CORNING

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System level modeling of thermoelectric generators for automotive applications

Peng Chen and Mark Soulliere

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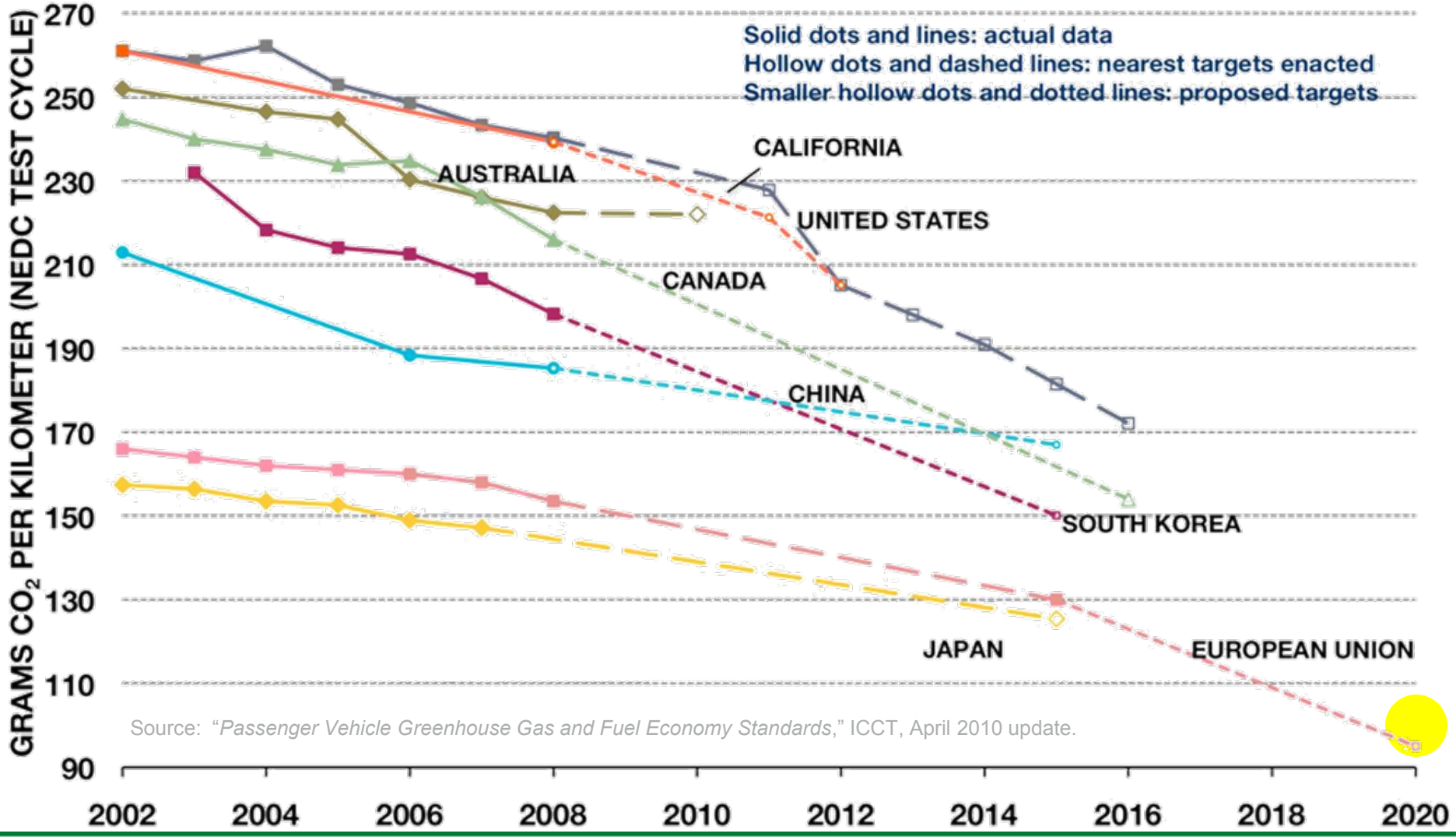
Outline

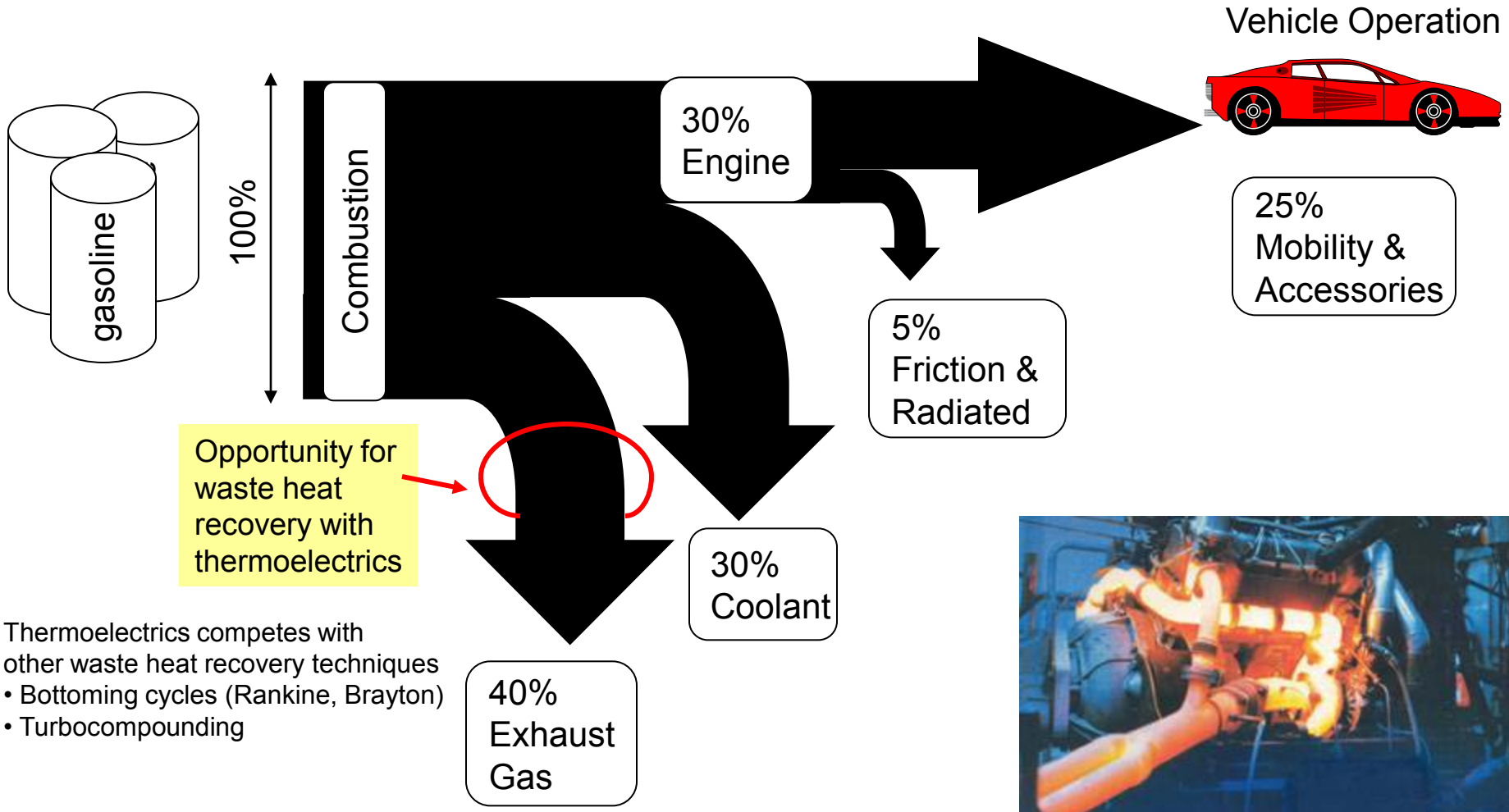
- Overview
- TEG Modeling activity in Corning
- Conclusions

Automotive industry needs to meet CO_2/fuel economy regulations



Source: "*Passenger Vehicle Greenhouse Gas and Fuel Economy Standards*," ICCT, April 2010 update.

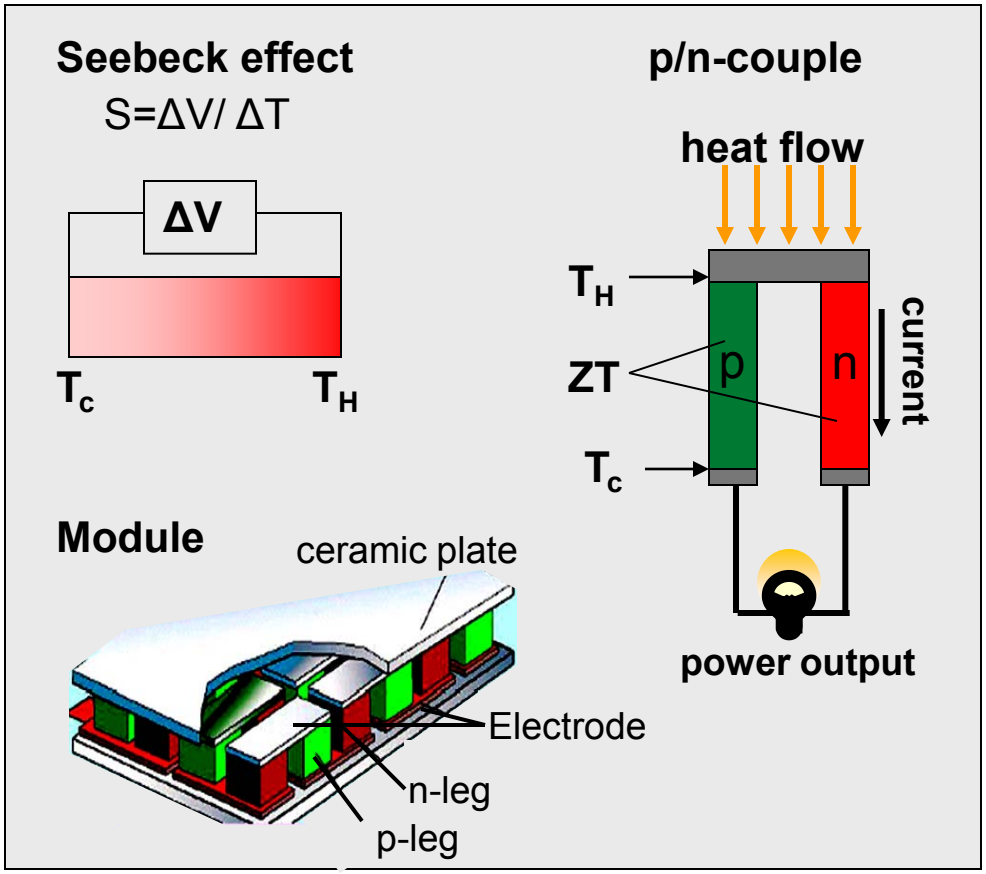
Thermoelectrics can lower fuel consumption in cars by converting waste heat to electricity



Thermoelectrics competes with other waste heat recovery techniques
- Bottoming cycles (Rankine, Brayton)
- Turbocompounding

Graphic adapted from http://www.osti.gov/fcvt/HETE2004/Stabler.pdf

Thermoelectric generators transform waste heat into electrical power



Energy conversion efficiency

$$\eta_{max} = \frac{T_H - T_C}{T_H} \frac{\sqrt{1+\overline{ZT}}-1}{\sqrt{1+\overline{ZT}}+\frac{T_C}{T_H}}$$

Temperature difference

Figure of Merit

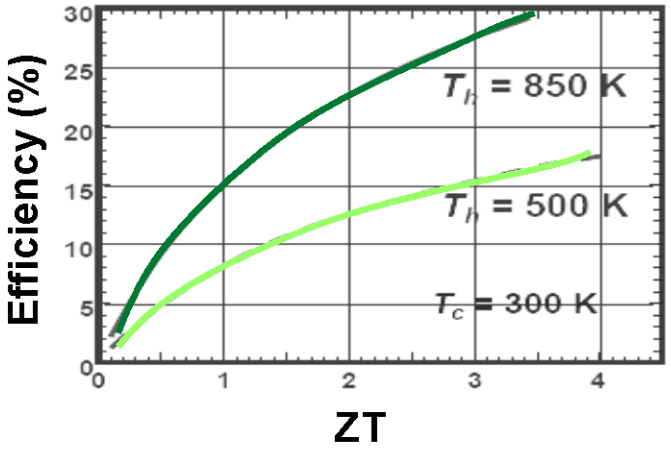
$ZT = T S^2 \sigma / k$

where

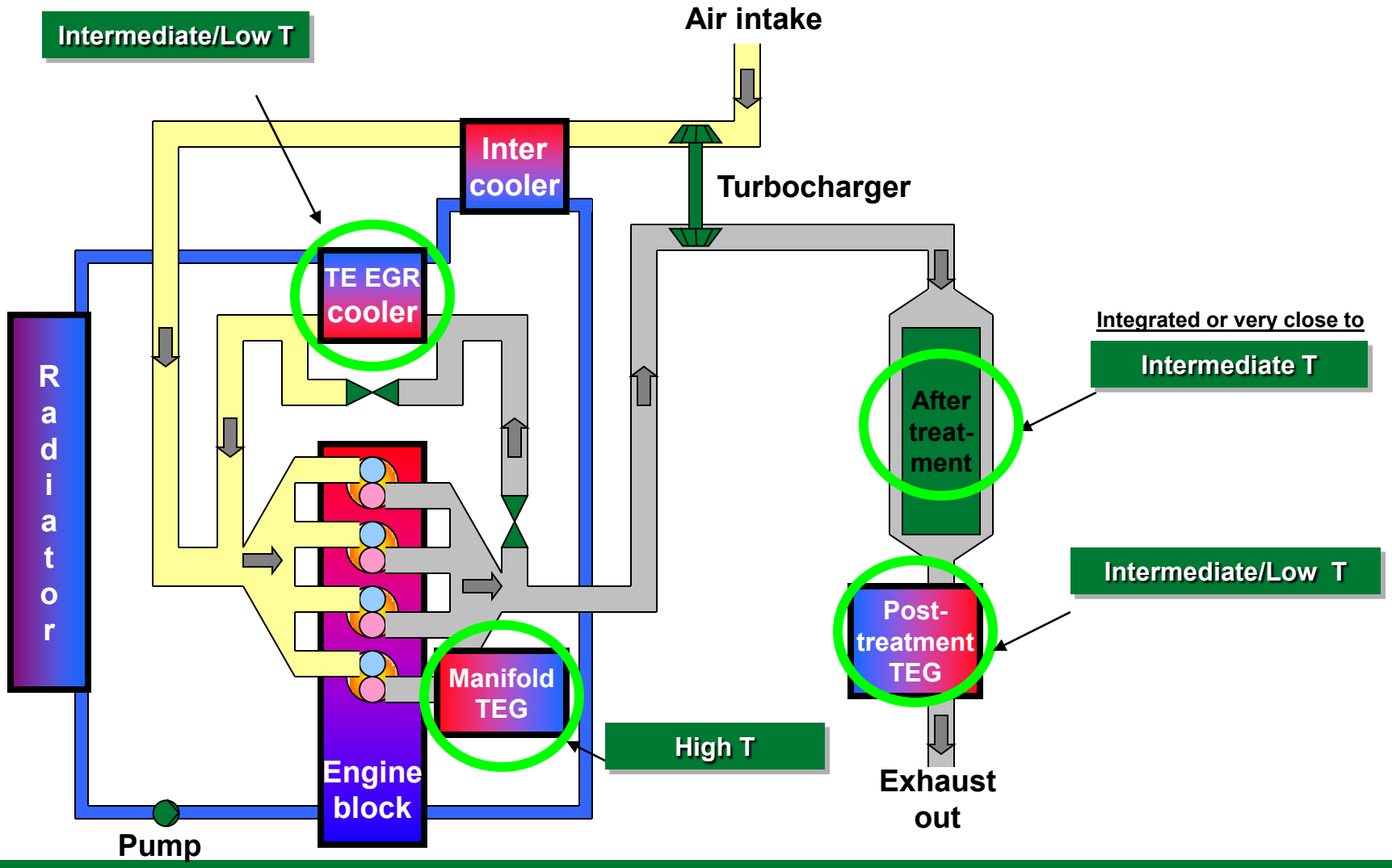
S = Seebeck coefficient

σ = Electrical conductivity

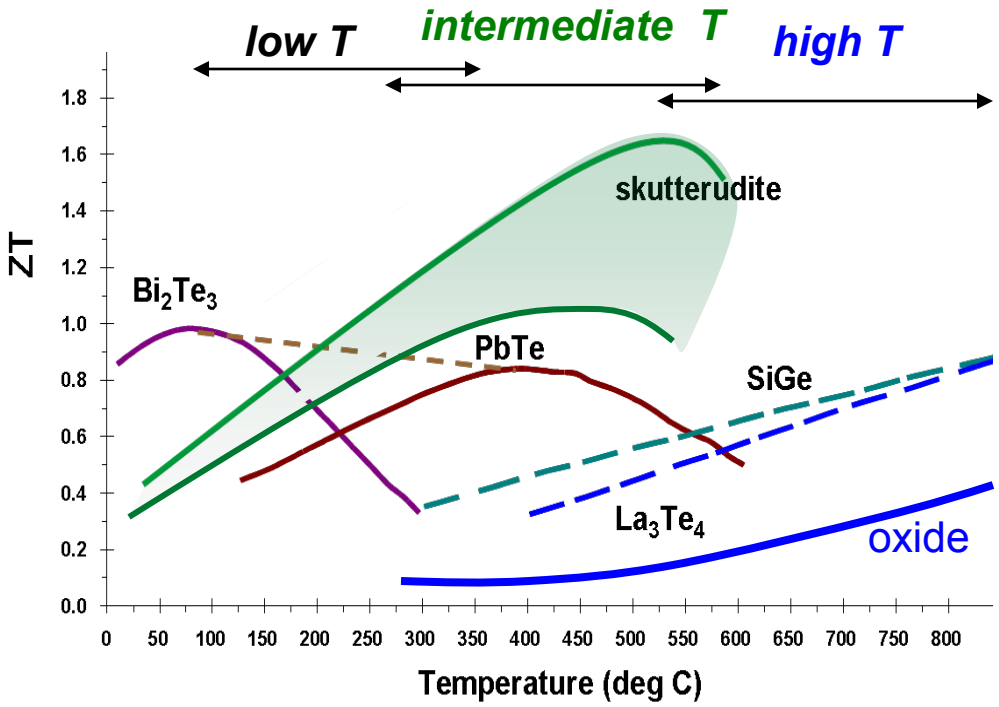
k = Thermal conductivity



Several automotive locations are being considered for TE generators



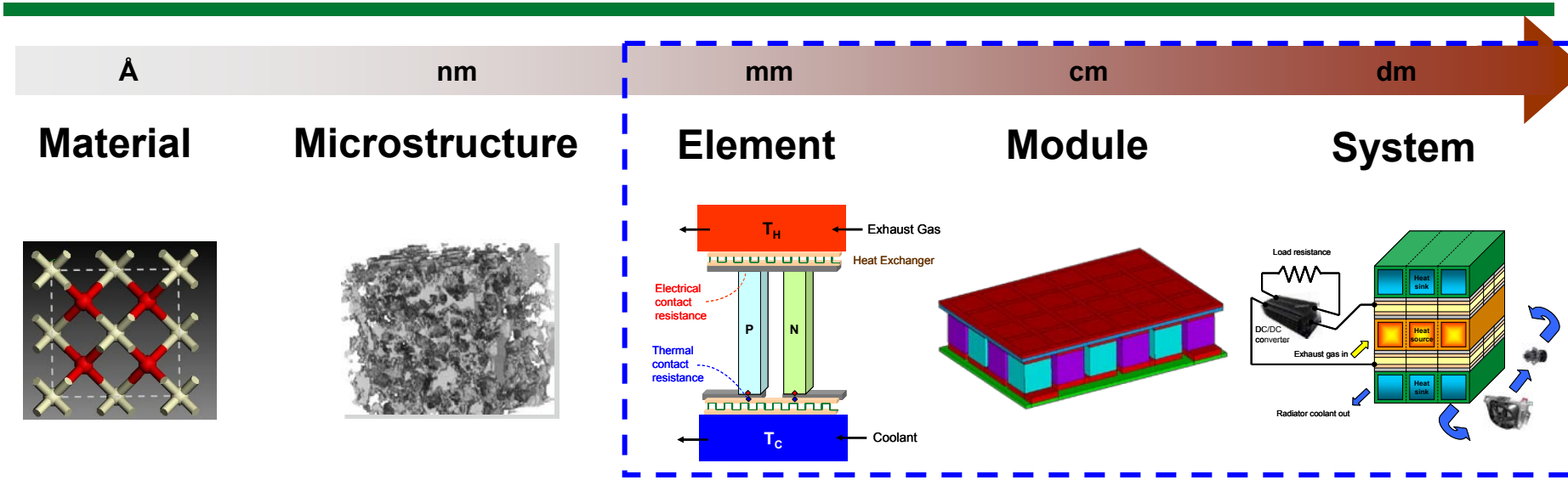
Different locations in the car require different TE materials



- Critical parameters for practical viability
  - Performance
  - Cost and raw material availability
  - Toxicity
  - High temperature stability and durability

➔ Skutterudite is a good candidate for post-aftertreatment locations

Corning has multiscale TE modeling activities

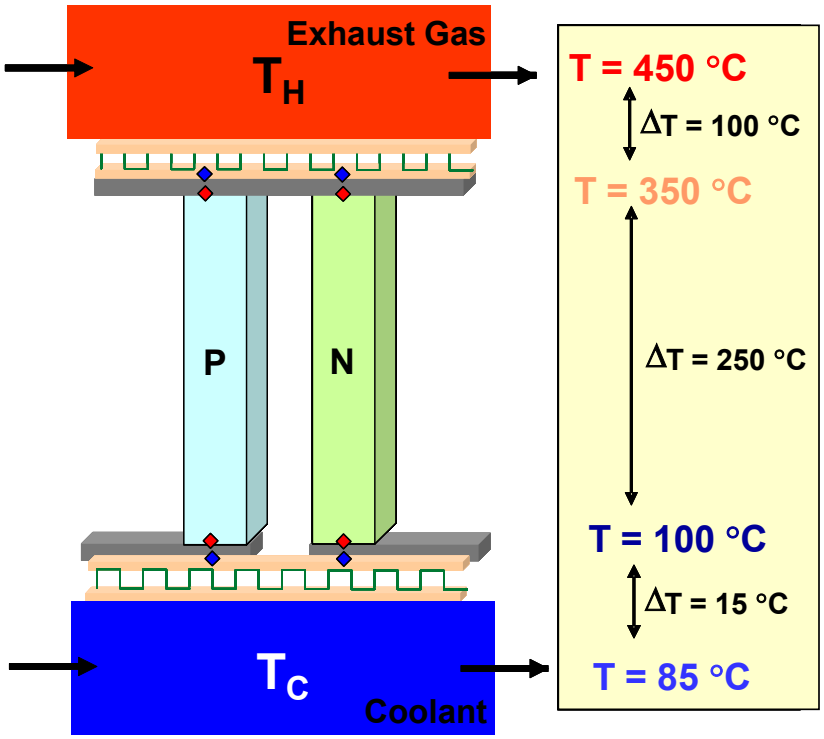


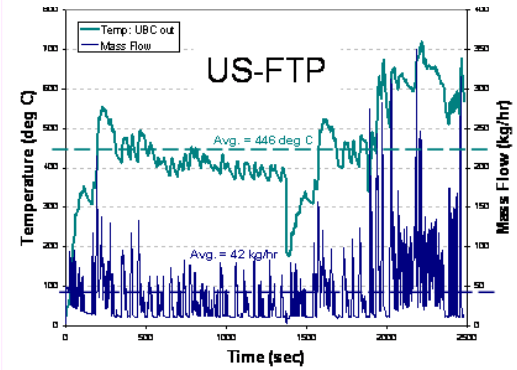
- **Objectives**
  - To provide guidance and help understanding for empirical research and measure progress
  - To guide requirements for Corning's advanced materials

Model developed and validated with experiment data

Design Knobs
- Thermoelectric material properties
- Geometry
- System Integration

Prescribed Conditions
- TEG Location – temperature, space
- Driving Conditions



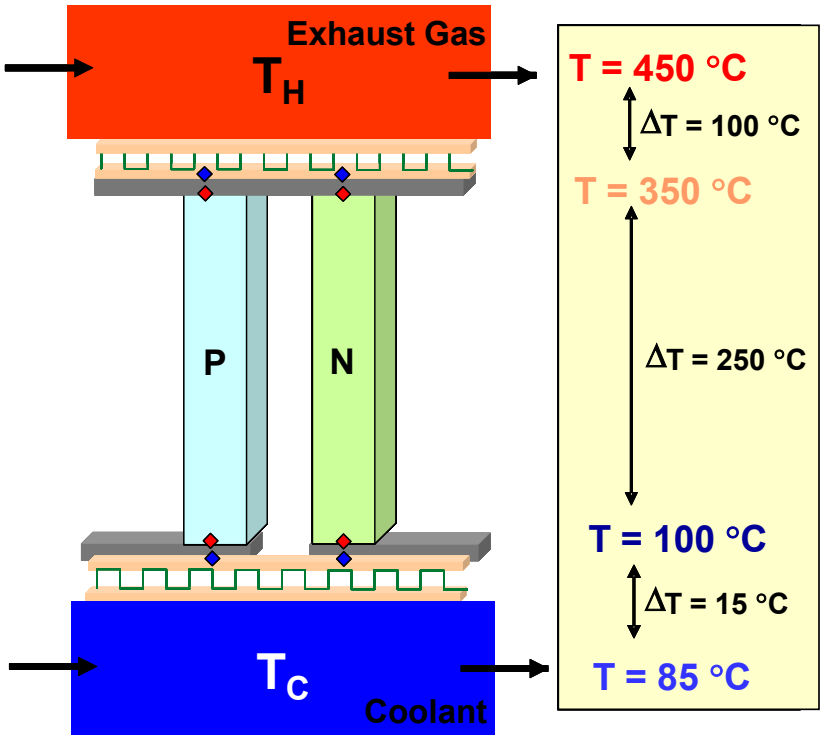


Hot-side temperature dictated by above choices
Lower temperature in EU drive cycles pose challenges

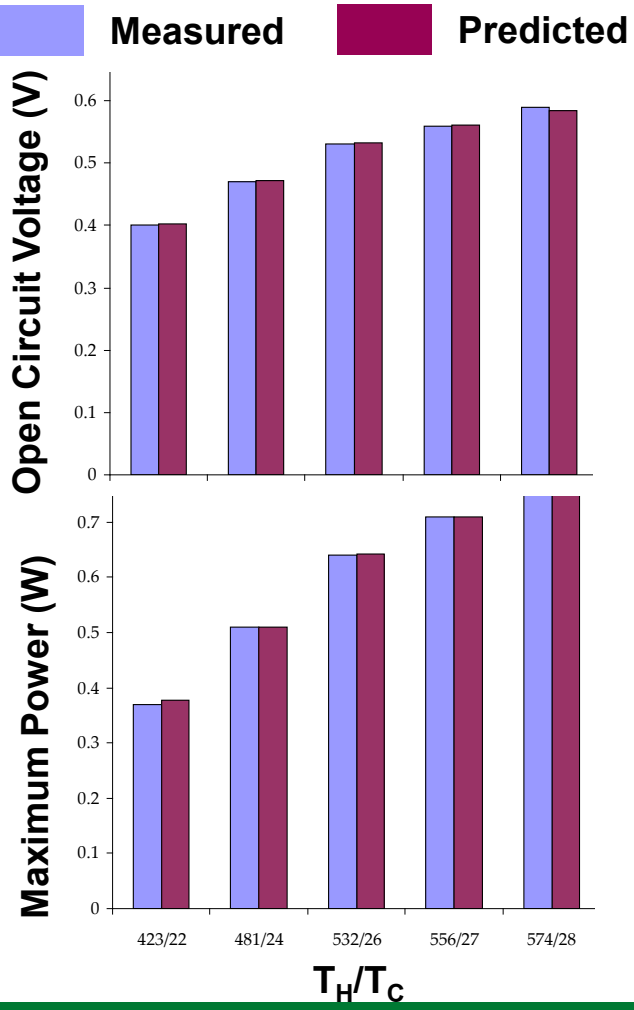
Model developed and validated with experiment data

Design Knobs

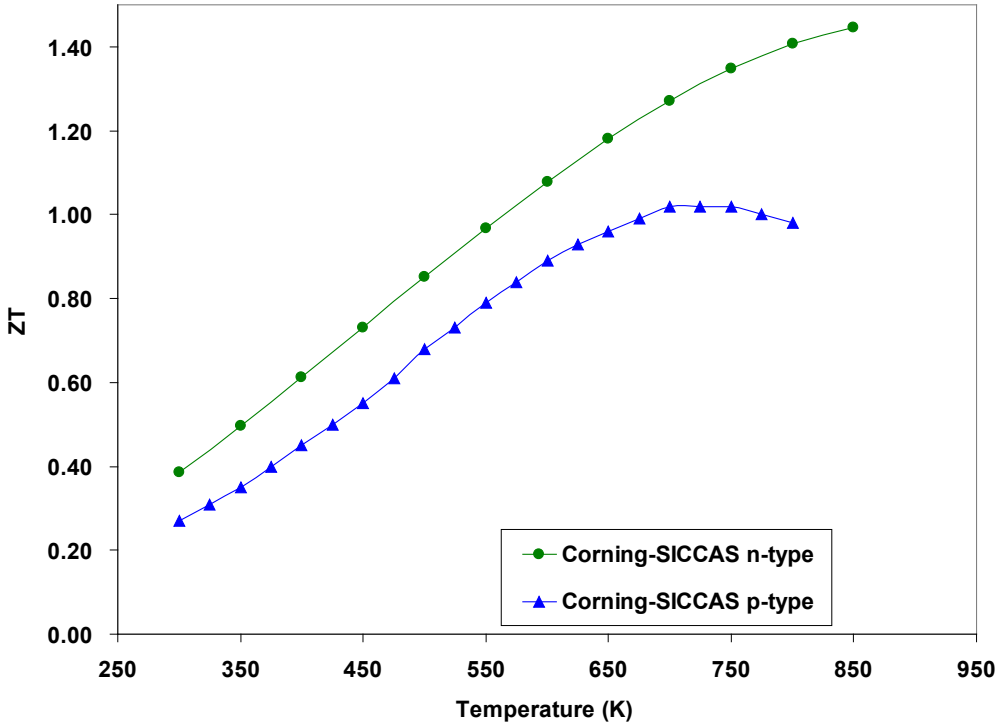
- Thermoelectric material properties
- Geometry
- System Integration



Model validated with Experiment



High performance n-type and p-type SKDs

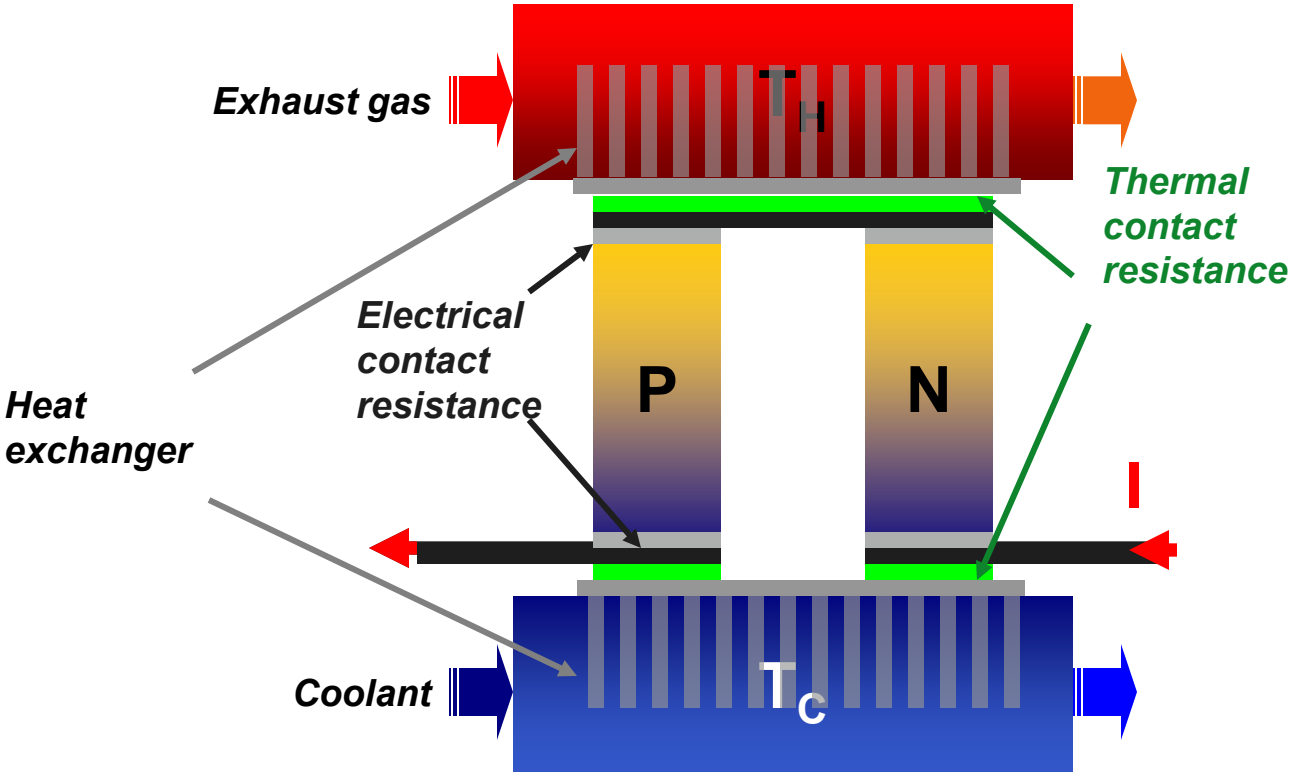


Developed high performance SKD materials:

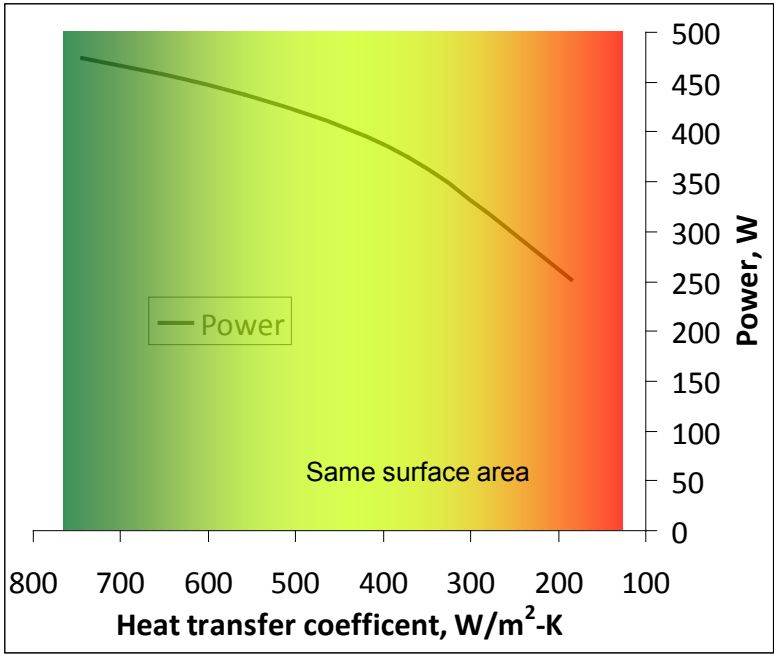
n-type: **ZT^{max} = 1.46** for at 800-850K

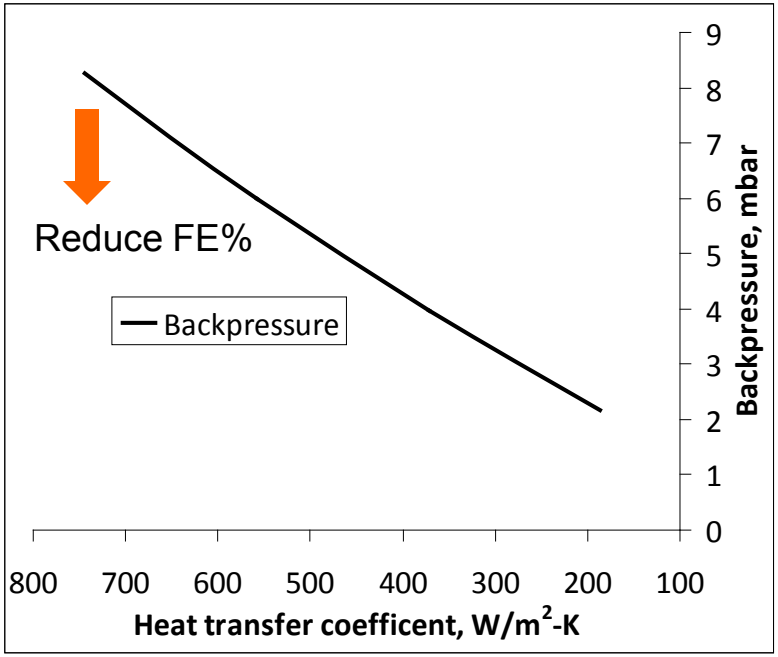
p-type: **ZT^{max} = 1.02** at 700-750K

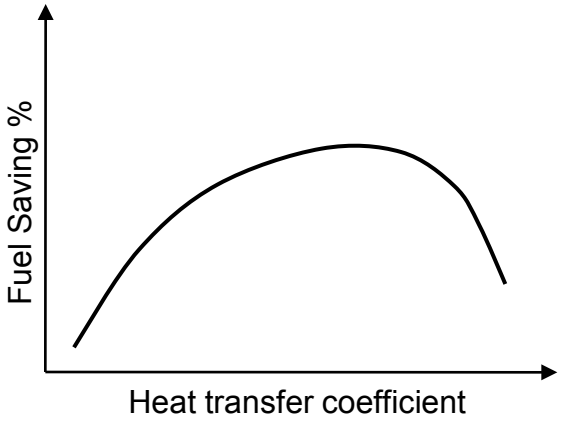
Material is the key, but heat exchanger design, contact resistance can degrade TEG performance



Heat exchanger design is important:
There is a trade-off between generated power and backpressure



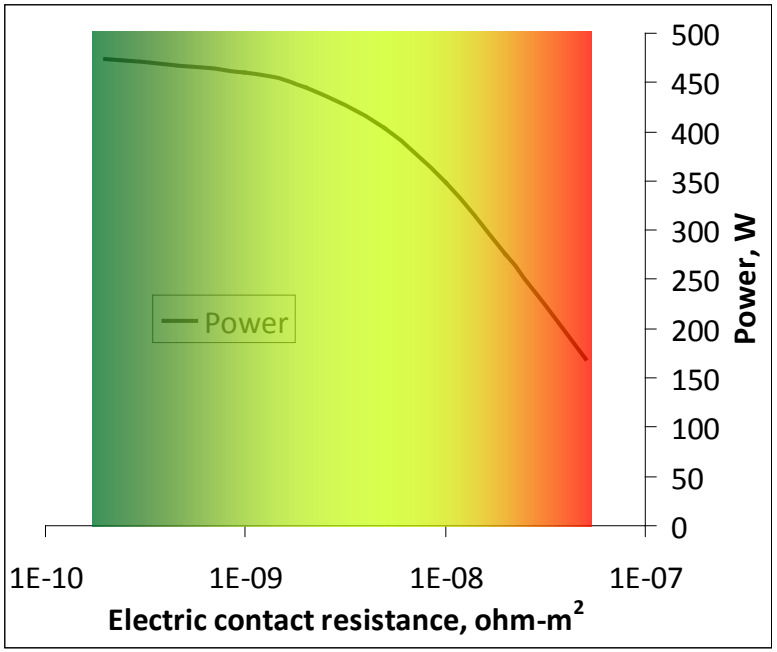




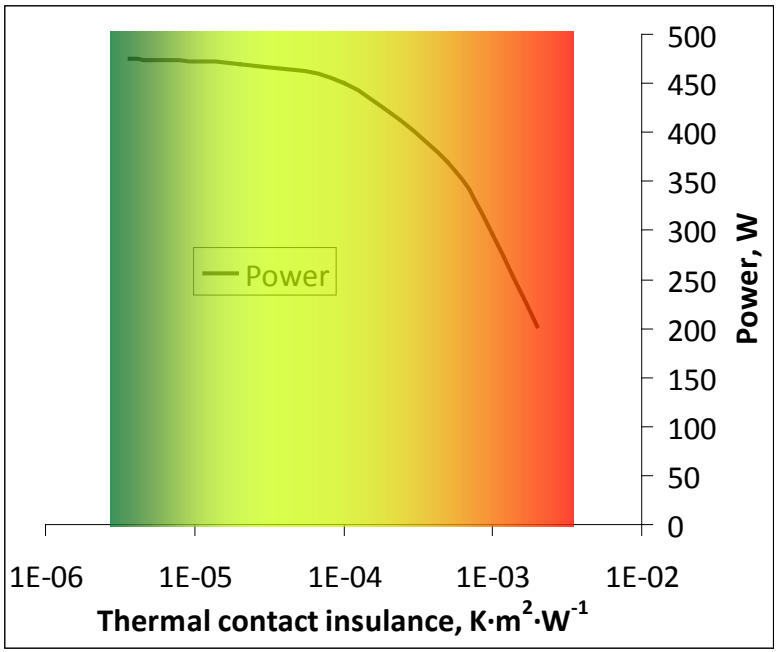
Vehicle speed @ 60 MPH

Need to find a optimized heat exchanger to maximize fuel savings

Contact resistance is a key parameter to improve system efficiency



Thermal contact resistance impact

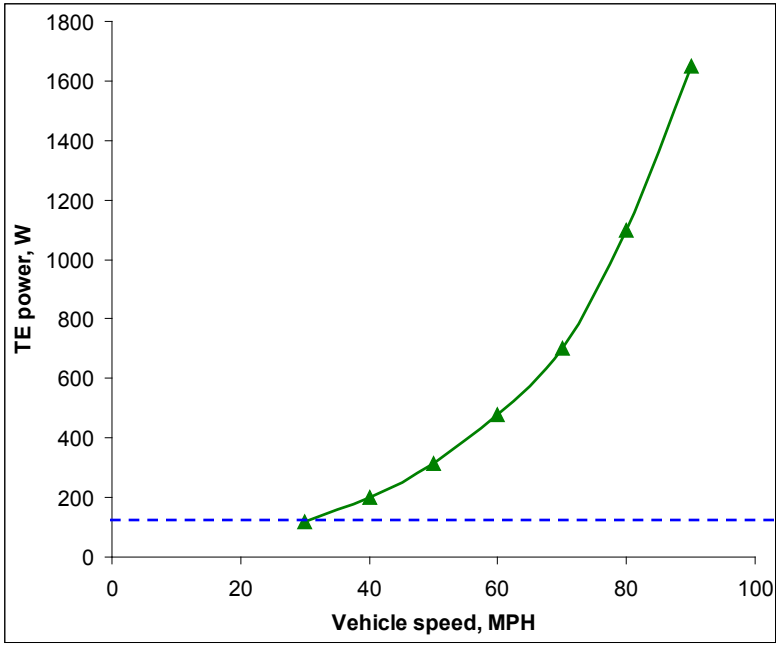


Electrical contact resistance impact

These are challenging targets to meet

Vehicle speed @ 60 MPH

Expected performance with our material, optimized heat exchanger and good contact resistances



FTP Drive Cycle TE Power

- Exhaust temperature and mass flow rate are key to TE power output and efficiency.
- They are determined by drive conditions
- At 65 mph, 500W can be expected at post-aftertreatment location.

Conclusions

- Key improvements in addition to material ZT and temperature range are needed to achieve targeted fuel savings:
  - Reduction in thermal and electric contact resistances
  - Light weight, low backpressure and high efficiency heat exchanger
- Hot side temperature is crucial for better efficiency
  - Drive cycle affects exhaust temperature
  - TEG location determines hot-side temperature

Corning is committed to deliver high quality TE elements.