Thermoelectric Vehicular Applications Status Mid 2009

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Department of Energy
Vehicle Technologies

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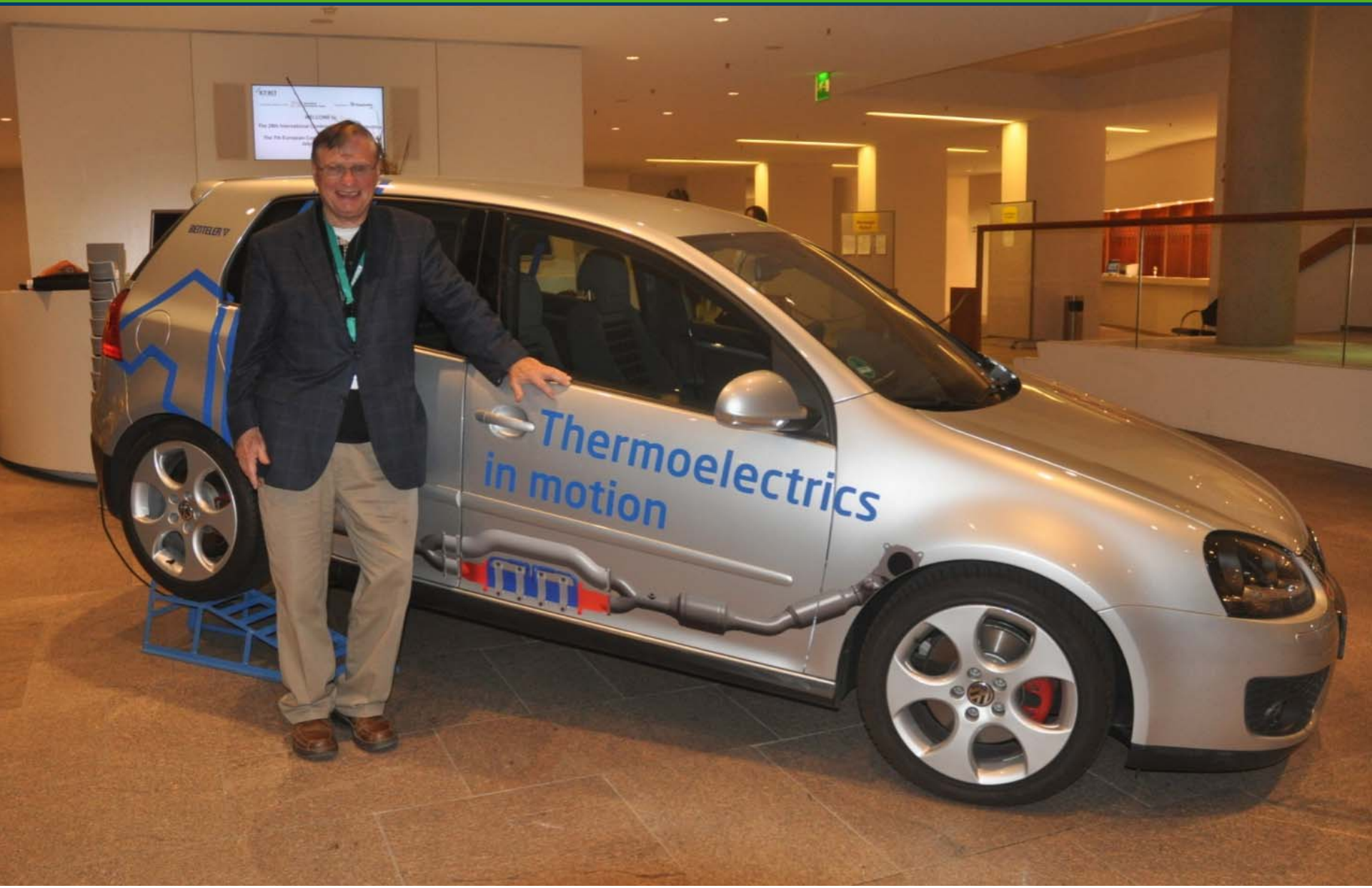
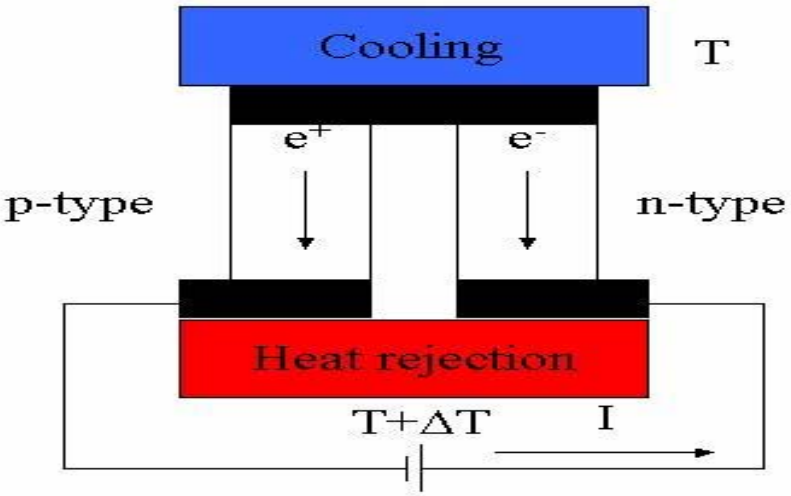
MIT-NESCAUM Symposium on Energy
Dedham, MA

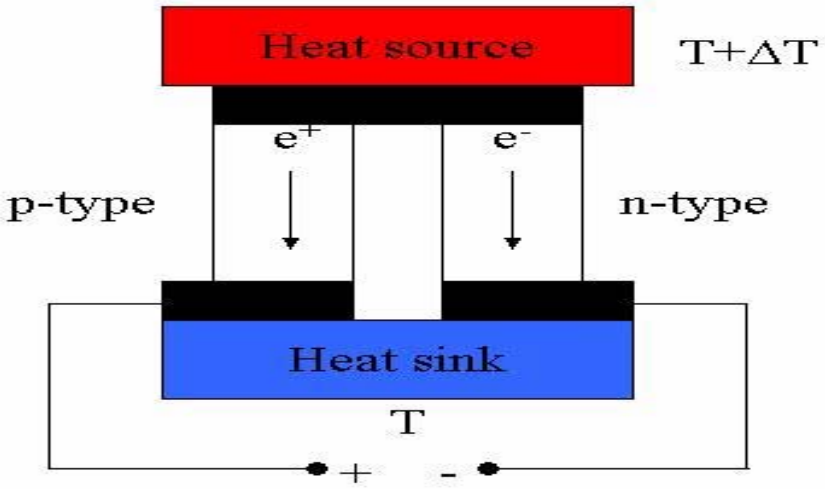
International Thermoelectric Conference 2009 – Frieburg, Germany



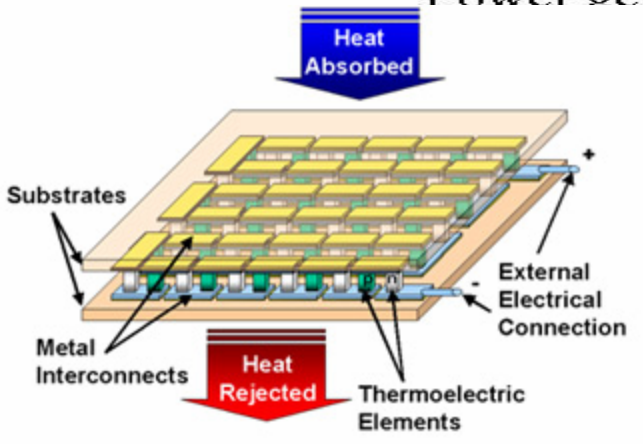
Thermoelectric Generator and HVAC



Refrigeration



Power generation



TE materials performance: Figure of Merit (ZT) *[courtesy Oregon State]*

Electrical conductivity

Seebeck coefficient or thermopower ($\Delta V/\Delta T$)

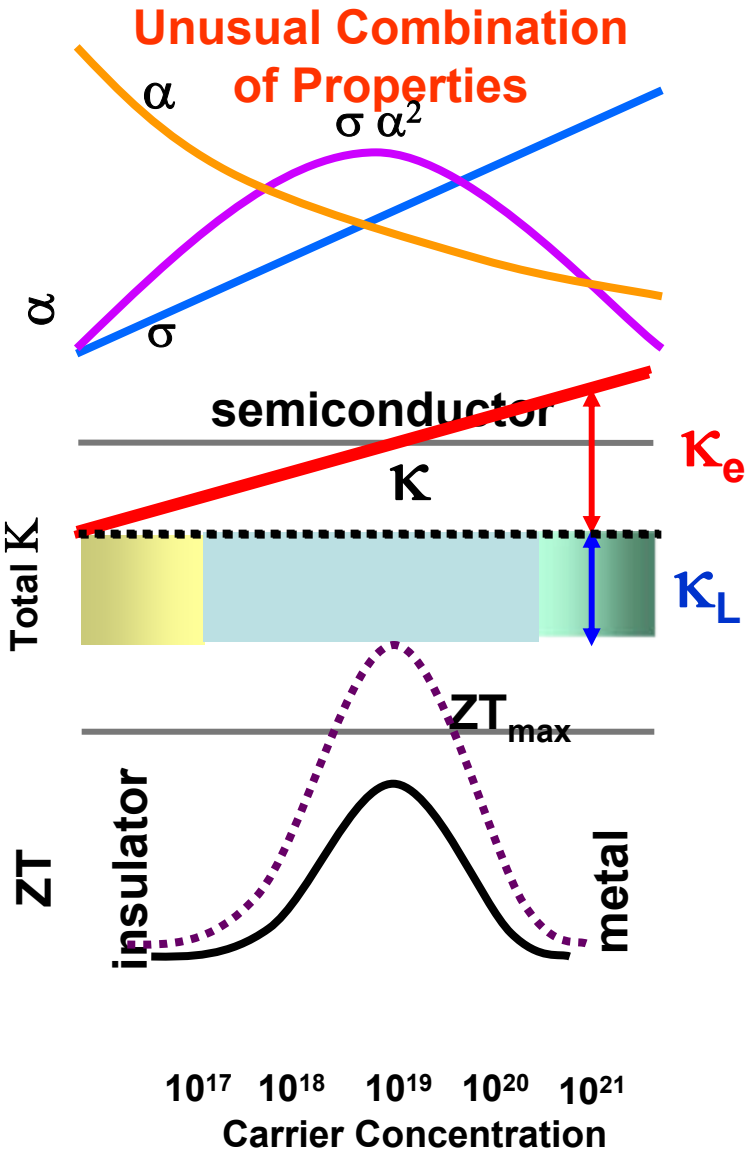
$$ZT = \frac{\sigma \alpha^2}{(\kappa_e + \kappa_L)} \bullet T$$

Total thermal conductivity

$\sigma\alpha^2$ = **Power Factor**

$\sigma = 1/\rho$ = **electrical conductivity**

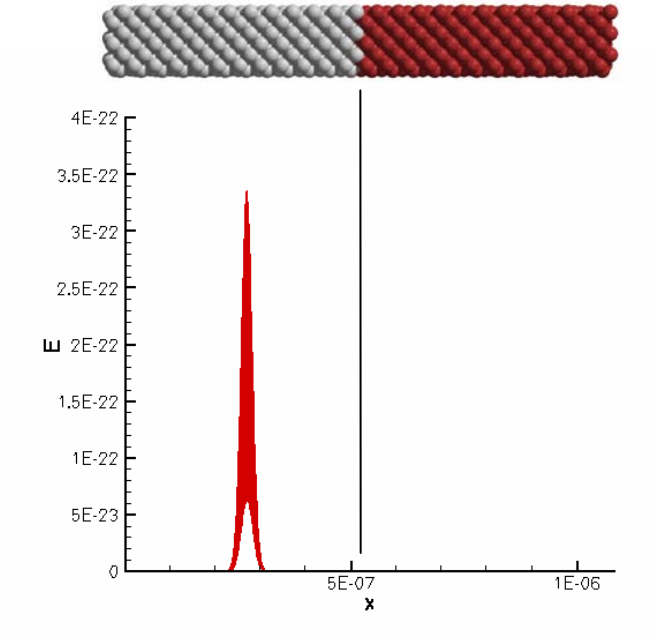
ρ = **electrical resistivity**

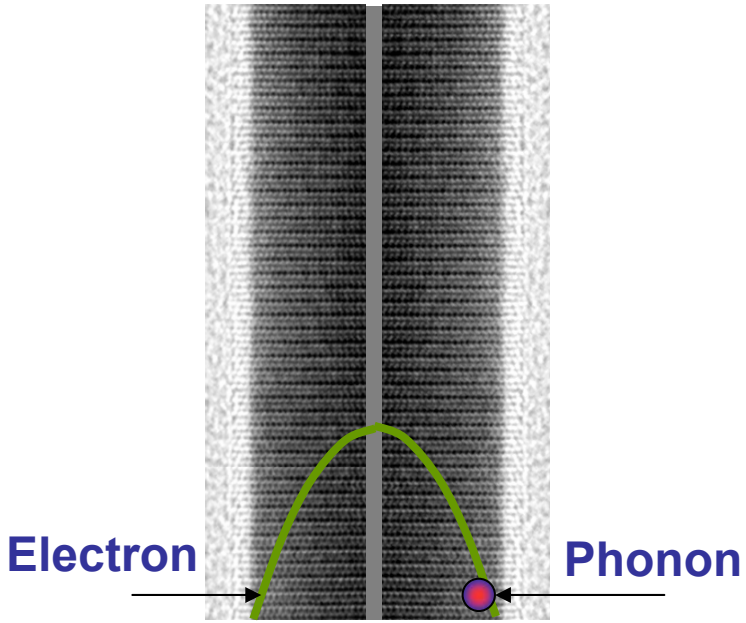


Nanoscale Effects for Thermoelectrics (courtesy Millie Dresselhaus, MIT)

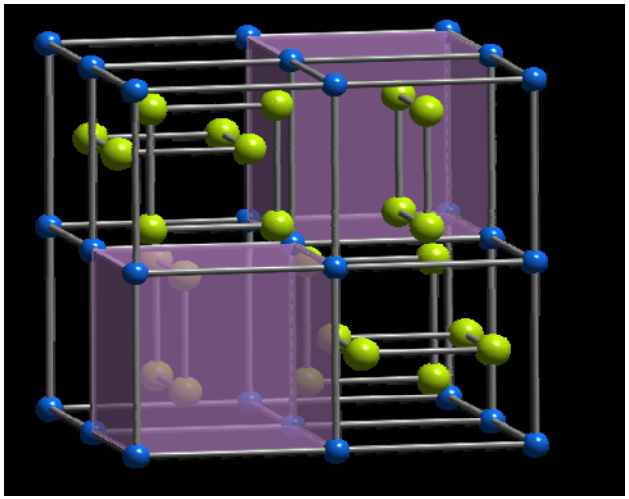
Interfaces that Scatter Phonons but not Electrons

	Electrons	Phonons
Mean Free Path	Λ=10-100 nm	Λ=10-100 nm
Wavelength	λ=10-50 nm	λ=1 nm

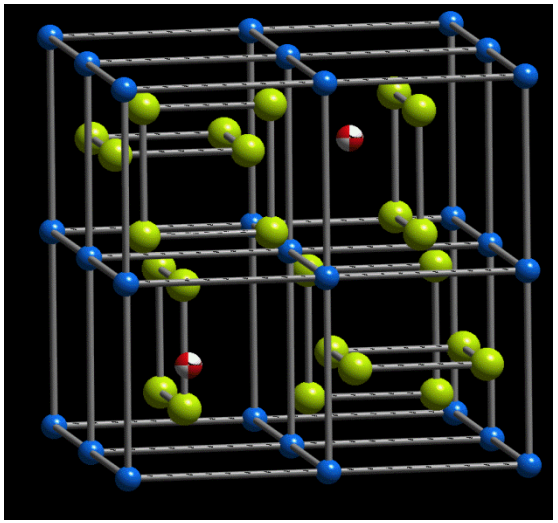




Crystal Structure of Skutterudites Courtesy Oregon State



$CoSb_3$ $[Co_8(Sb_4)_6]$



R_xCoSb_3

- Cobalt atoms form a *fcc* cubic lattice
- Antimony atoms are arranged as a square planar rings
- There are 8 spaces for the Sb_4 units
- 6 are filled and 2 are empty

Atoms can be inserted into empty sites. Atoms can "rattle" in these sites – scatter phonons and lower the lattice thermal conductivity.

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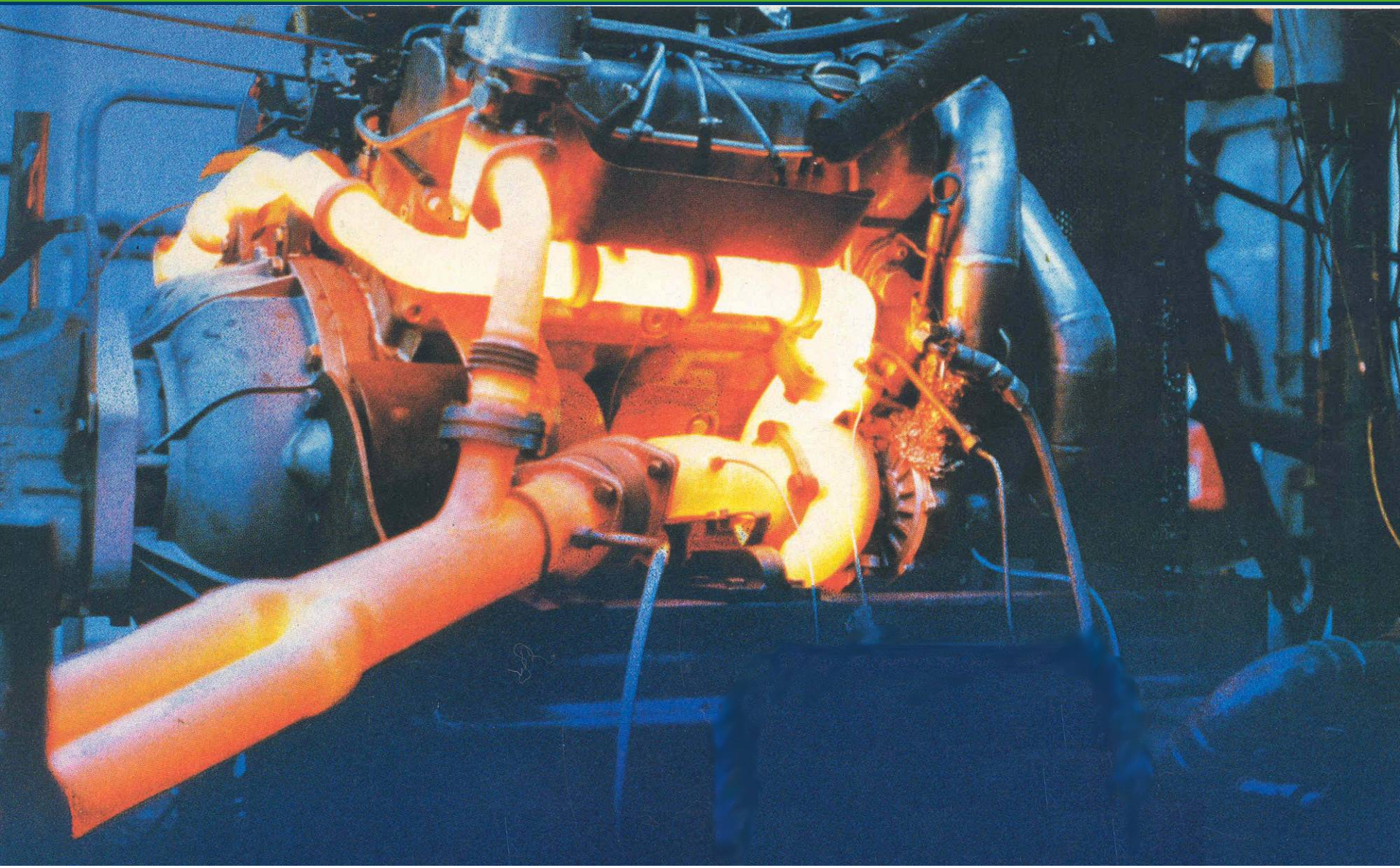
Available Energy in Auto Engine Exhaust



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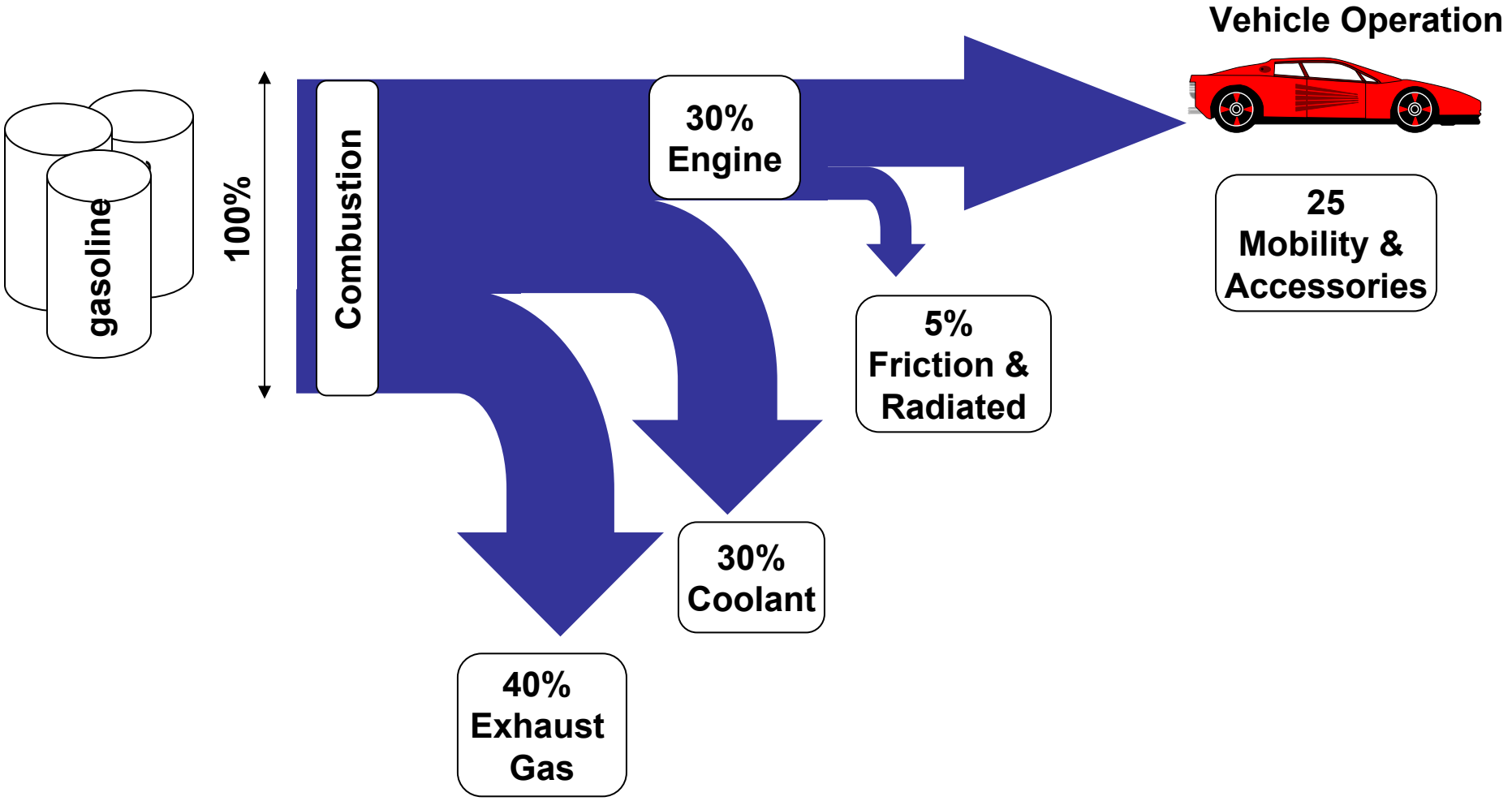
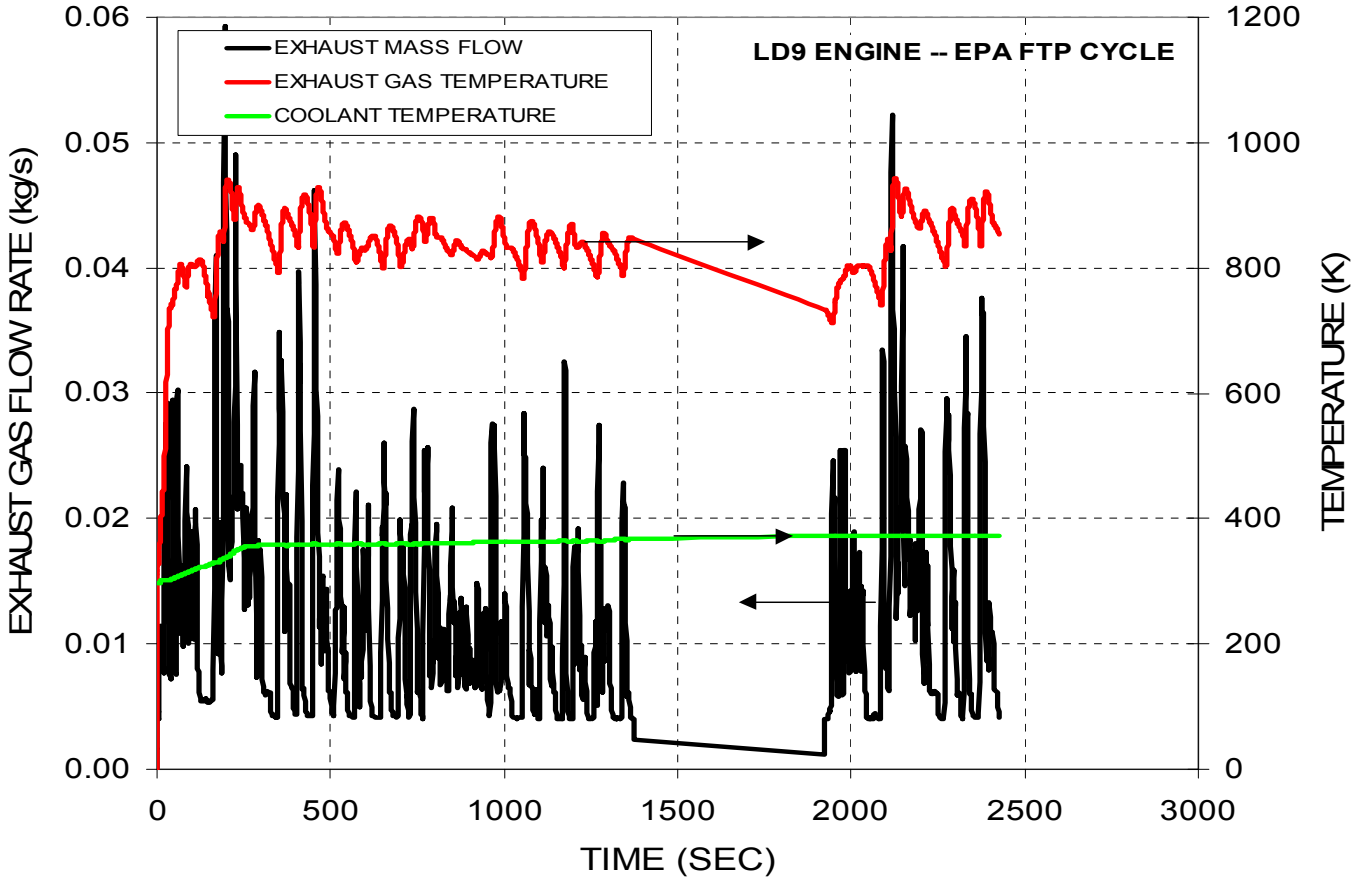
Potential Thermoelectric Heat Sources



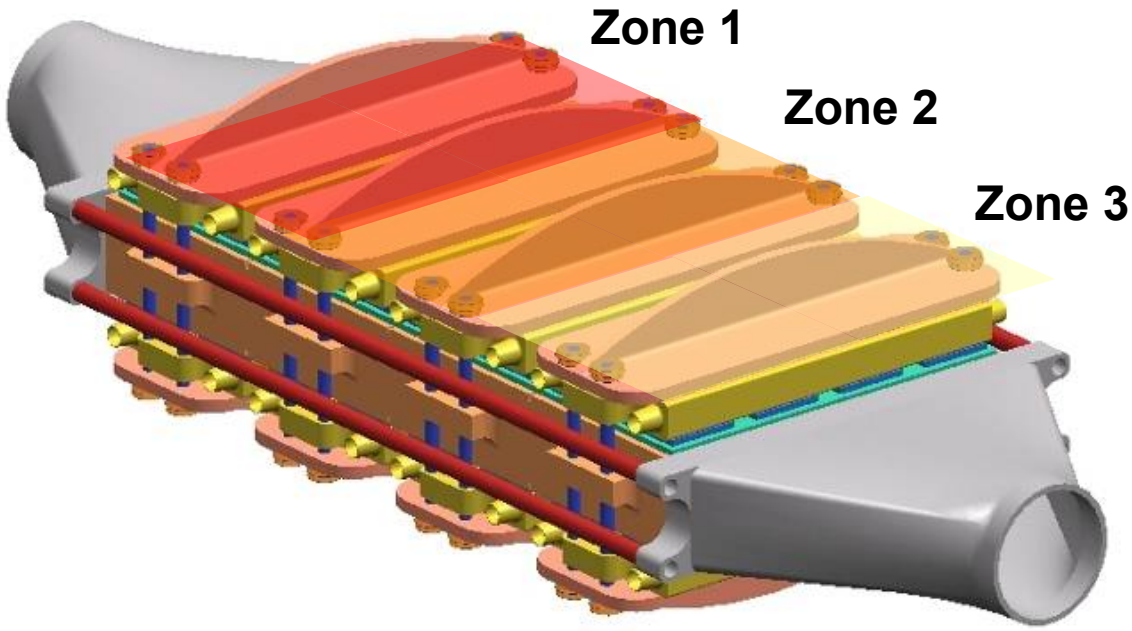
Spark Assisted Gasoline internal Combustion Engine (Light Truck or Passenger Vehicle)

Exhaust Flow and Temperatures for a 4- Cylinder Engine

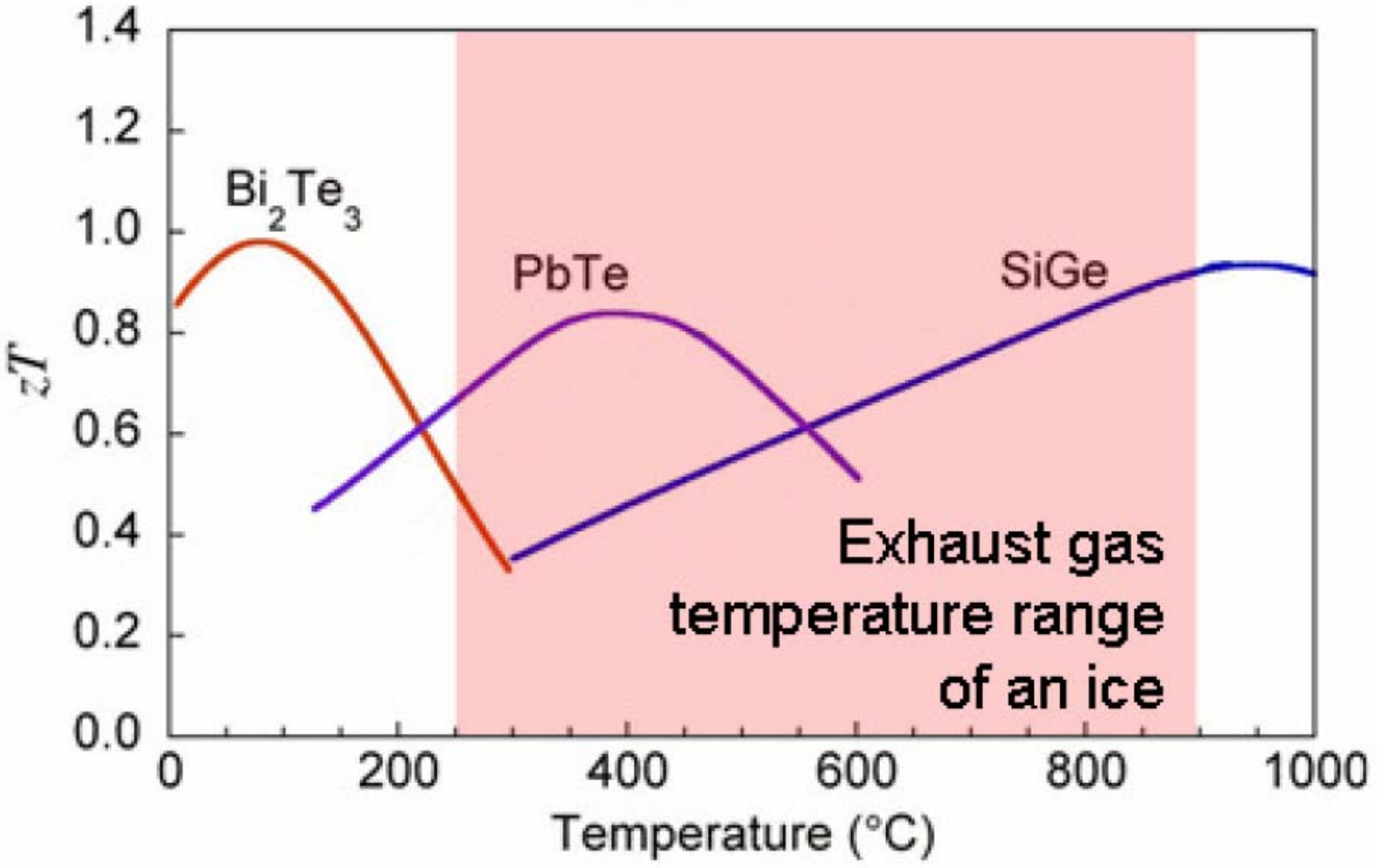


There are tens of kW heat energy in the exhaust & coolant

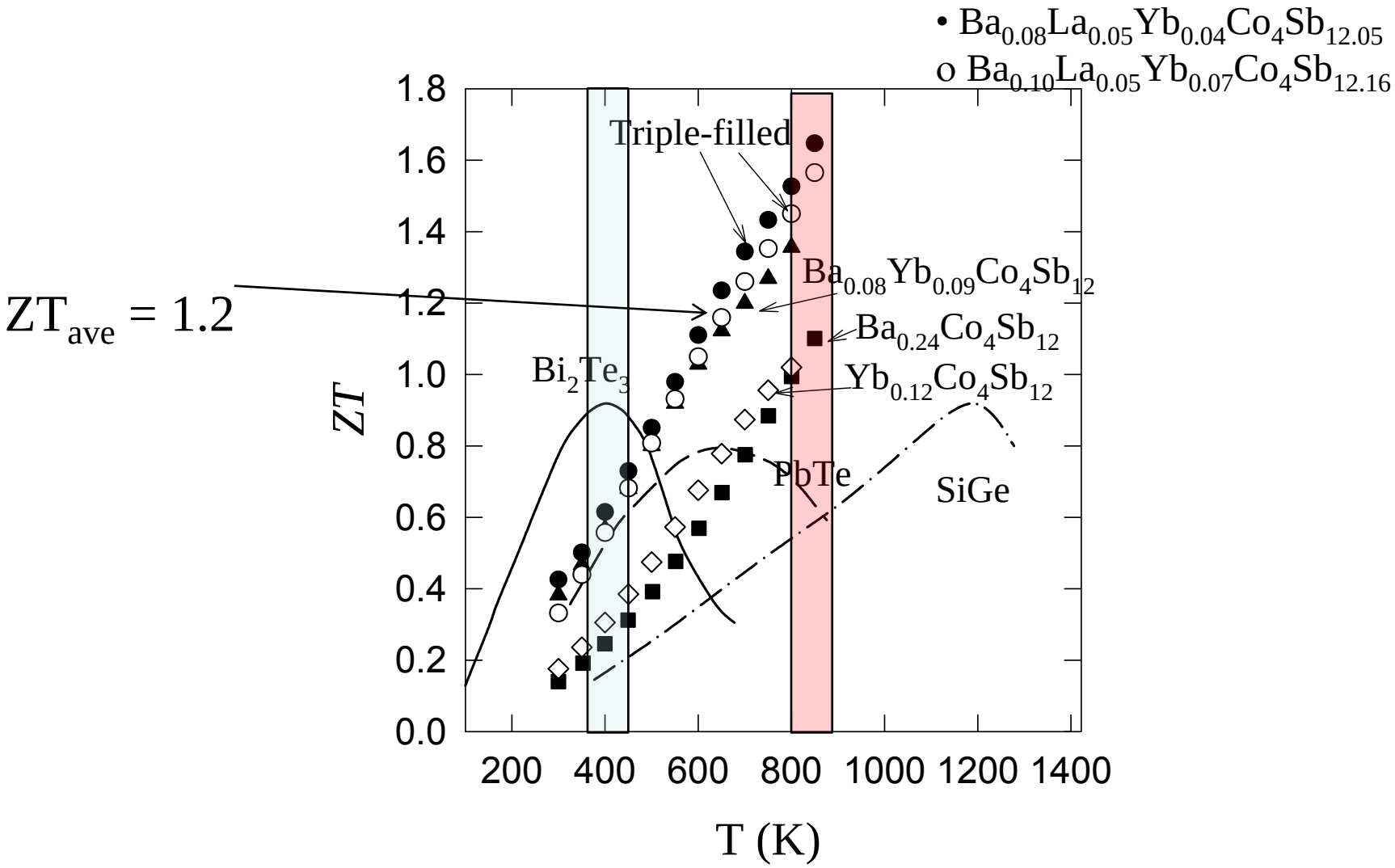
Thermoelectric Modules optimized for Thermal Zones



TEG Candidate Materials – 2005



Highest ZT Achieved in Triple-filled Skutterudites



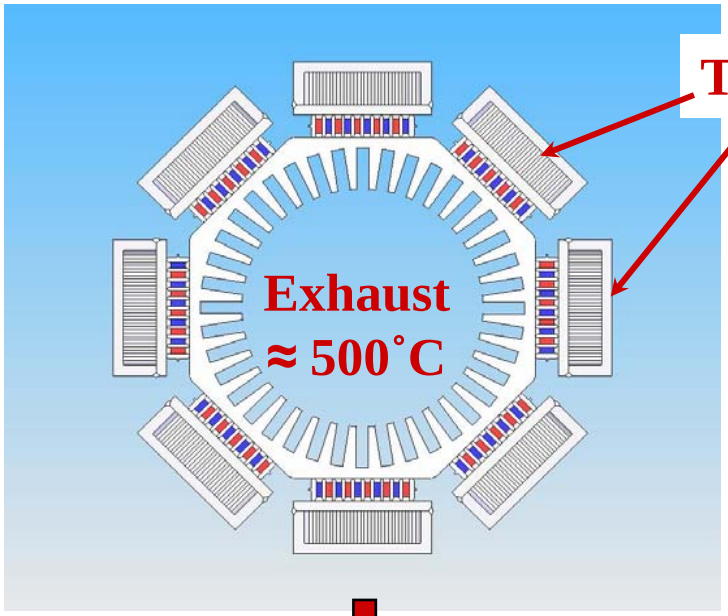
1. X. Shi, et al. Appl. Phys. Lett. **92**, 182101 (2008)
2. X. Shi, et al., submitted (2009)

TE Power Generation from Engine Waste Heat

Heat Rejection
Waste Heat > 60%

$T_H \approx 500^\circ C$

$T_C \approx 110^\circ C$



Carnot Efficiency

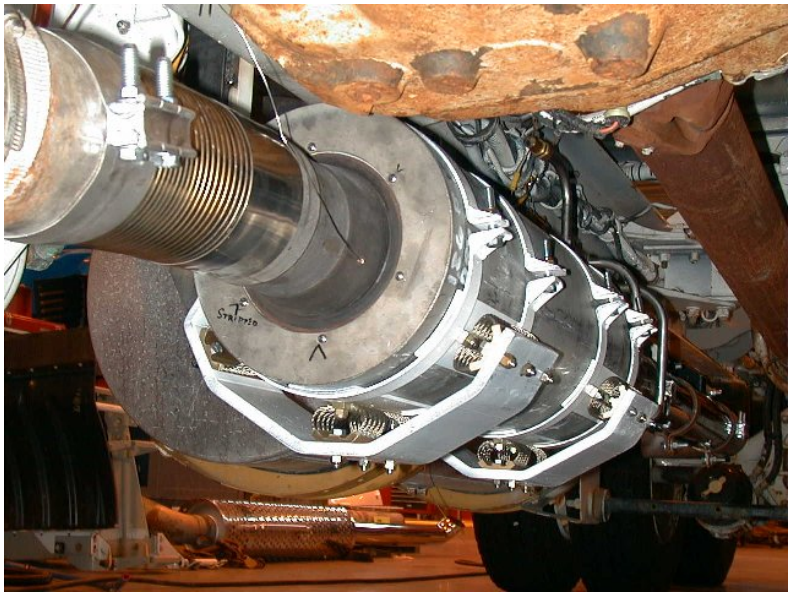
$$\eta_C = \frac{T_H - T_C}{T_H}$$

TE Efficiency

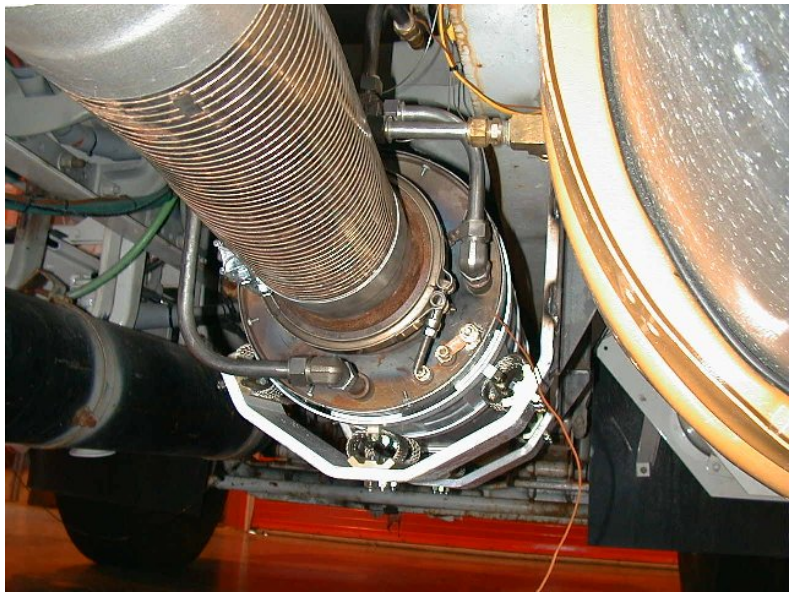
$$\eta = \left(\frac{T_H - T_C}{T_H}\right)\left(\frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_C}{T_H}}\right)$$

Waste Heat Recovery
Goal > 10% Increase in fuel economy

Installed Thermoelectric Generator on Heavy Duty Truck



Front View



Rear View

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Beltless or More Electric Engine

Truck Electrification

Electrify accessories
decouple them from engine
Match power demand to real time need
Enable use of alternative power sources

Modular HVAC

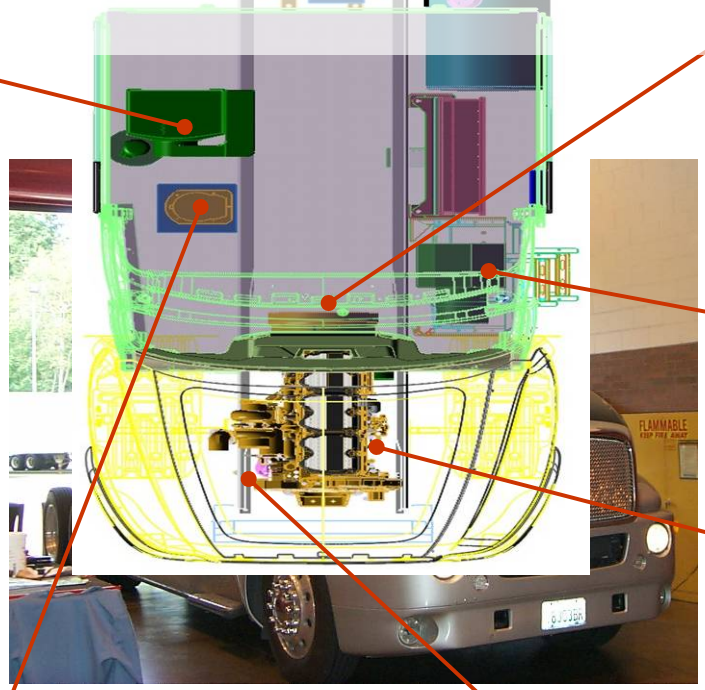
Variable speed compressor more efficient and serviceable
3X more reliable compressor no belts, no valves, no hoses leak-proof refrigerant lines instant electric heat

Shore Power and Inverter

Supplies DC Bus Voltage from 120/240 Vac 50/60 Hz Input Supplies 120 Vac outlets from battery or generator power

Down Converter

Supplies 12 V Battery from DC Bus



Starter Generator Motor

Beltless engine product differentiation improve systems design flexibility more efficient & reliable accessories

Auxiliary Power Unit

Supplies DC Bus Voltage when engine is not running - fulfills hotel loads without idling main engine overnight

Electric Oil Pump

Variable speed
Higher efficiency

Electric Water Pump

Higher reliability variable speed faster warm-up less white smoke lower cold weather emissions

Compressed Air Module

Supplies compressed air for brakes and ride control

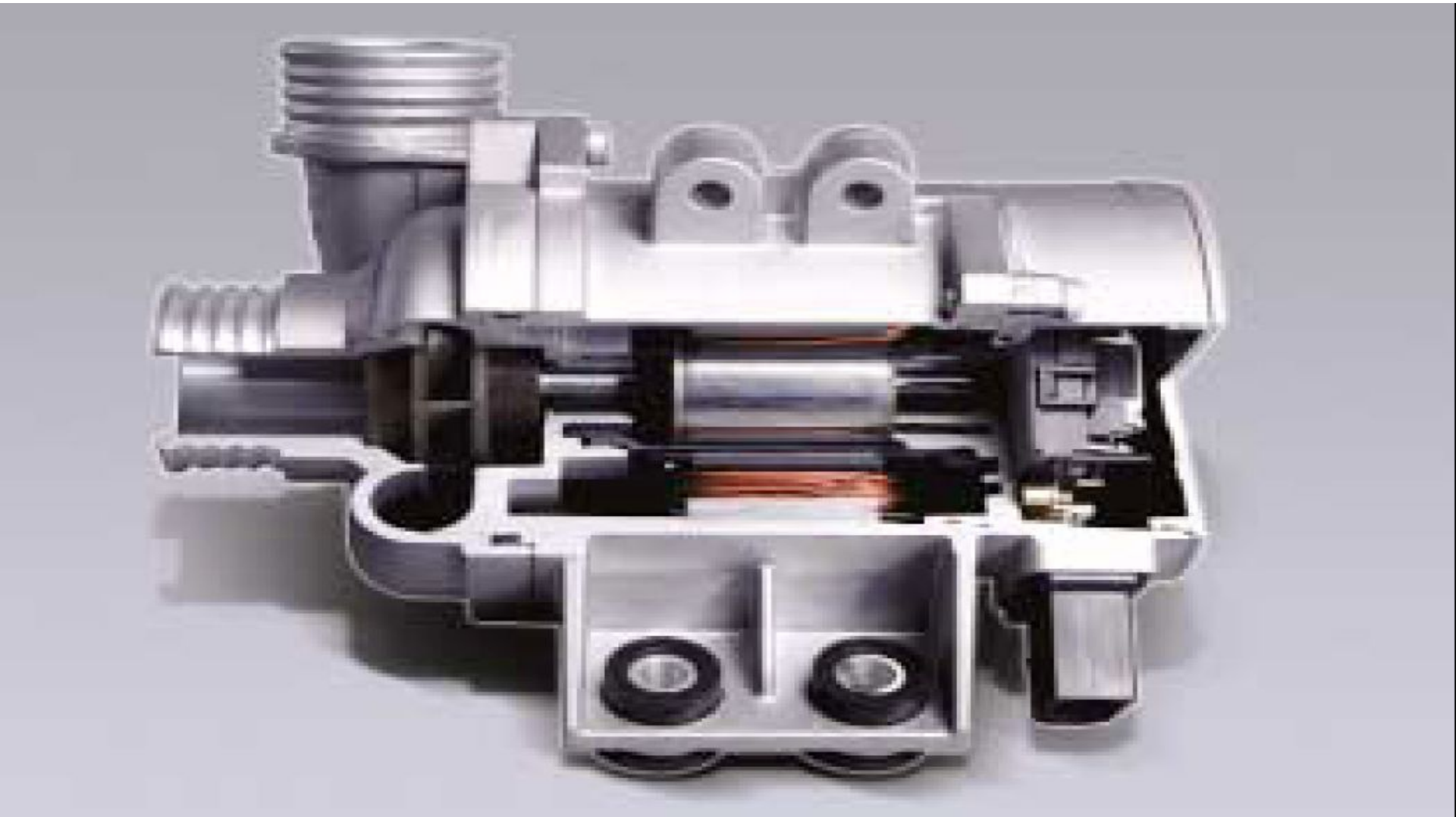
DOE Vehicular Thermoelectric Generator Projects

Competitive Award Selections

(March 2004 RFP)

Awardees	Additional Team Members
High Efficiency Thermoelectric	
General Motor Corporation and General Electric	, University of Michigan, University of South Florida, Oak Ridge National Laboratory, and RTI International
BSST, LLC.	Visteon, BMW-NA, Ford, Marlow Industries
Michigan State University	NASA Jet Propulsion Laboratory Cummins Engine Company Tellurex, Iowa State

BMW's Electric Water Pump Improves Fuel Economy 1.5 to 2.0 %



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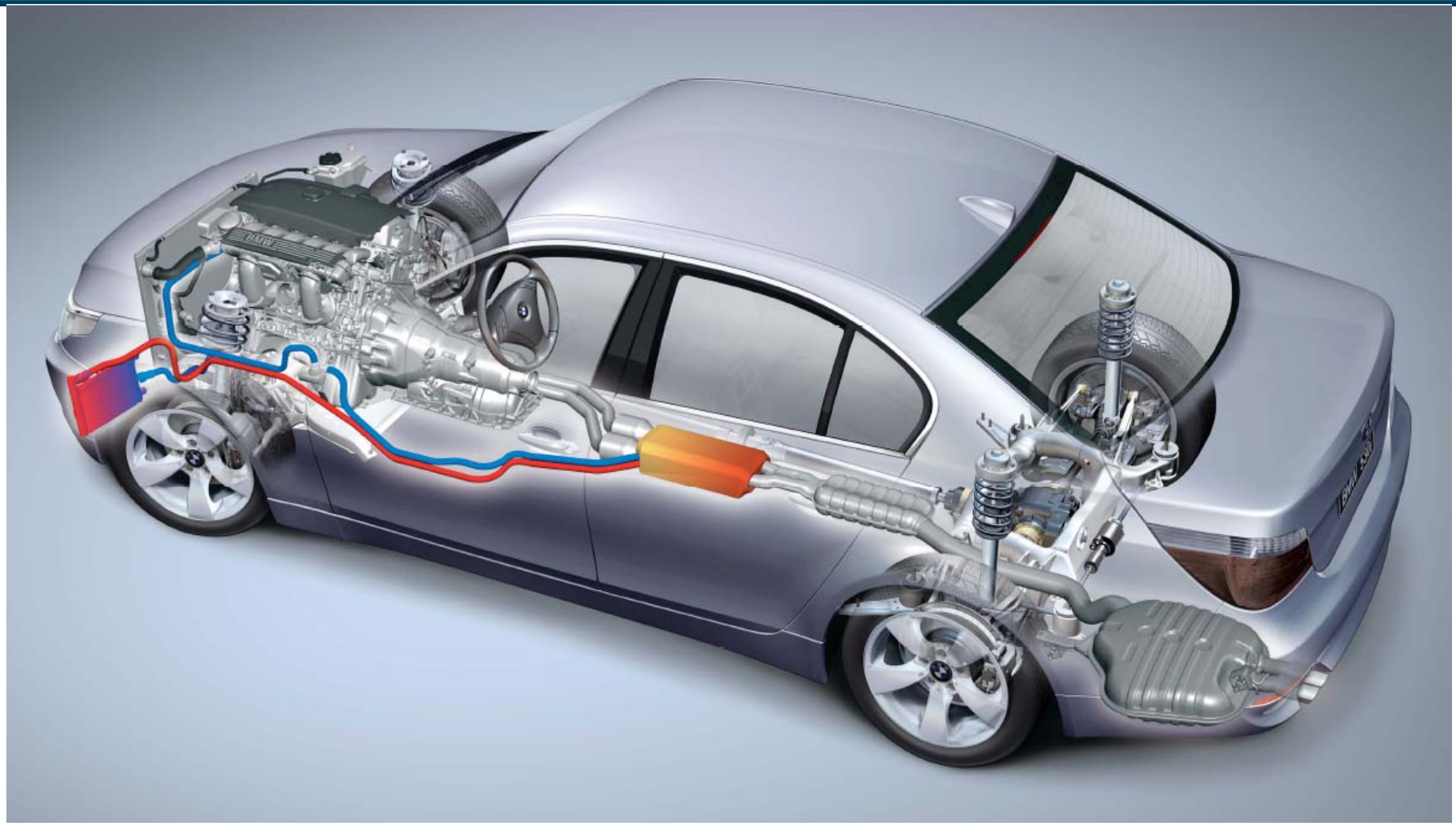
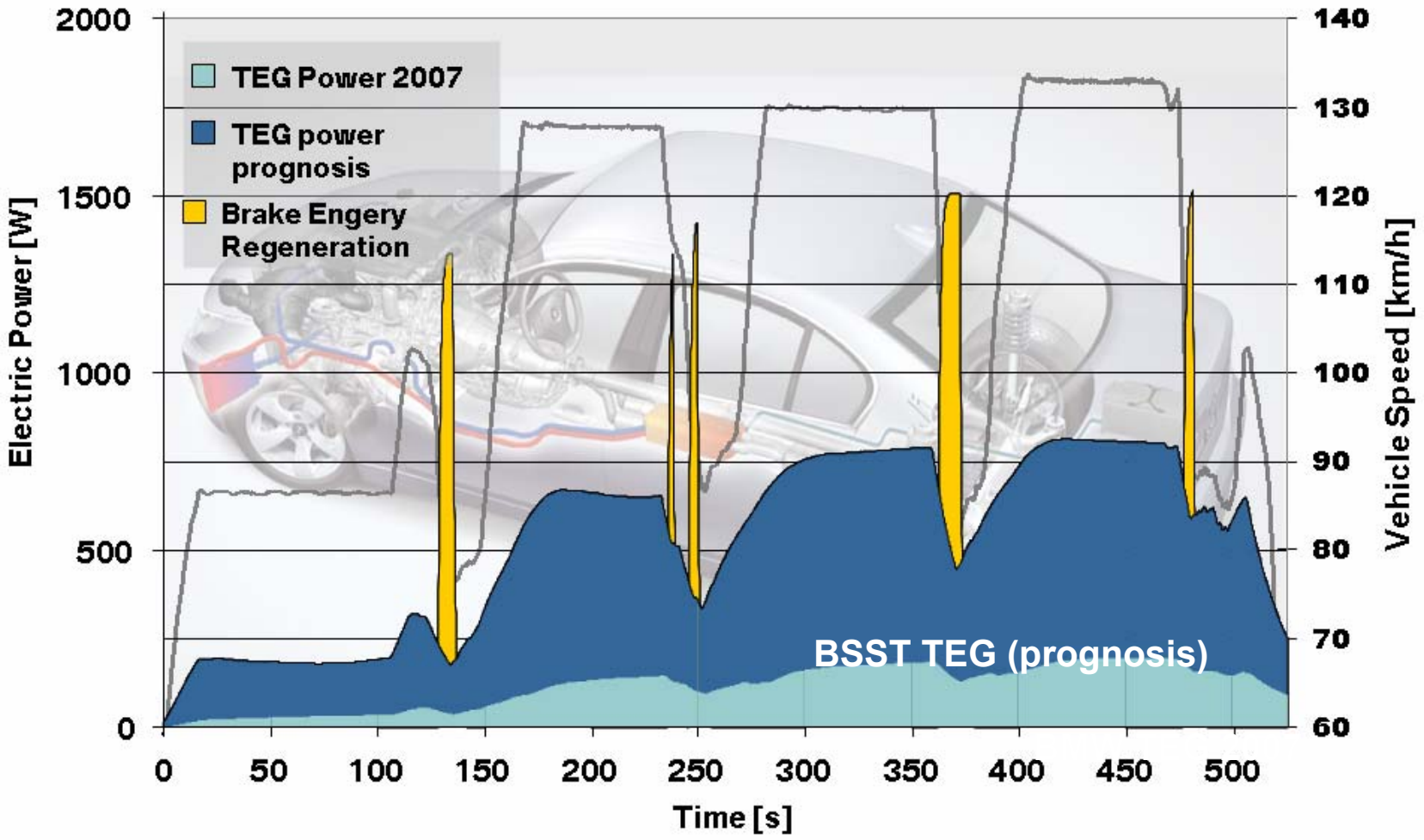
BMW Series 5 , Model Year 2011, 3.0 Liter Gasoline Engine w/ Thermoelectric Generator



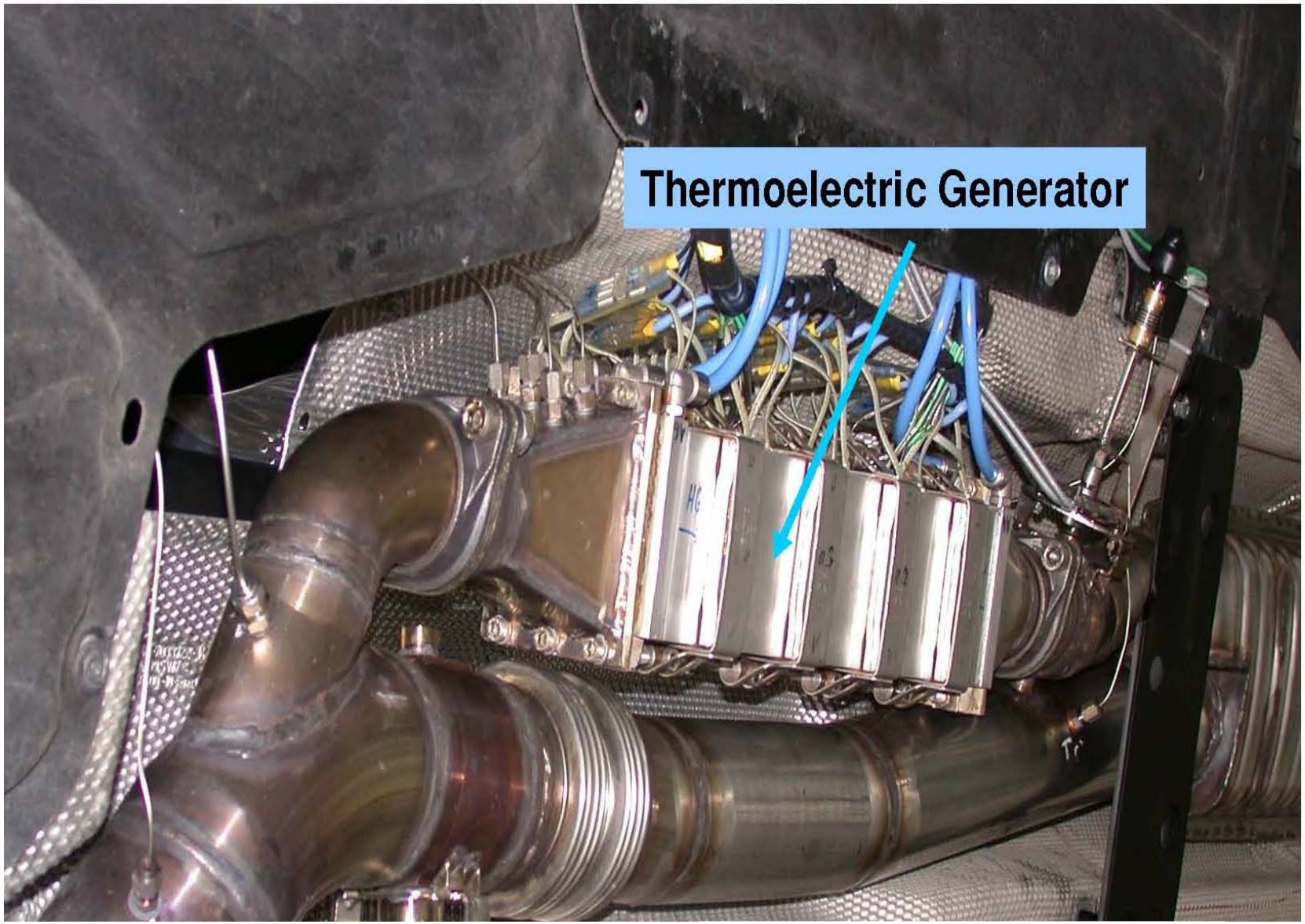
FreedomCAR & Fuel Partnership
Visteon
BSST innovative solutions in temperature control
BMW
MINI

TEG is ideally compatible with Regenerative Braking

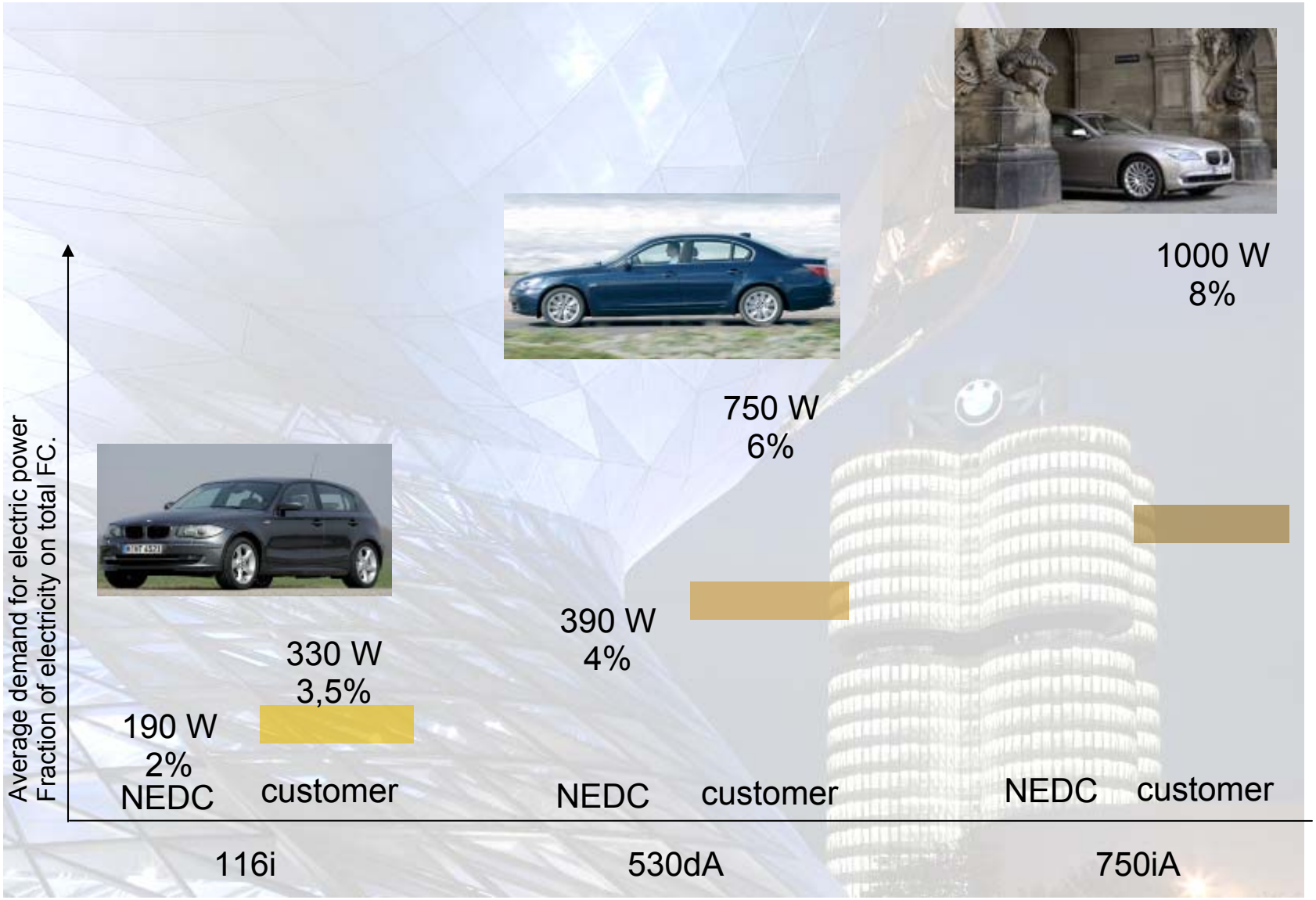


Slide courtesy of BSST

TEG Installed in BMW Series 5 Test Vehicle

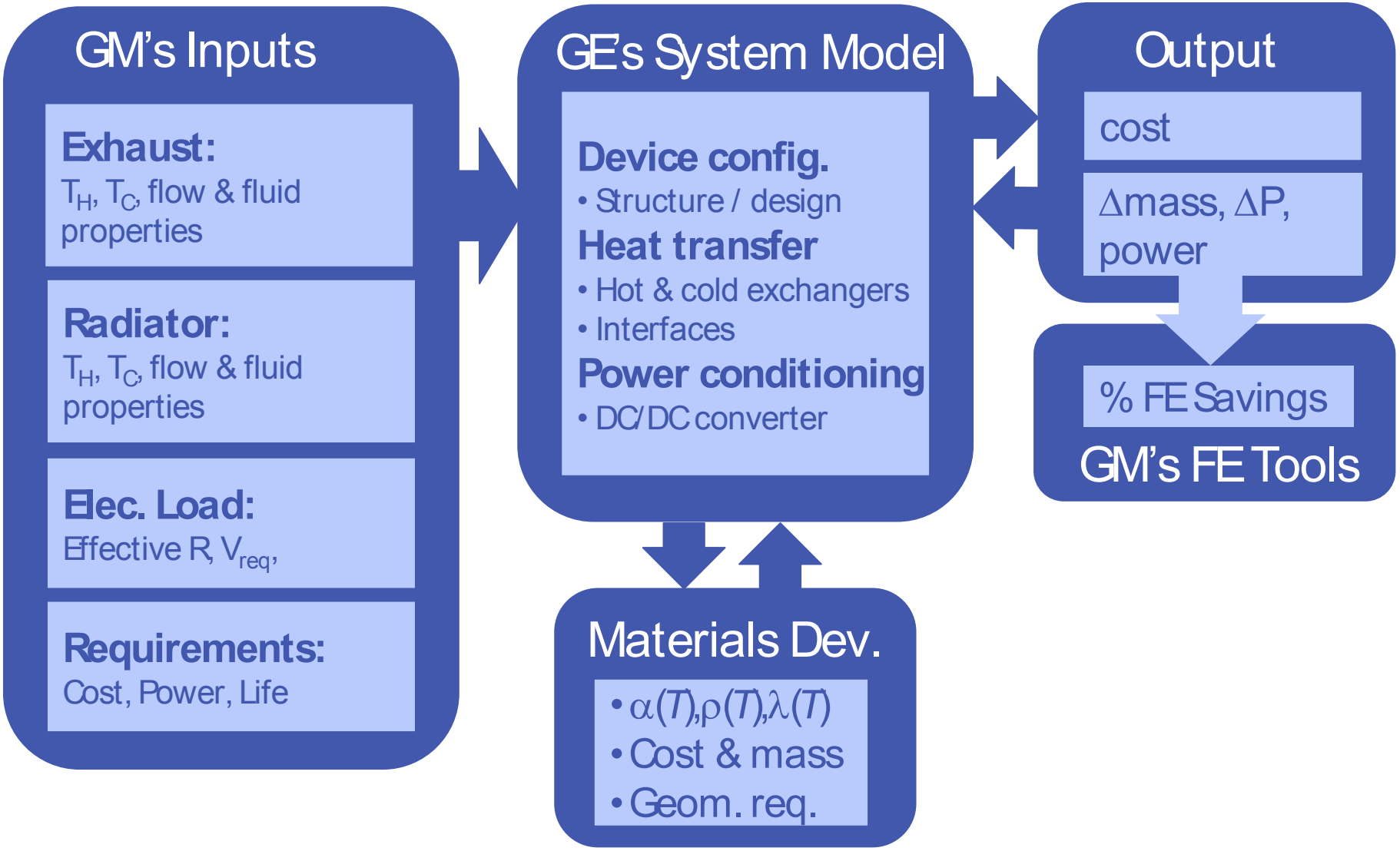


Thermoelectric Waste Heat Recovery. BMW Sedans



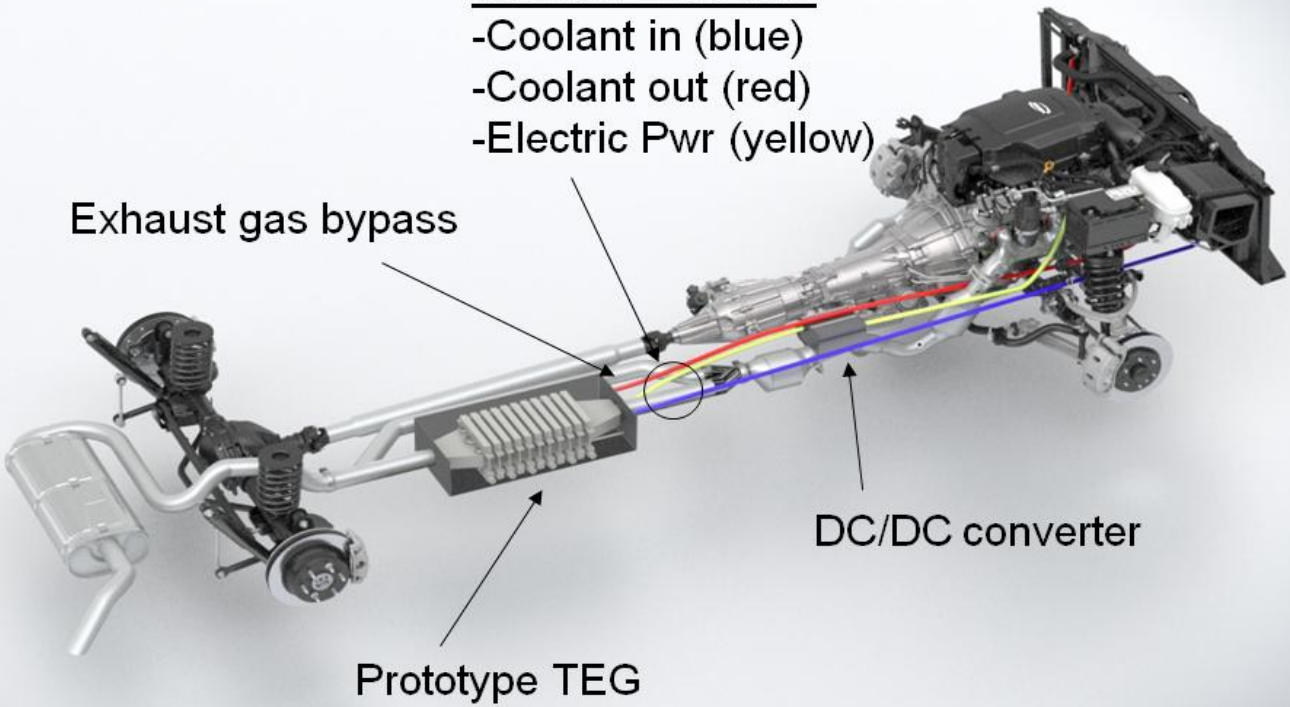
Slide courtesy of BSST

Program Flow Chart



GM TE Generator on a Chevy Suburban

TEG installed in a rear drive vehicle.
GM Suburban



Slide courtesy of General Motors Corp.

Automotive (TE HVAC) Thermoelectric Heating Ventilation and Air Conditioning

Competitive Awards to Ford and GM

Co-Funded with the California Energy Commission

Develop TE Zonal or Distributed Cooling/Heating System

Maintain Occupant Comfort without Cooling Entire Cabin

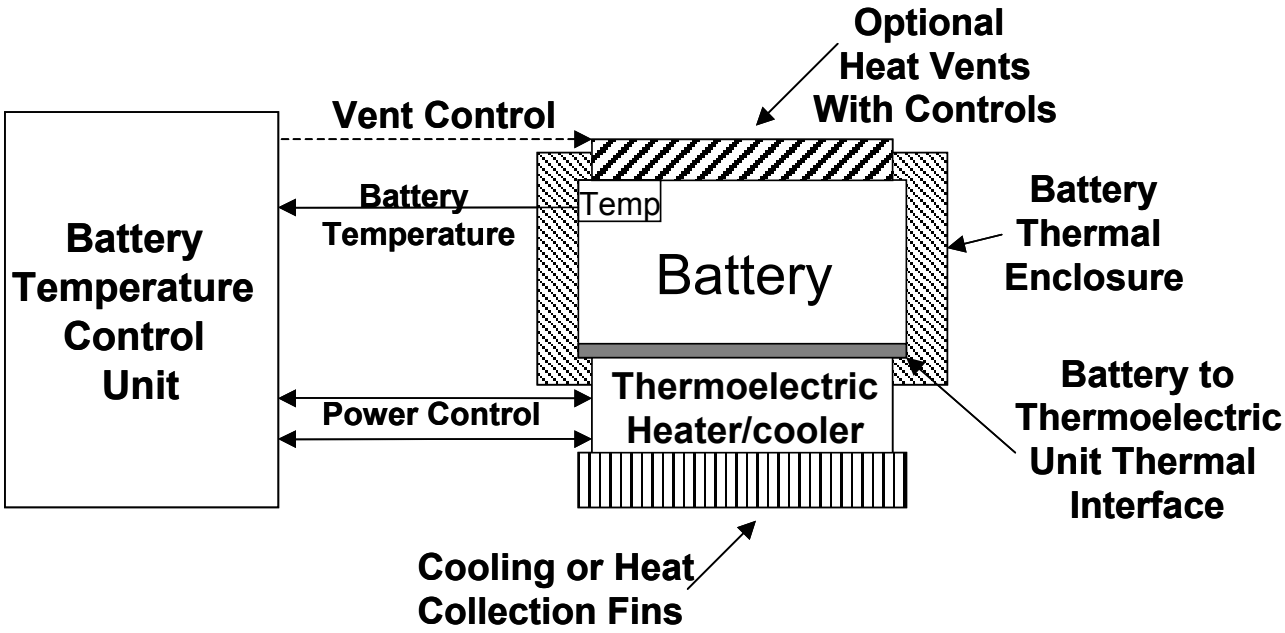
Reduce Energy used in Automotive HVAC's by 50%

Eliminate all Toxic, Greenhouse and Flammable Gases Associated with Automotive HVAC

Zonal HVAC System

Zonal TE devices located in the dashboard, headliner, A&B pillars and seats / seatbacks

A Battery Temperature Control System



significant warranty cost savings
improved battery reliability
improved battery efficiency & performance
enables more flexible packaging

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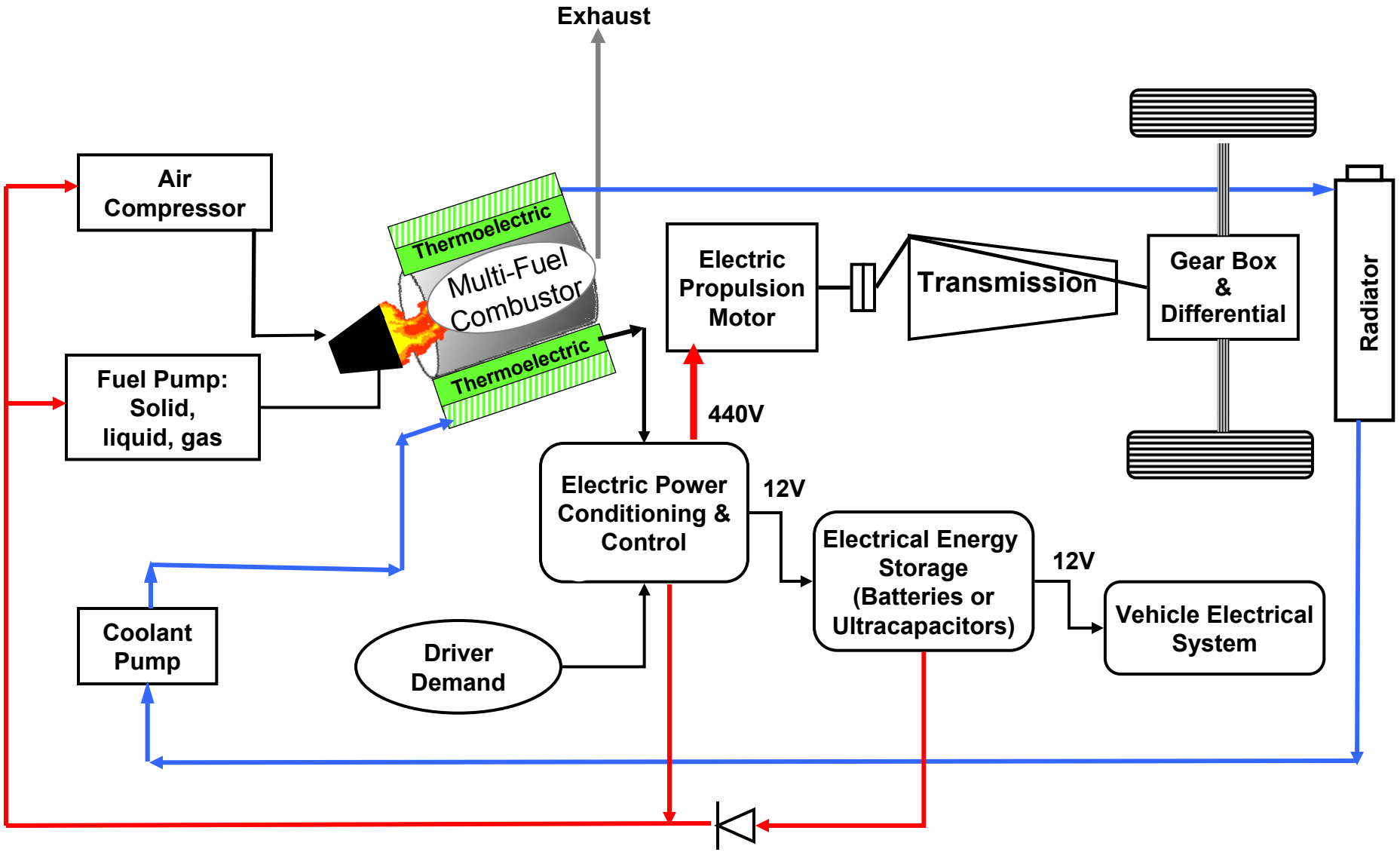
Vehicular Thermoelectric Hybrid Electric Powertrain



Vehicular Thermoelectric Application Possibilities

Near Term (3-6 yrs)

- Thermoelectric Generator providing nominal 10% fuel economy gain augmenting smaller alternator
- "Beltless" or more electric engines
- Thermoelectric HVAC augmenting smaller A/C

Mid Term (7-15 yrs)

- Thermoelectric Generators installed in diesel or gasoline engine exhaust
  - 55% efficient heavy duty truck engine
  - 50% efficient light truck, auto
- Thermoelectric Generators and HVAC w/o alternators or A/C
- Aluminum/Magnesium frame & body replacing steel (Process waste heat recovery) mass market cars

Long Term (16-30 yrs)

- 35% efficient Thermoelectrics w/ 500 ^{0}C ΔT
  - Replace Internal Combustion Engine (ICE)
  - Dedicated combustor burns any fuel

DOE's Thermoelectric Program