flow (W)	Pressure drop (Pa)
Regular fin	425	280	145	1226	306
Optimized fin	355	335	20	1160	300

- The optimized fin design reduces TEG temperature drop from 145 ^oC to 20 ^oC;
- The temperature uniformity improves system performances and reduces system integration cost.

Thermoelectric modeling using FEM



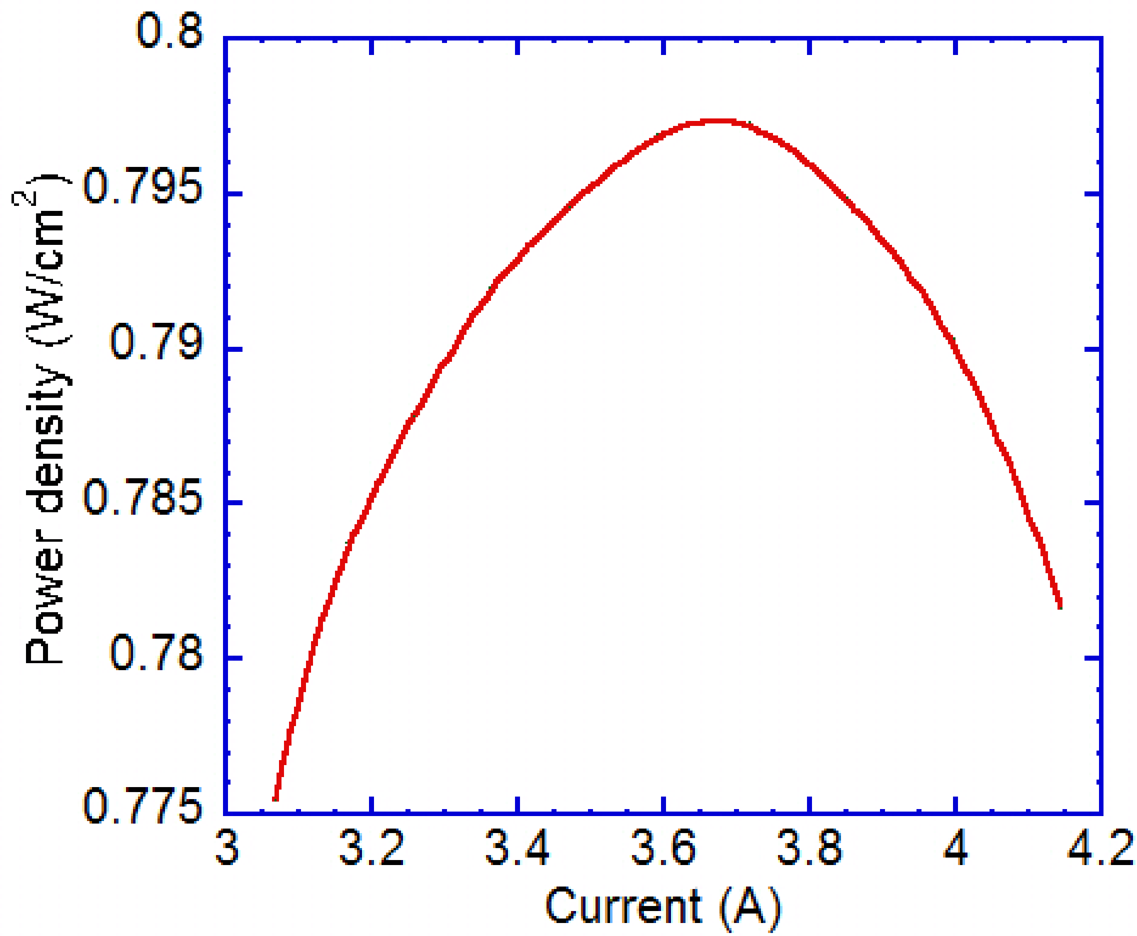
Temperature distribution in TEG system



Electric voltage in TEG system

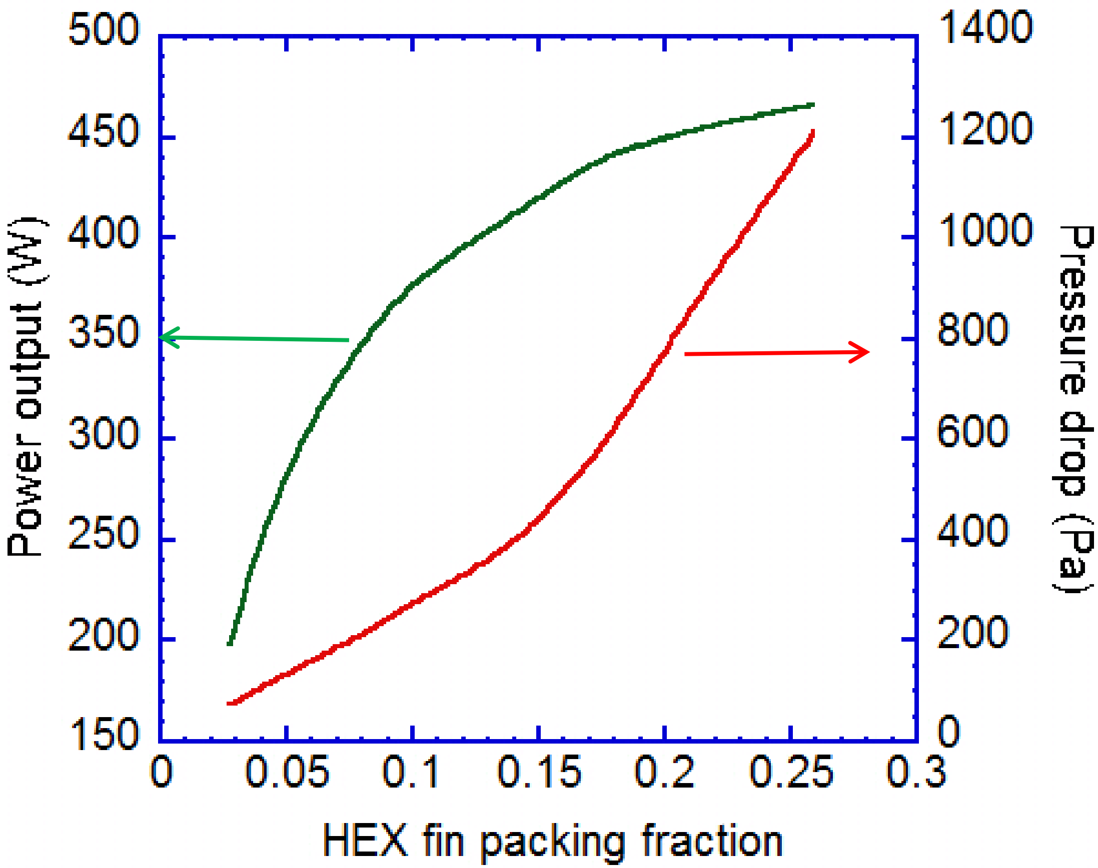
Detailed thermoelectric system design can be completed using FEM method in Ansys.

Electric power output



Based on GMZ Half Heusler materials, power density ~0.8 W/cm^2 can be achieved.

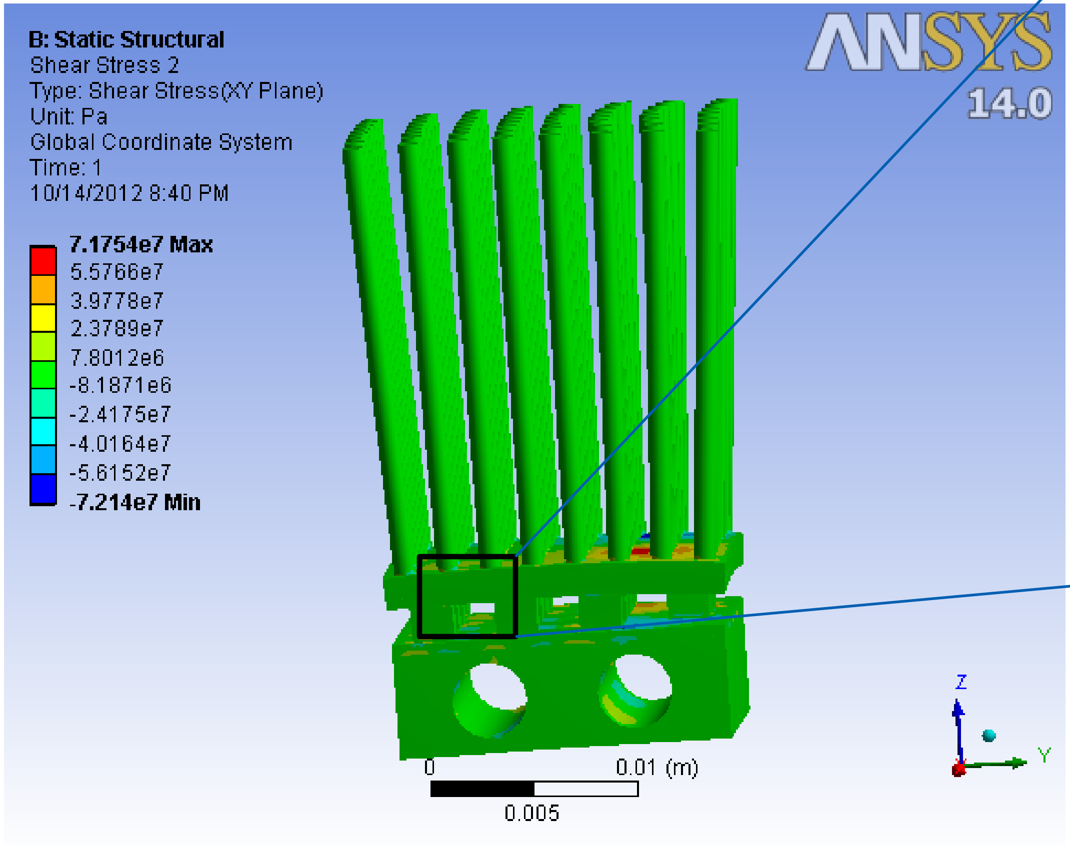
TEG system performance

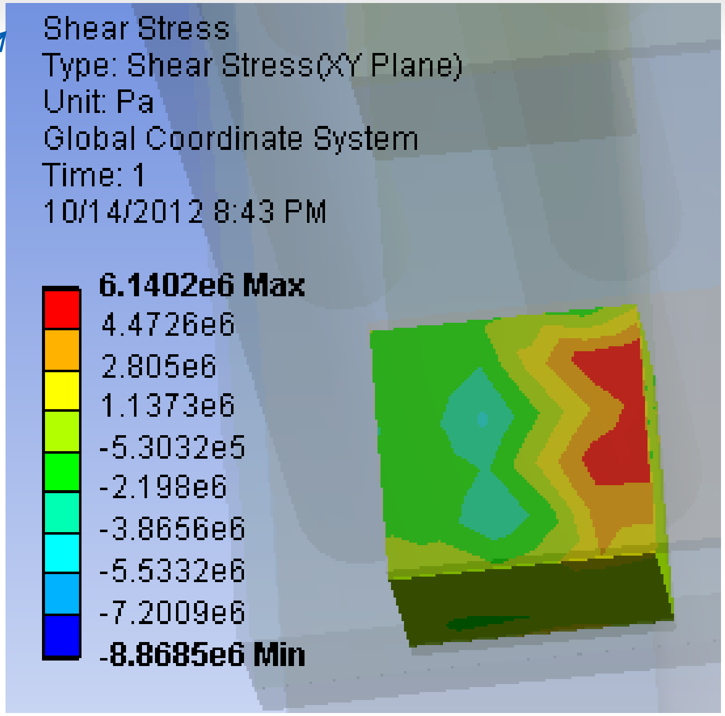


- Exhaust temperature: 600 °C
- Mass flow rate: 30 g/s

- Electric power output: ~ 400 W
- Pressure drop: ~1 KPa

Structural thermal modeling- thermal stress and reliability





Thermal stress near the contacts of TE legs is critical to system reliability

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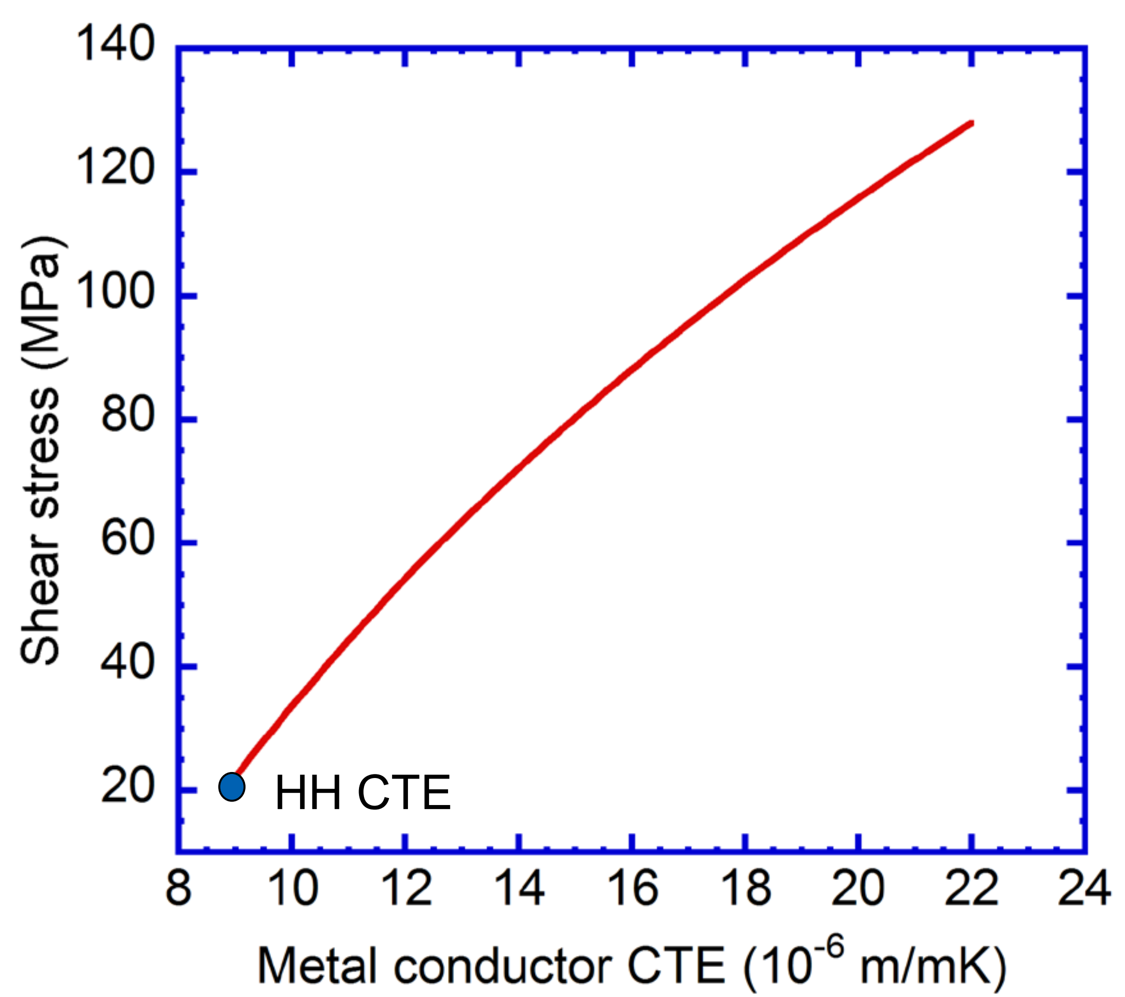
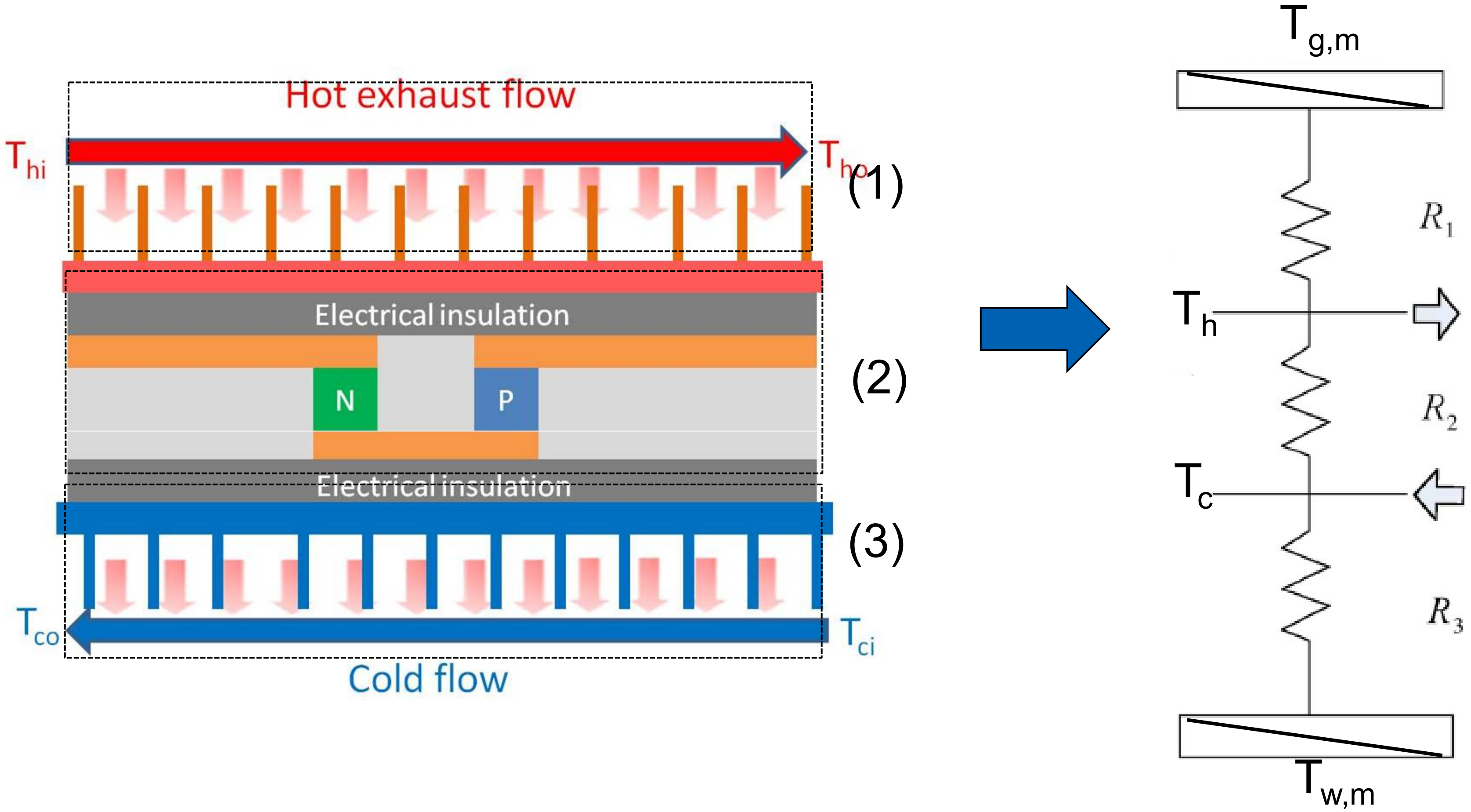
Thermal stress and material CTE



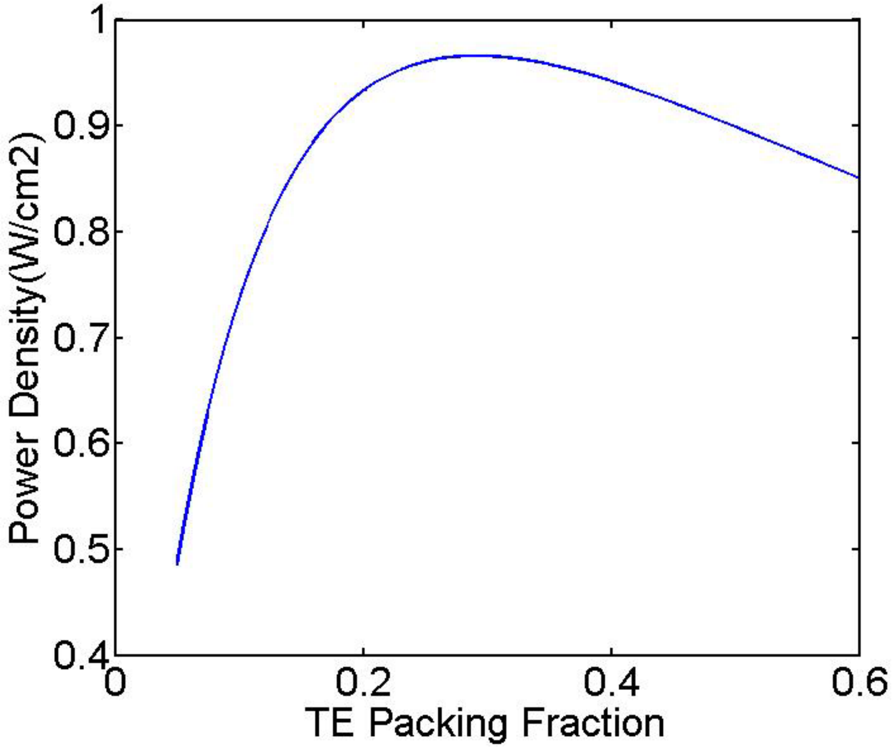
It is critical to minimize thermal stress by choosing CTE closely matched materials

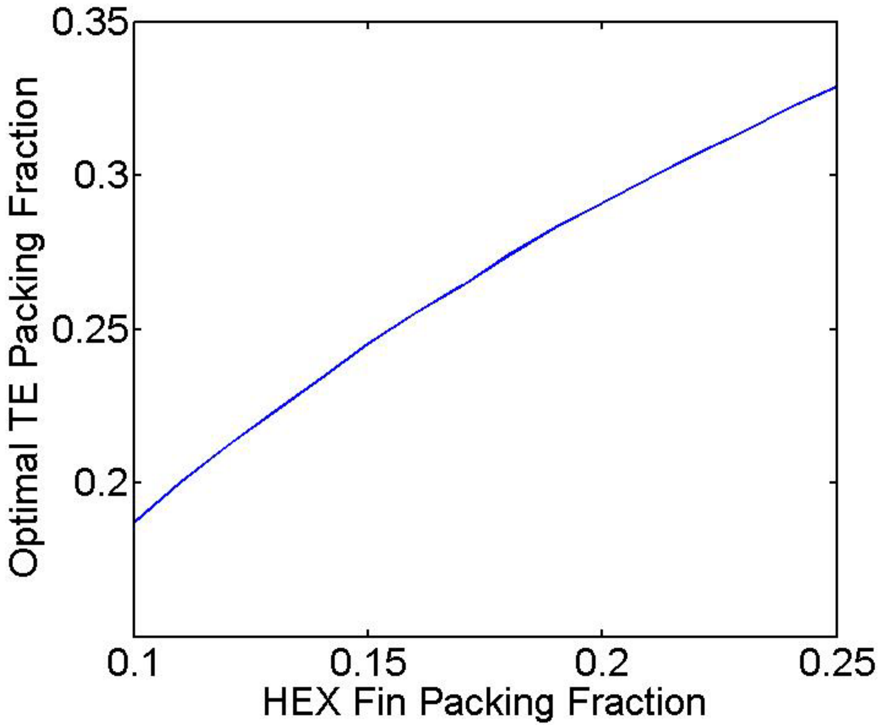
Simplified 1-D TEG system model



- Thermal and thermoelectric transport considered in the 1-D model;
- Quick optimization of key design parameters.

Optimization of TEG system using 1D model





- TE packing fraction should be optimized to achieve peak power density

Conclusions

- A comprehensive 3-D model has been developed to design TEG system towards maximum performances, reliability, and minimum cost;
- With the knowledge base developed in 3-D modeling, a 1-D model was developed for quick system optimization.

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