DOE's Launch of High-Efficiency Thermoelectrics Projects

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U.S. Department of Energy

10th Diesel Engine Emissions Reduction Conference
San Diego, California
August 29-September 2, 2004

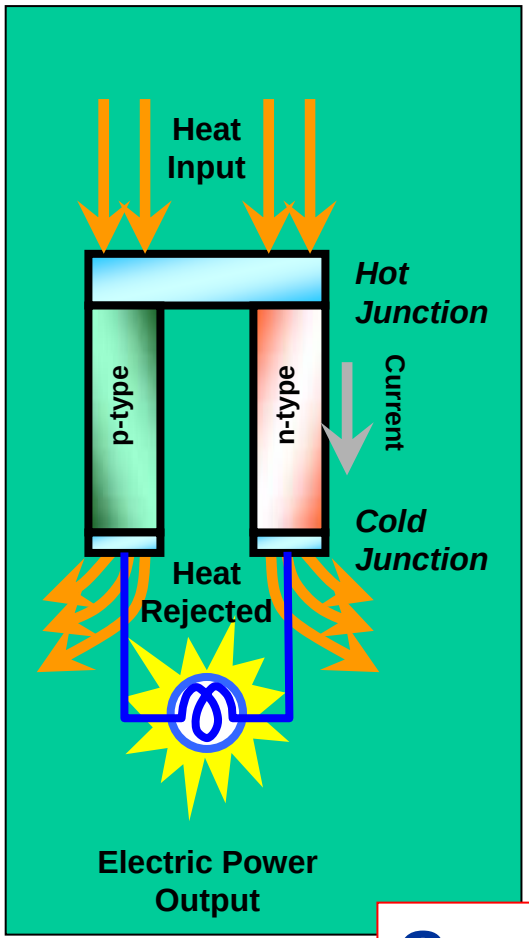
Introduction

Thomas Johann Seebeck (1770-1831)

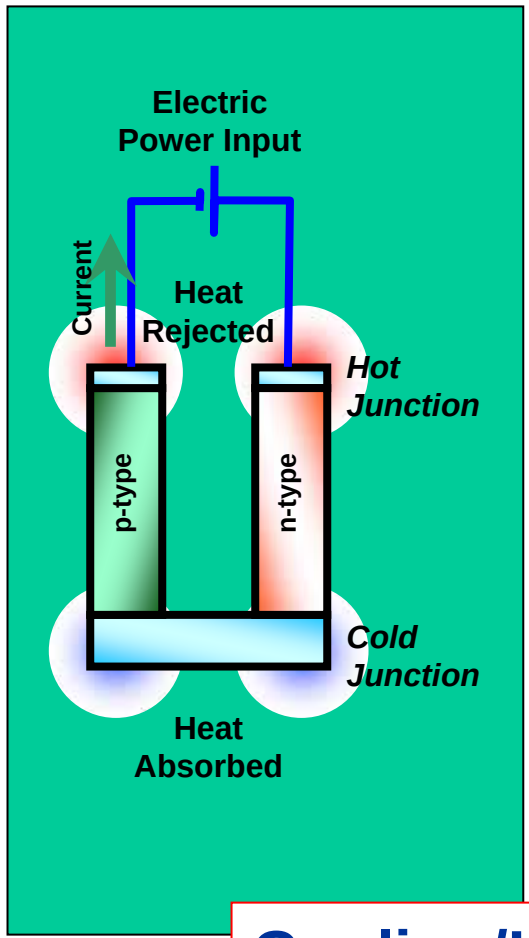
Thomas Johann Seebeck conducted research applying a ΔT across a large number of material couples in the 1820's

- Looking for magnetic effect
- Some of his couples later proved to be 3% efficient
- converting heat to electricity
  - Essentially the efficiency of contemporary steam engines
  - Imagine what could have happened, had Seebeck fully understood what he had discovered
- Mechanically-driven electrical generators would not appear till about 40 years later.

TE Generator and Cooler/Heater

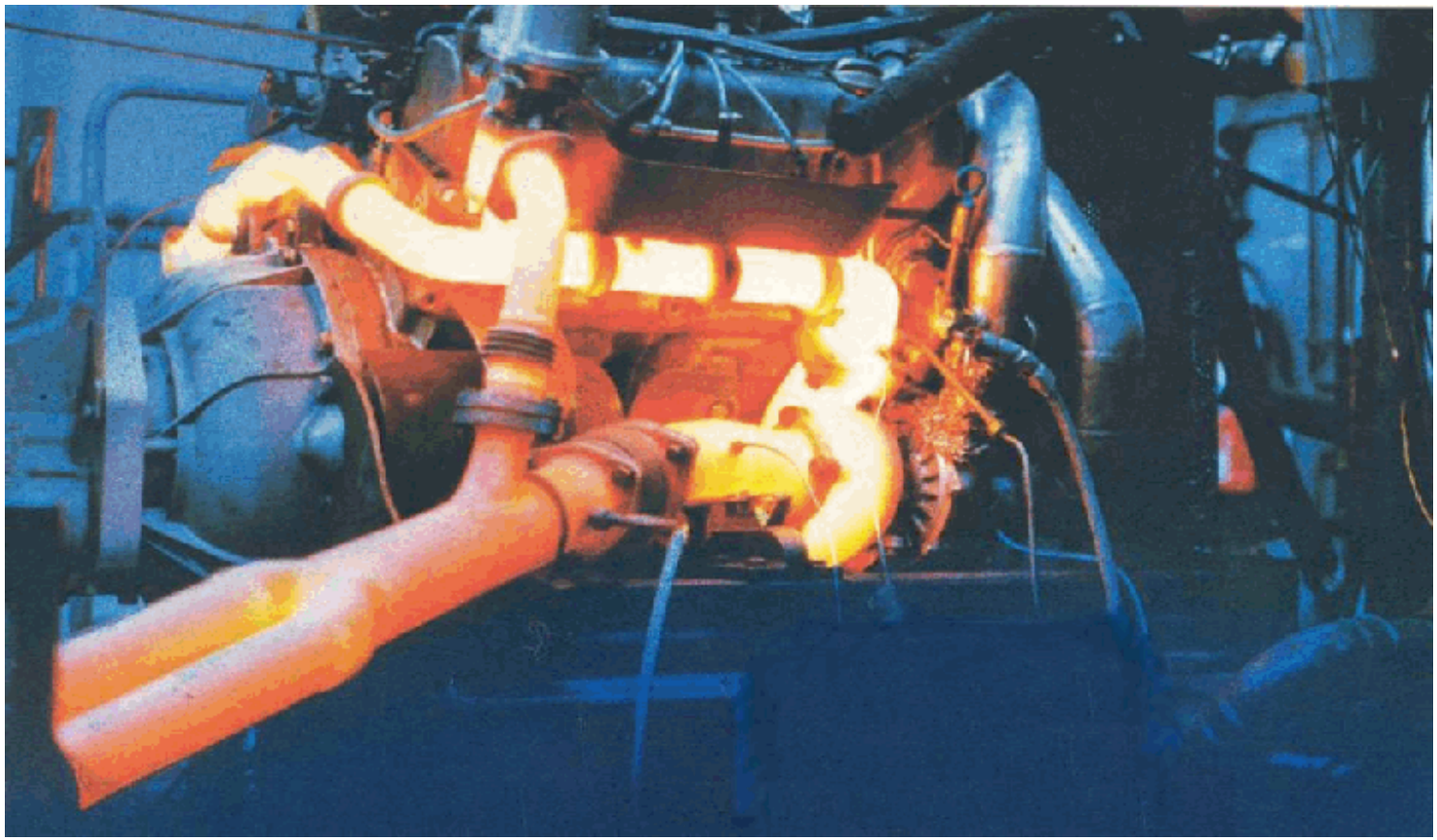


Generator

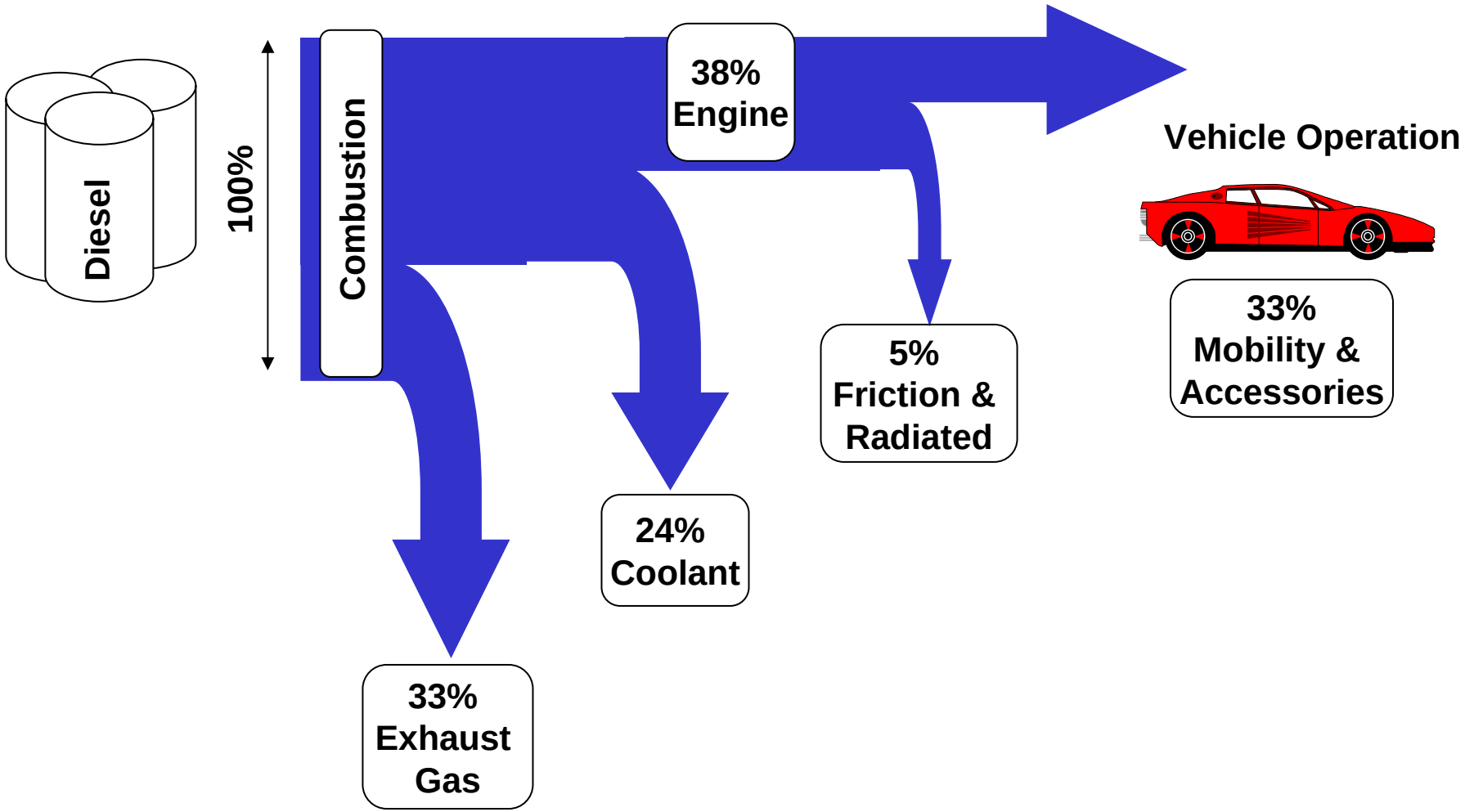


Cooling/Heating

Available Energy in Engine Exhaust



Potential Thermoelectric Heat Sources

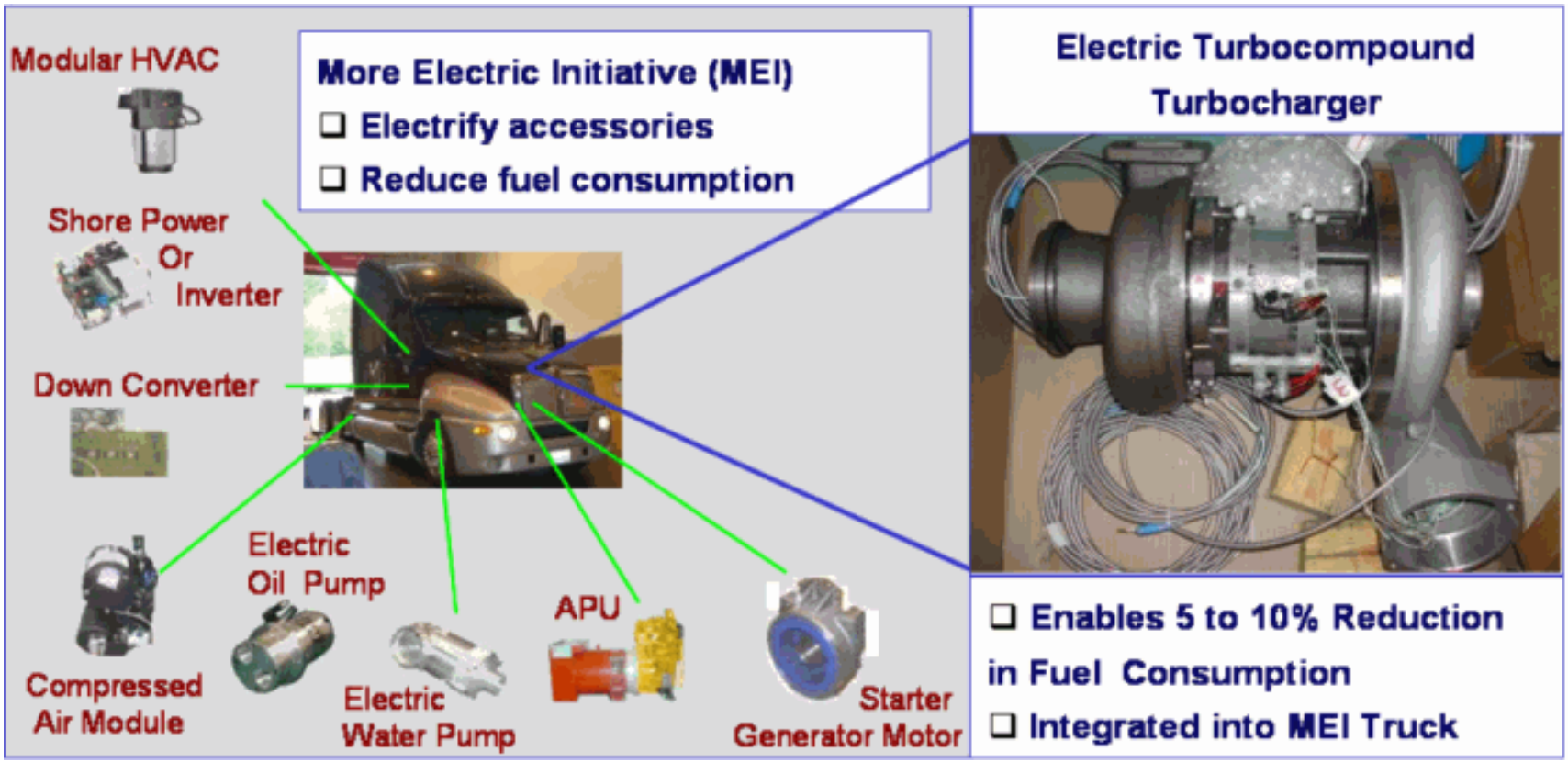


Diesel Engine (Light Truck or Passenger Vehicle)

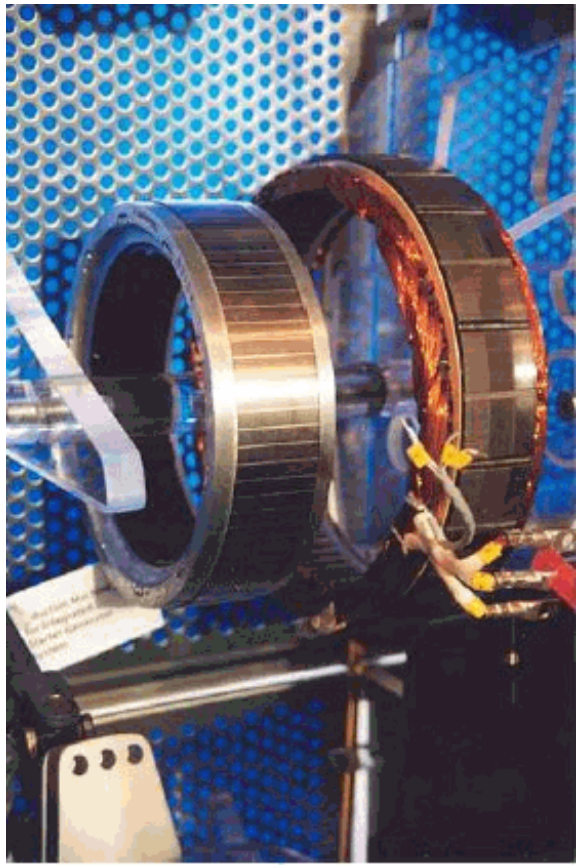
Typical Diesel Engine Waste Heat ΔT's

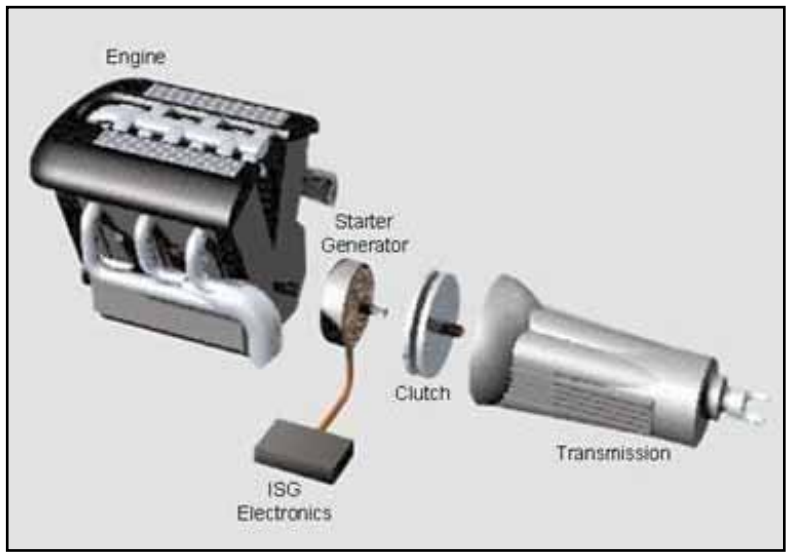
Component	ΔT
Radiator	≈ 70°C
Lube Oil Sump	≈ 70°C
Brakes	≤ 350°C
Exhaust System	≤ 400°C
EGR Loop	≈ 250°C
Turbocharger Compressor (Output)	≈ 33°C

Diesel Engine Waste Heat Recovery Utilizing Electric Turbocompound Technology



Integrated Starter, Alternator/Motor Damper (ISAD)





Carbon Balance Through Internal Combustion Engine

Gasoline C_7H_{16}

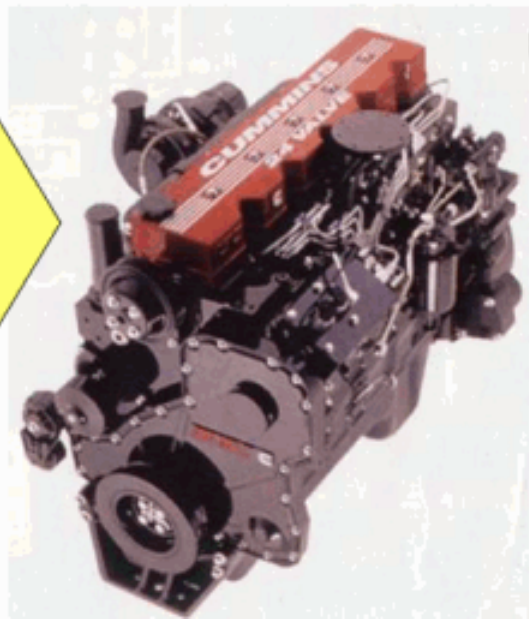
Diesel $C_{18}H_{30}$

Methanol CH_3 OH

Ethanol C_2H_5OH

Natural Gas (Primarily Methane, CH_4)

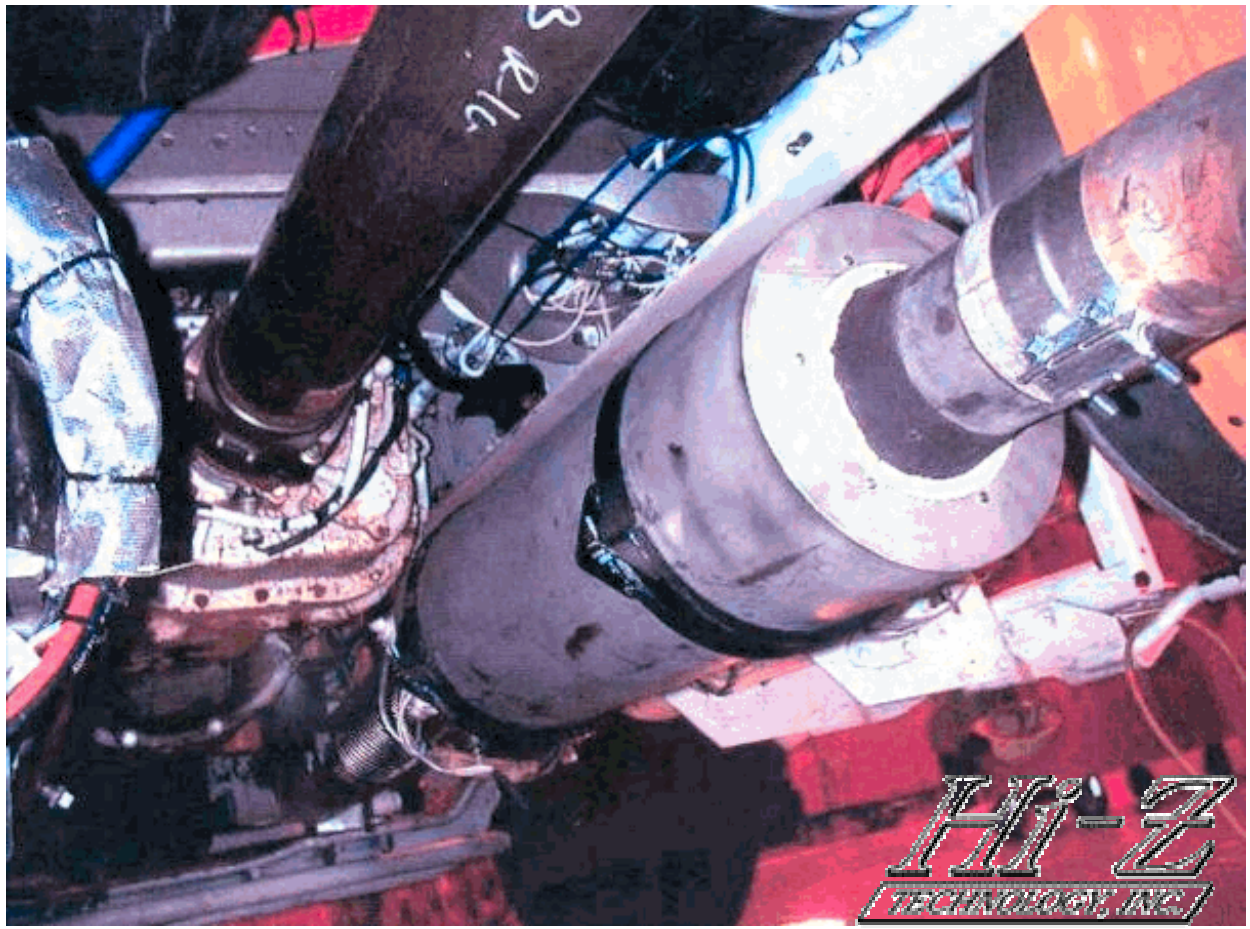
Propane C_3H_8



Carbon

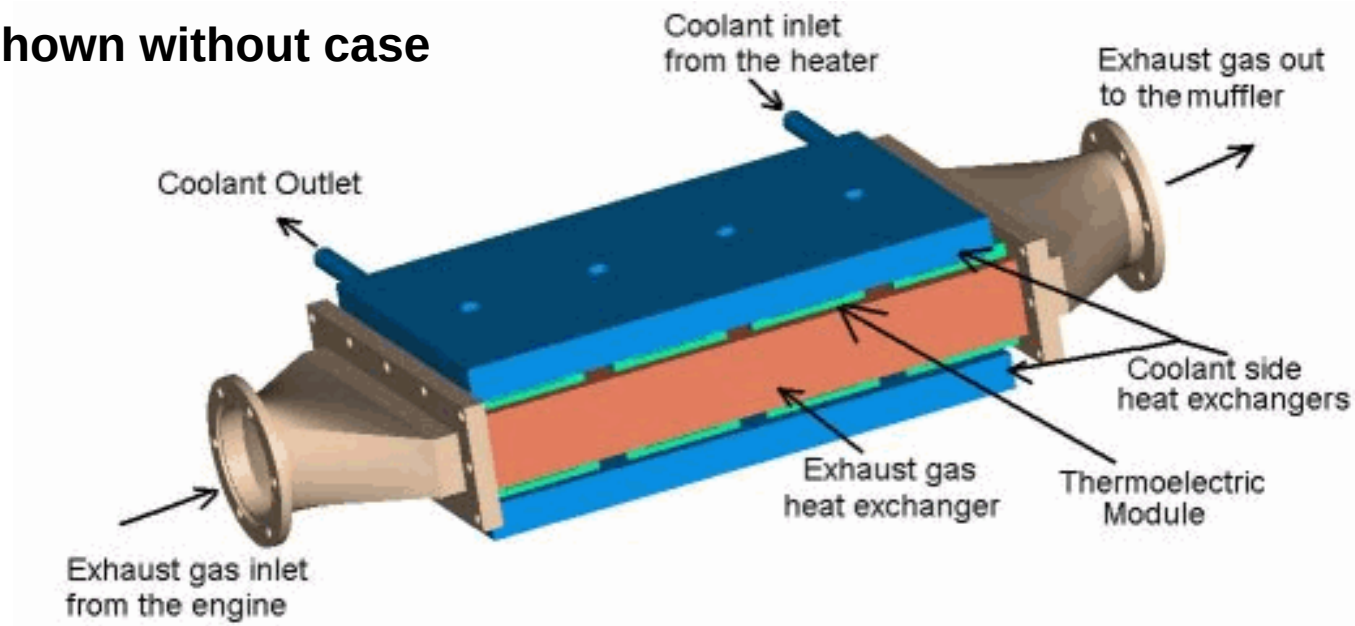
- PM
- HC
  Unburned
  Fuel, Lube Oil
- CO
- CO_2

Potential Location for the Thermoelectric Generator



330 W Thermoelectric Generator for Light-Truck

Shown without case



Clarkson UNIVERSITY
Potsdam, New York 13699

NYSERDA

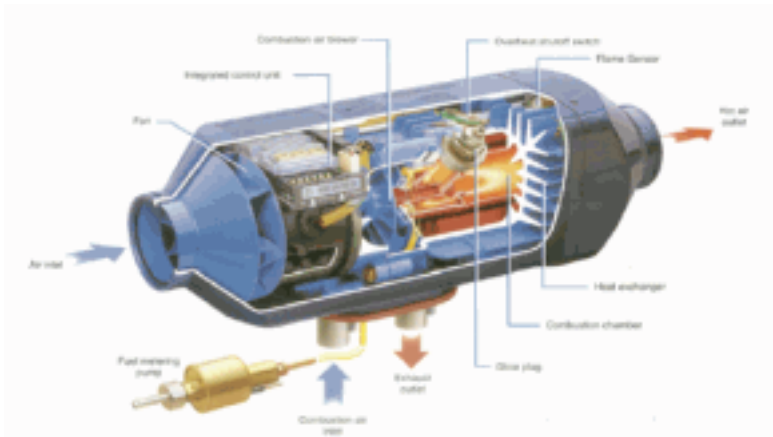
Hi-Z TECHNOLOGY, INC.

DELPHI
Driving Tomorrow's Technology

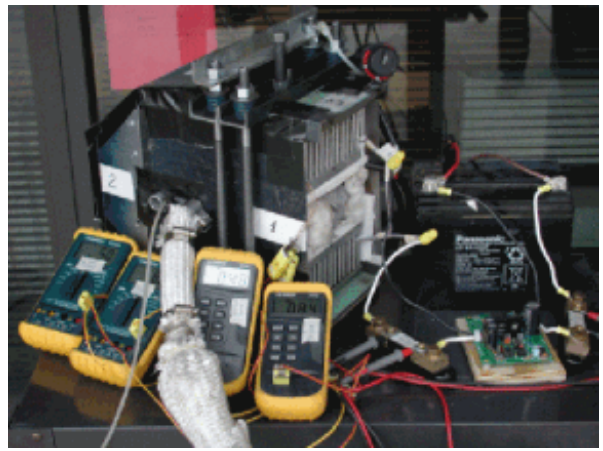
GM

Self-Powered Diesel Fired Heater

U.S. Patent #6,527,548



Diesel Firing Heater



Thermoelectric Powered Heater Prototype

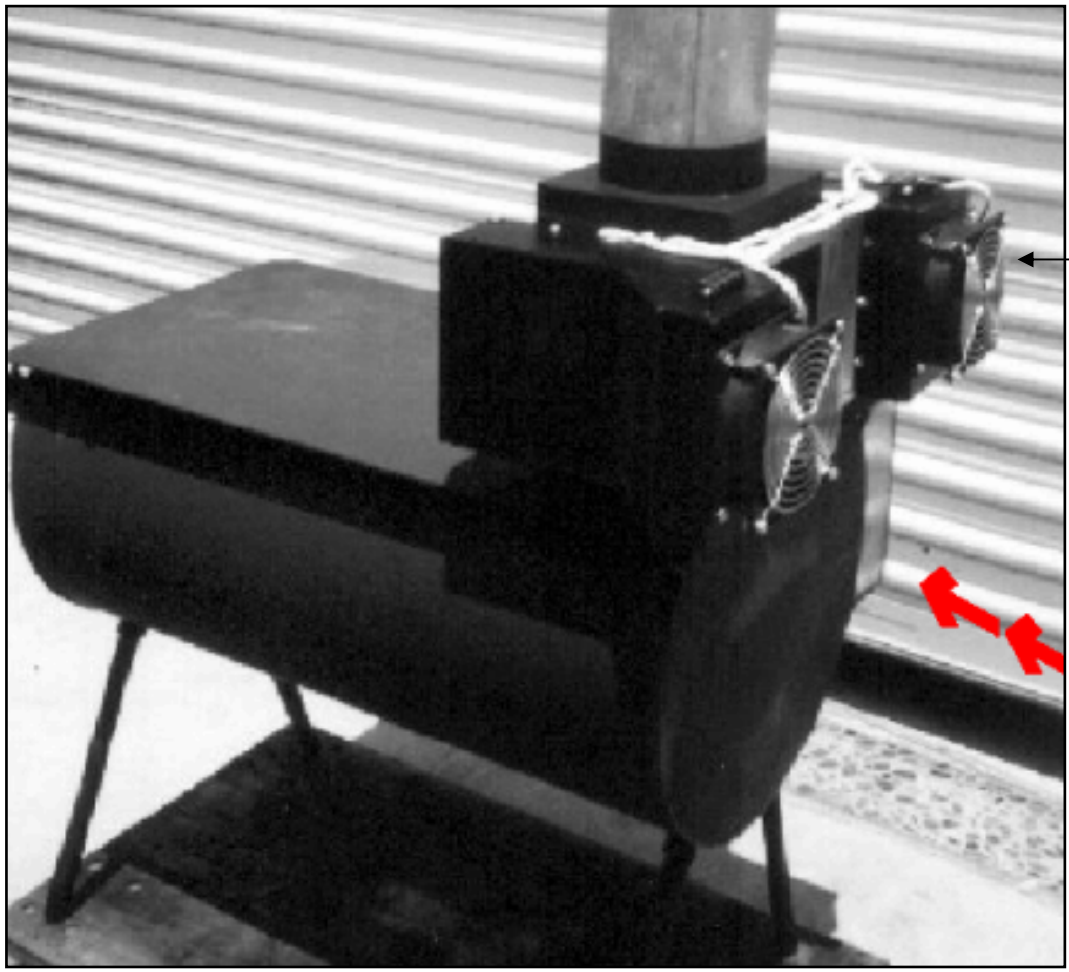
Hi-Z TECHNOLOGY, INC.

Thermoelectric Watch

CITIZEN
Eco-Drive Thermo
Watch

- Converts temperature difference between body and surrounding air into electrical energy
- No battery change needed
- When not being worn, second hand moves in 10-second increments (non-power generation mode), returning to normal when put on (power generation mode)
- No. of semiconductors in thermocouple array: 1,242 pairs
- Operating time from a full charge: Approx. 6 months (approx. 16 months in power saving mode)

Wood Stove



Cooking surface

Exhaust Hot Gases Converted to Electricity

Hot Water Container

Hi-Z TECHNOLOGY, INC.

TE Wine Cooler

Holds 47 Wine Bottles!

SPECIALBUY

$139

47 Bottle Wine Cooler

- 4.6 cu. ft. capacity
- Black interior, exterior and shelves
- Reversible double paned amber tinted door
- Light with manual ON/OFF switch
- Temperature range from 39-61 °F

BC130D (562911)

Sunbeam

THE HOME DEPOT

You can do it.
We can help.

SE NE SW MW NW PW

HDCLAMP1203A

Thermoelectric Cooling Fruit Saver

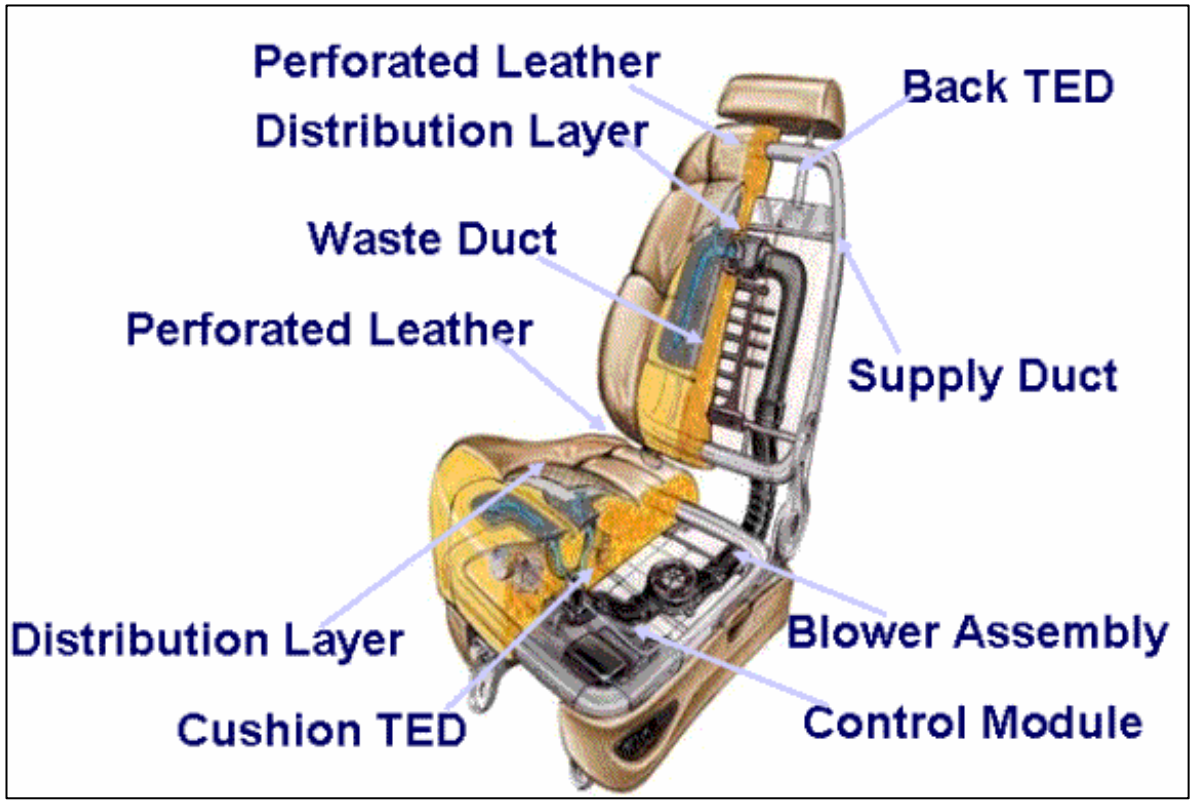
TE Energy Recovery Benefit

2004 Jaguar XJ

- Use of aluminum results in a 500 lb weight reduction, with consequent fuel saving
- Currently, only luxury cars use Aluminum frame and body, due to high cost.
- If we can recover sufficient energy from the Aluminum manufacture process, it may become feasible to use it for mass-produced cars, due to reduced cost.

CCS™ Vehicle Seat Application

Production CCS™ Assembly



Cooling Devices of Tomorrow?

Now

Thermoelectric Hot & Cold Mini Fridge ($1.5\ ft^3$)

Future?

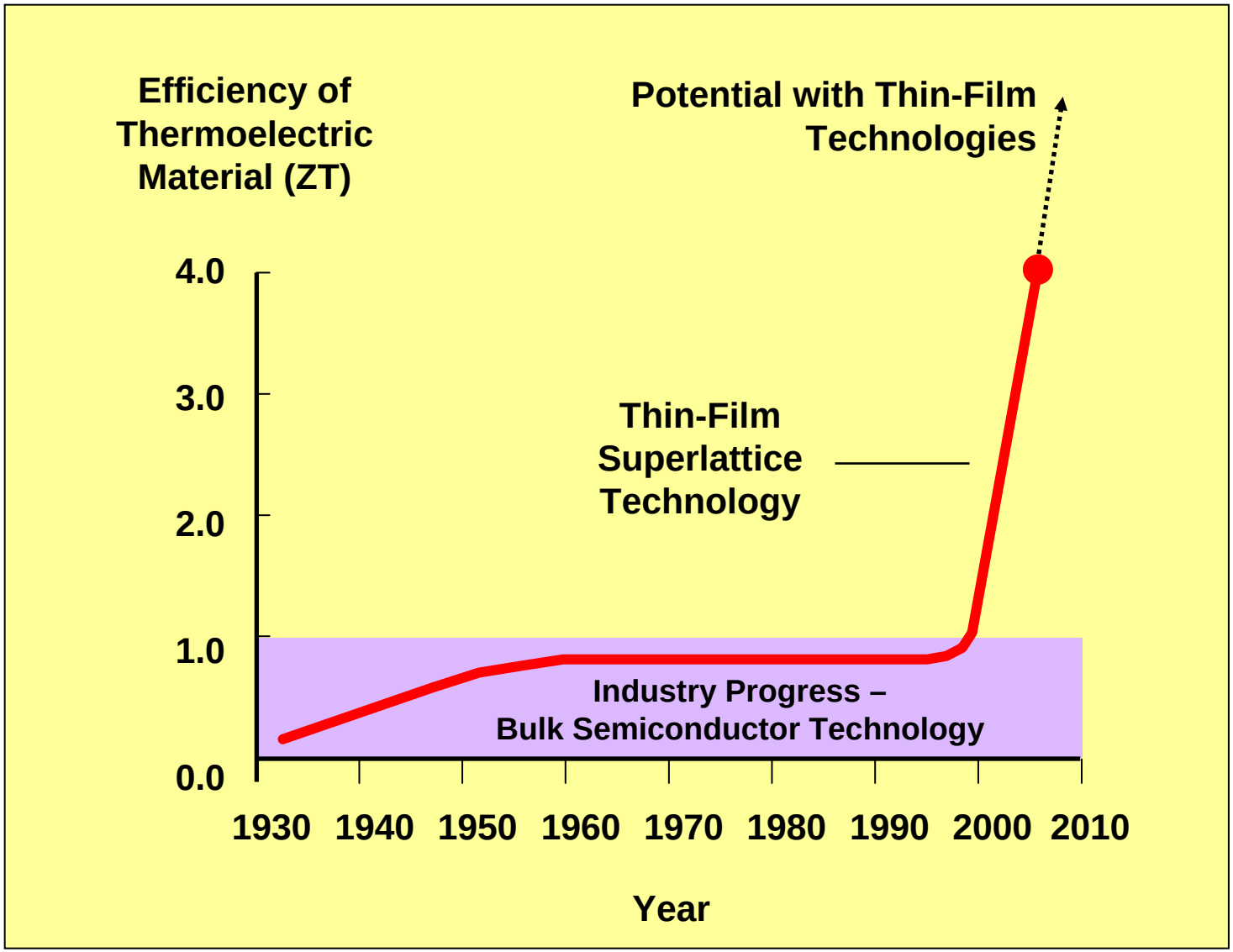
Side-by-side Refrigerator/Freezer ($27.5\ ft^3$)

Environmental Benefits

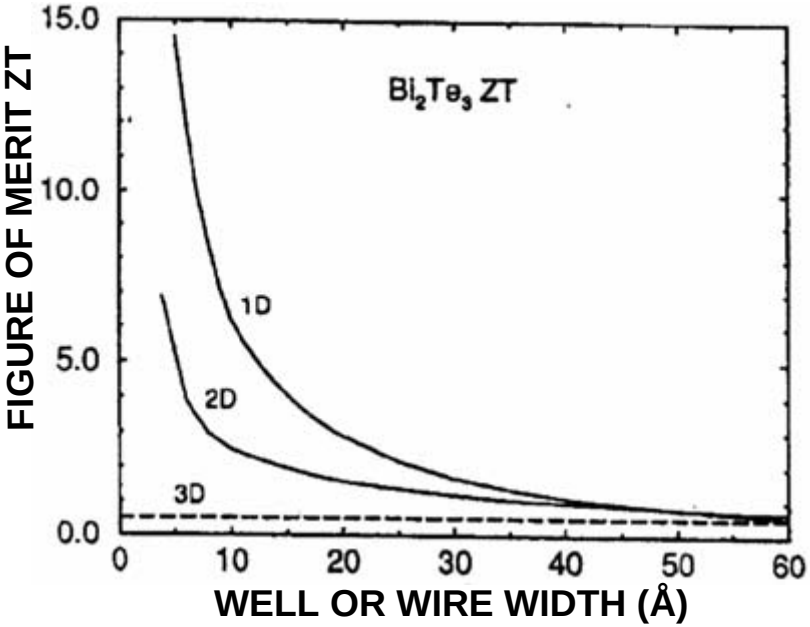
- Use of thermoelectrics for air conditioning and refrigeration would proportionally reduce R-134a usage

- R-134a has 1,800 times greater greenhouse gas impact than CO2 on a per molecule basis.

Recent Breakthrough in Thermoelectric Efficiency



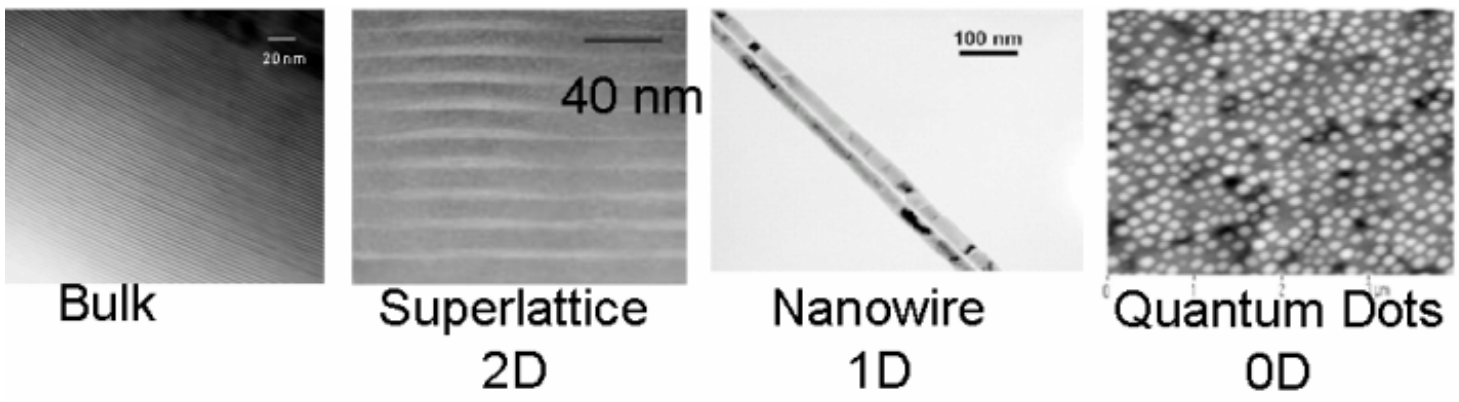
Prediction of Quantum Confinement Effects in Low-D Systems



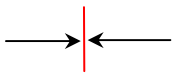
Note: Conduction is assumed to be along the extended dimension

2D, 3D: Hicks and Dresselhaus, Phys. Rev. B47 (1993), p. 12727-31

1D: Hicks and Dresselhaus, Phys. Rev. B47 (1993), p. 16631-34



Size Comparison: Nanowire vs. the Human Hair

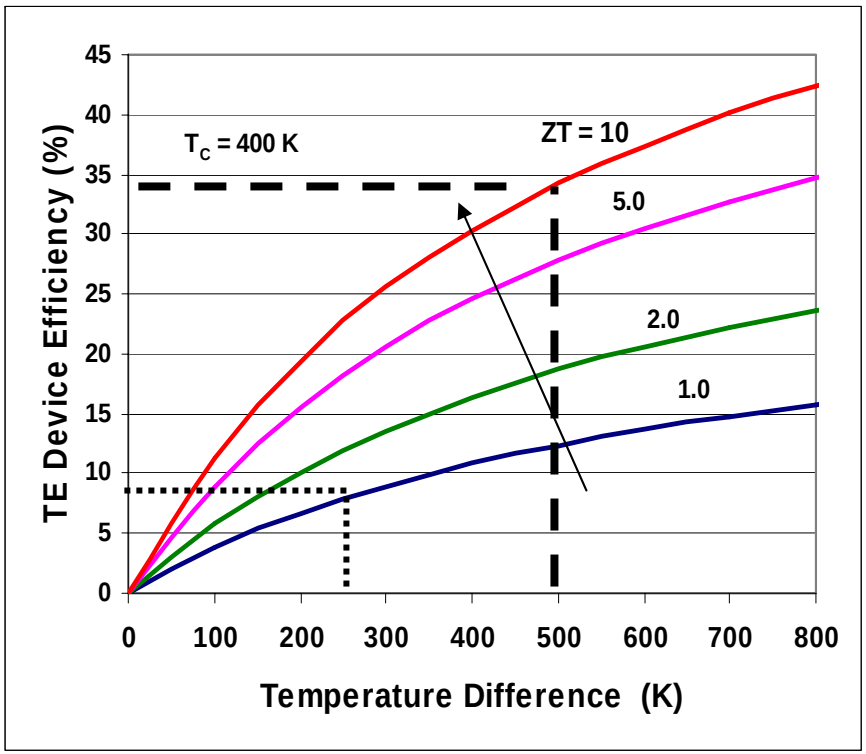


Width of a Nanowire (1,200 times smaller)

Width of the Human Hair

	Width
Human Hair	~60 µm (60,000 nm)
Nanowire	~50 nm

Replacing Vehicular Internal Combustion Engines



For a given ΔT, higher the ZT, higher the heat-to-electric conversion efficiency

If a ZT value of 10 could be achieved, a theoretical conversion efficiency of ~35% would be possible (for ΔT ~500 °C)

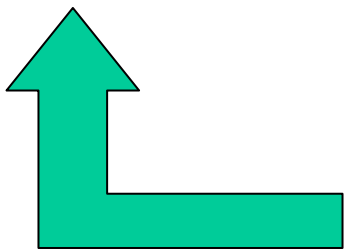
Thermoelectric Efficiency as a Percentage of Carnot Efficiency

- The Heat-to-electricity conversion efficiency (η) depends on the material-specific figure of merit (Z)

$$Z = \frac{S^2 \sigma}{k}$$

S: Seebeck coefficient (dV/dT),
σ : electrical conductivity, and
k: thermal conductivity

$$\eta = \left\{ \frac{T_{hot} - T_{cold}}{T_{cold}} \right\} \left\{ \frac{\sqrt{1 + ZT_{avg}} - 1}{\sqrt{1 + ZT_{avg}} + \frac{T_{cold}}{T_{hot}}} \right\}$$



Carnot efficiency.

The Challenge

Thomas Johann Seebeck (1770-1831)

Two centuries after Seebeck's work, which was not understood or exploited by his contemporaries, we face another challenge

- Recognize the potential of emerging high ZT thermoelectric technology
- Further understand the fundamentals
- Measure nano-scale properties
- Scale-up to commercial size
- Fabricate a waste heat recovery device for vehicle application