Thermoelectric Opportunities in Light-Duty Vehicles

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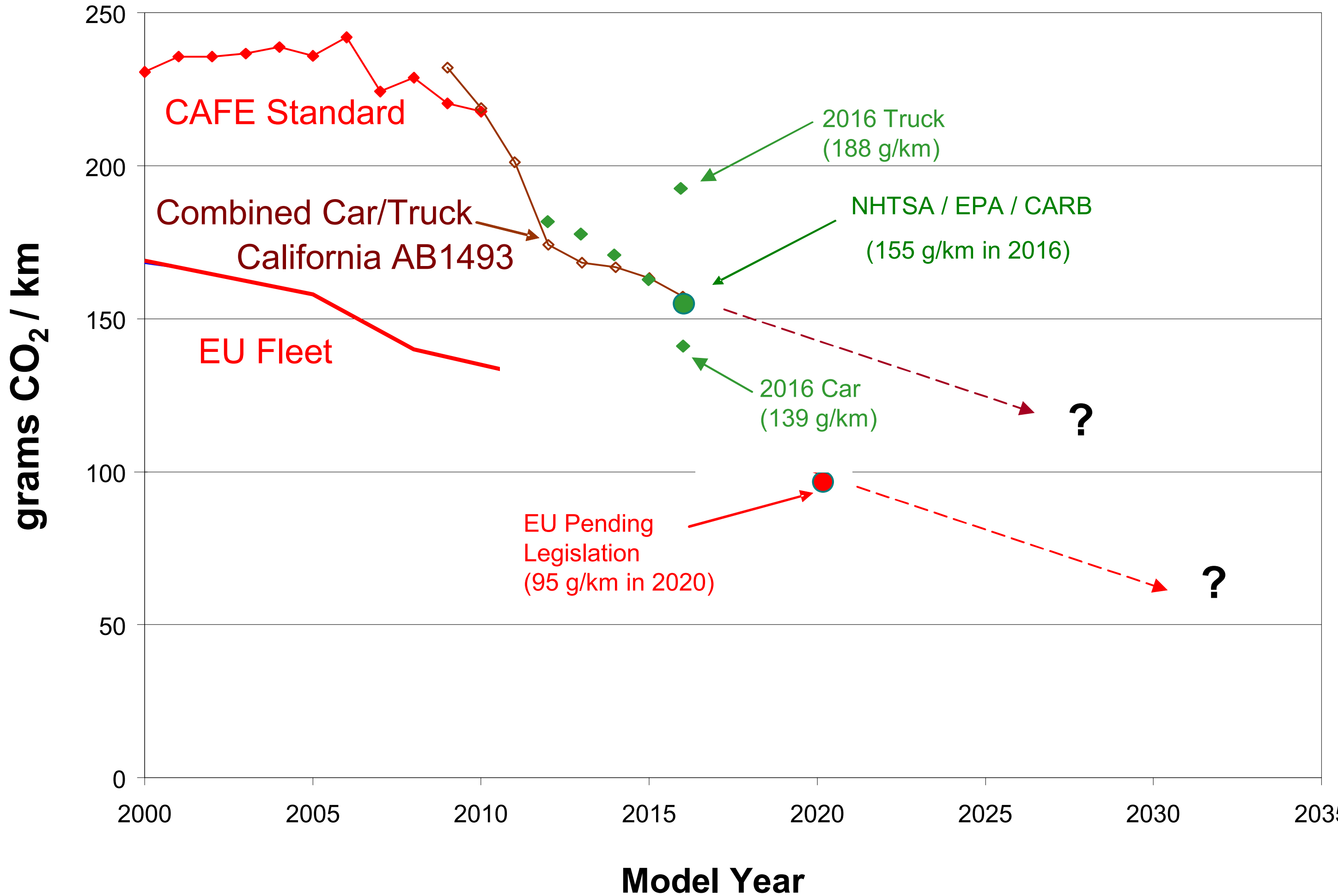
Thermoelectrics Applications Workshop
San Diego, CA
September 30, 2009

Future Trends in Light Duty Fleet

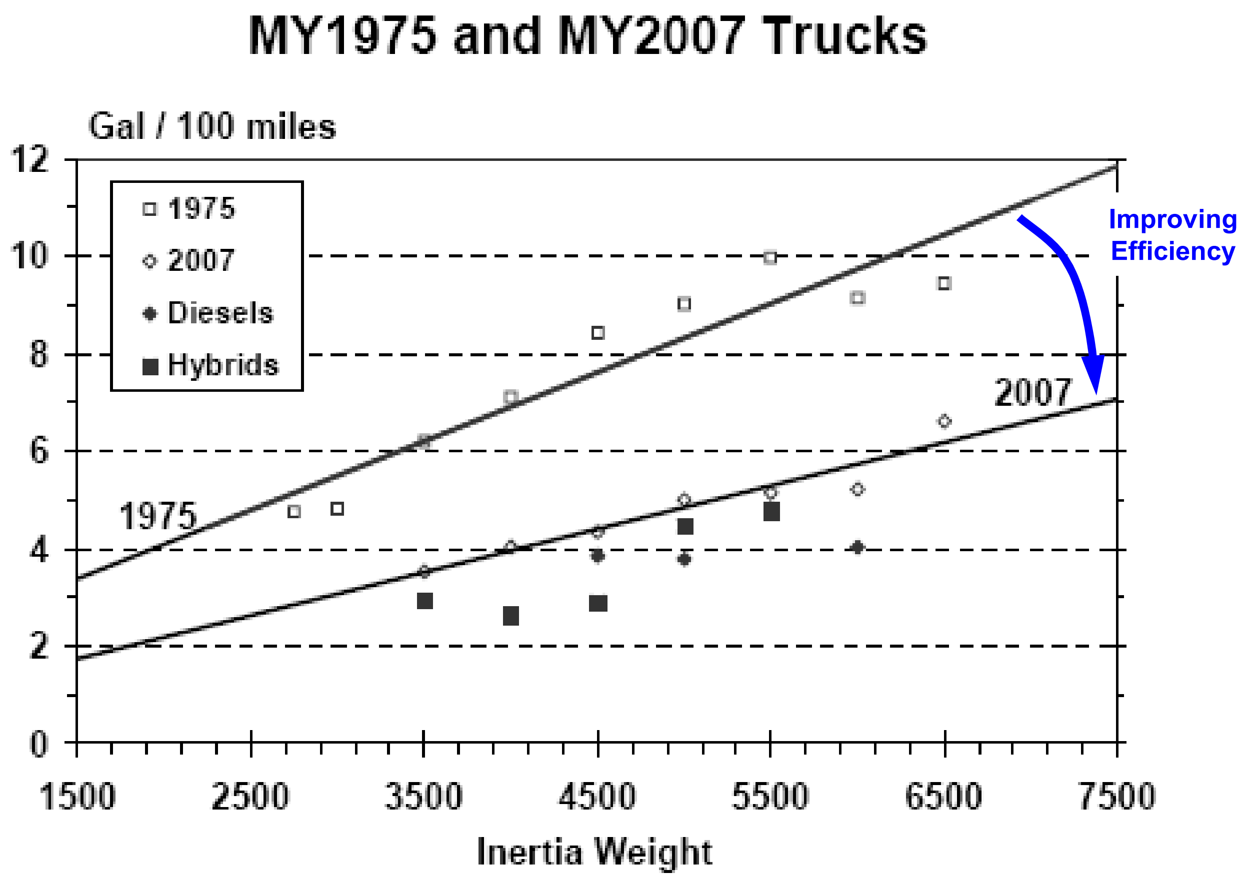


Vehicle CO_2 requirements are becoming more stringent and will require changes to fleets and technologies worldwide.

Strategies to Meet New CO_2 Standards

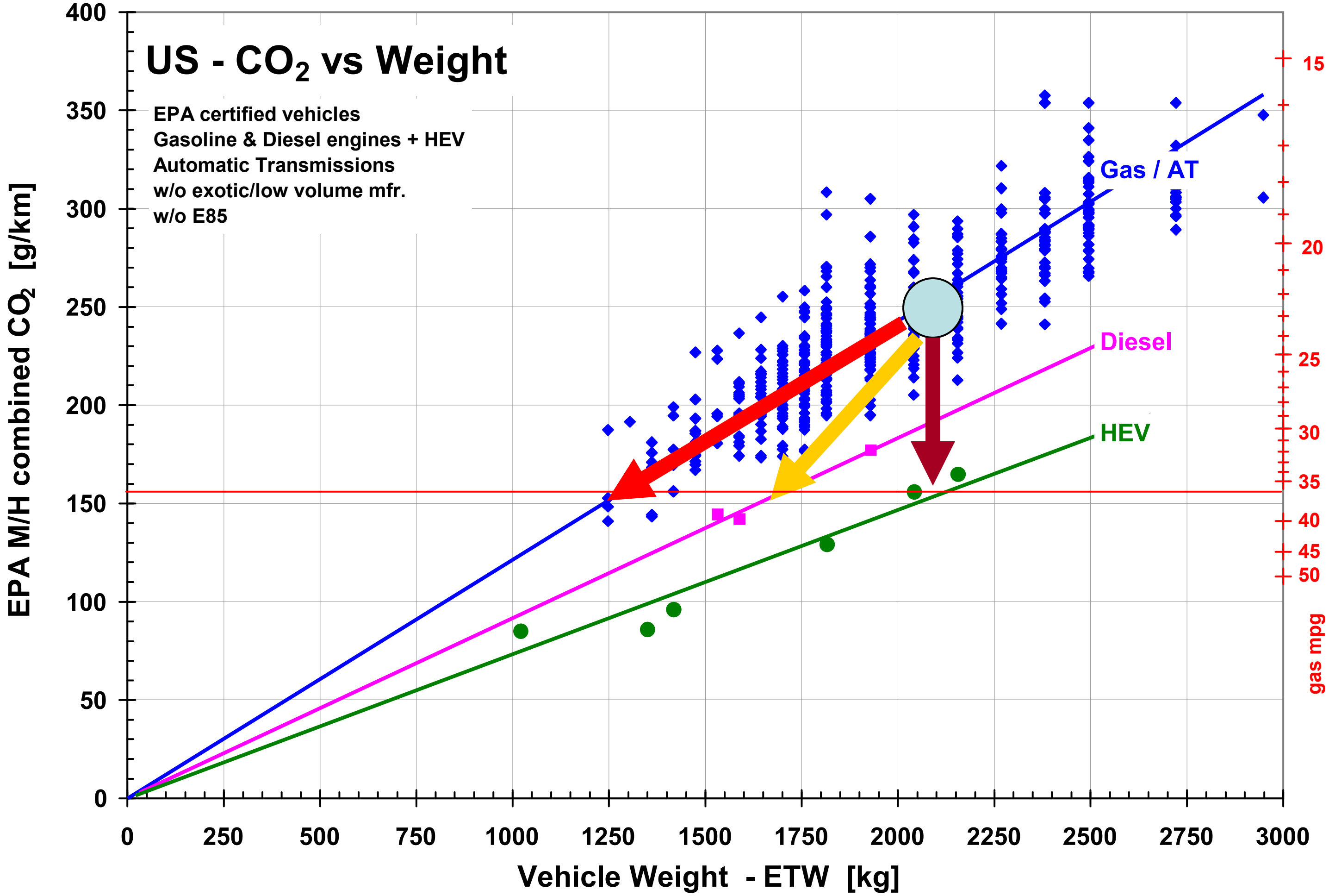
- Fleet Mix
  - More smaller vehicles (B-Class, C-Class)
- Vehicle Weight
  - Lightweight BIW, Closures, Powertrain/Driveline Components, …
- Advanced Powertrain/Driveline Technologies
  - GTDI, VCT, Diesel, Bio-fuels, HCCI, Friction Reduction, Dual-Clutch, 6+ Speed Trans., …
- Hybridization
  - Start-Stop, HEV, PHEV, BEV, FCEV
- Technologies for CO_2 Credits
  - A/C Leakage & Technology, Aerodynamics, Cabin Ventilation, …

Vehicle Efficiency Improvements Over Time



Vehicle efficiency can be improved within a given weight class.

Weight vs Powertrain Technology

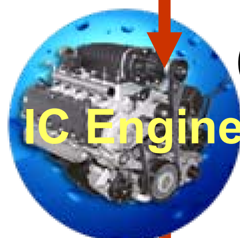


Multiple paths to achieve 2016+ CO_2 targets.

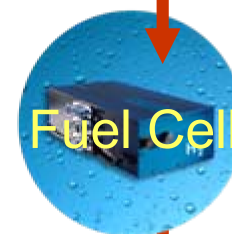
Compare Options in a Series HEV

Today's Grid & Future HEV P/T in Today's Platform*

0.33 kW-h_e/mile
(0.20 kW-h/km)



41 mpg_e



62 mpg_e

Coal:	211 g/km
Nat. Gas:	127 g/km
US Avg.:	130 g/km

Oil: 145 g/km

SR-NG:	116 g/km
Electrolysis:	344 g/km

ICE technology is competitive with alternative powerpacks on a CO_2 basis at a substantially lower cost.

What does the vehicle of the future look like?

EU: 95 g CO_2 / km

US: 155 g CO_2 / km

Fiesta:
1.6L Diesel - 98 g/km*

Focus:
1.4L Gas – 157 g/km*

Fusion HEV:
2.3L Gas – 141 g/km**

Future vehicles look a lot like today's vehicles!

* NEDC Cycle
** M/H Cycle

Trends Impacting the Implementation of Thermoelectrics into Vehicles

- Negative Trends:
  - Powertrain efficiency is improving
  - Exhaust temperature lower
  - Backpressure penalty more severe
  - Packaging space at a premium
  - Weight penalty more severe
  - Radiator packaging more challenging
  - Raw material costs increasing

- Positive Trends:
  - Powertrain efficiency is improving
  - New vehicle architectures being developed
  - Consumers more interested in efficiency
  - Higher premium paid for FEI
  - Vehicle electrification increasing
  - Vehicle thermal management challenges more severe

Where does Thermoelectric Technology fit into the Future Vehicle?

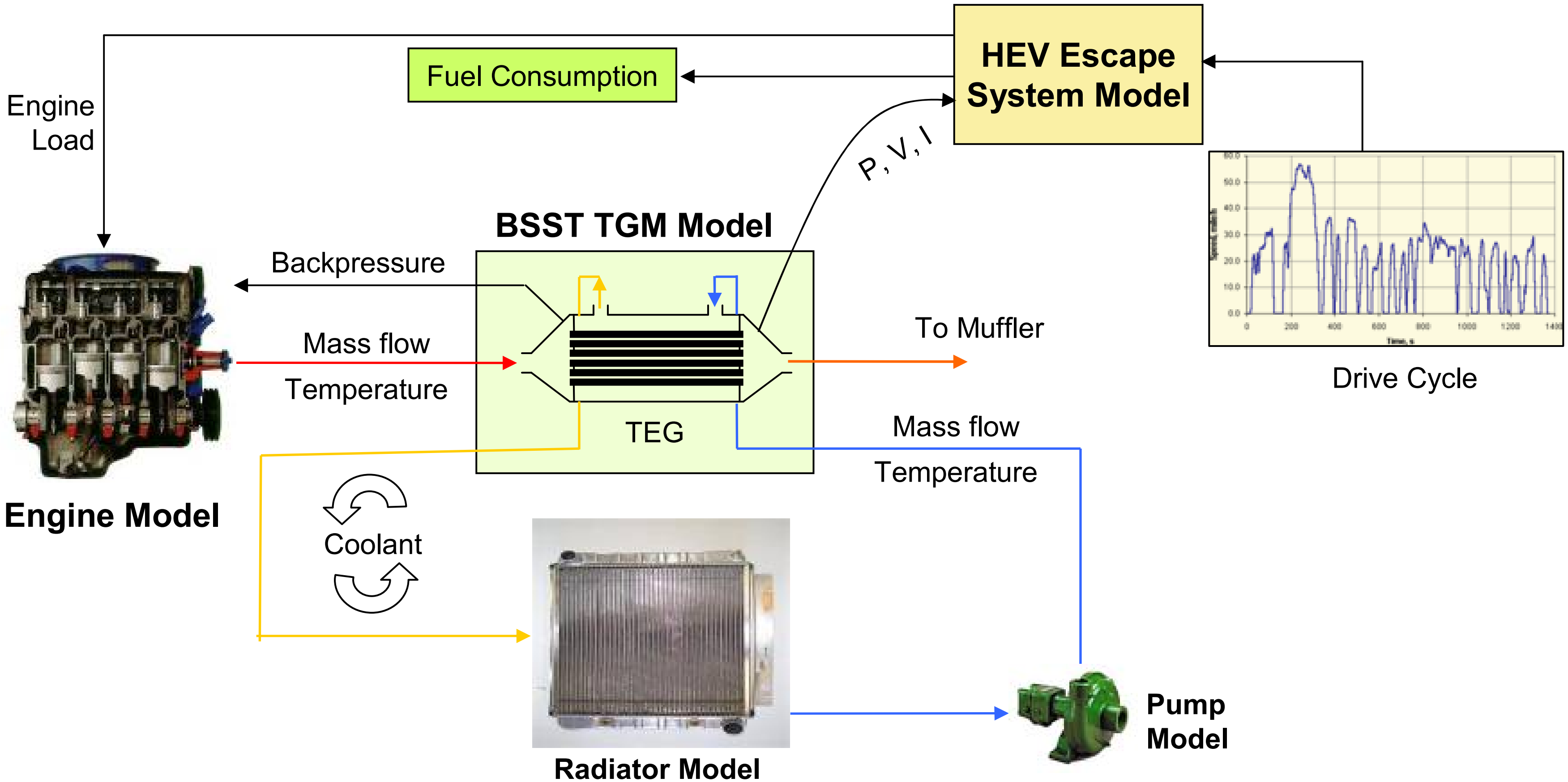
Incremental technologies:

- Heated / cooled seats, other contact surfaces
- Chip-level / board-level electronics thermal management
  - LEDs, Power Electronics, Sensors, …
- Remote-powered sensors & actuators
- Features: cup holders, storage bins, …

Breakthrough technologies:

- Waste heat recovery: Exhaust, Coolant
- Vehicle climate control: Distributed, Central
- Thermal management: ICE Powertrain, (H)(B)EV

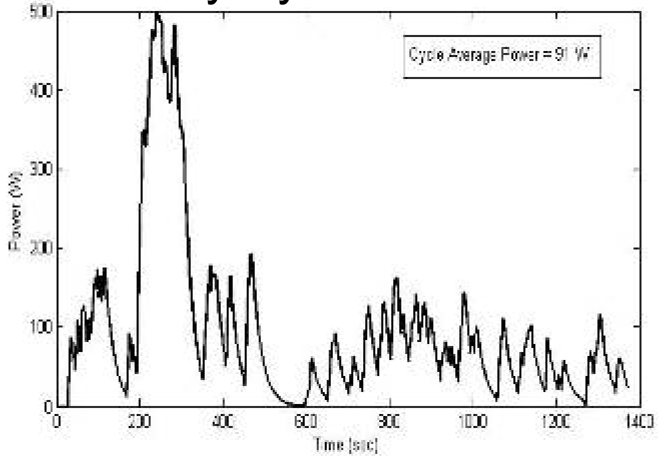
DOE TE Waste Heat Recovery Phase 3:
Transient Modeling of a TGM for a HEV Application



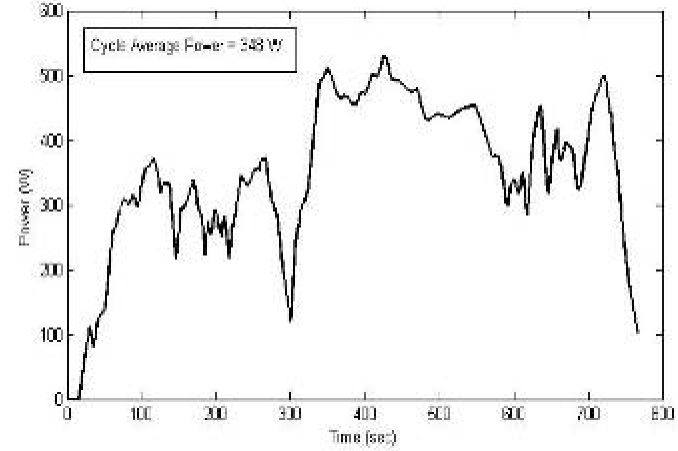
- 2.5L Atkinson Engine in Escape Hybrid vehicle is used.
- Major Design Constraints: TE Mass, Exhaust ΔP, Response Time

Transient Drive Results

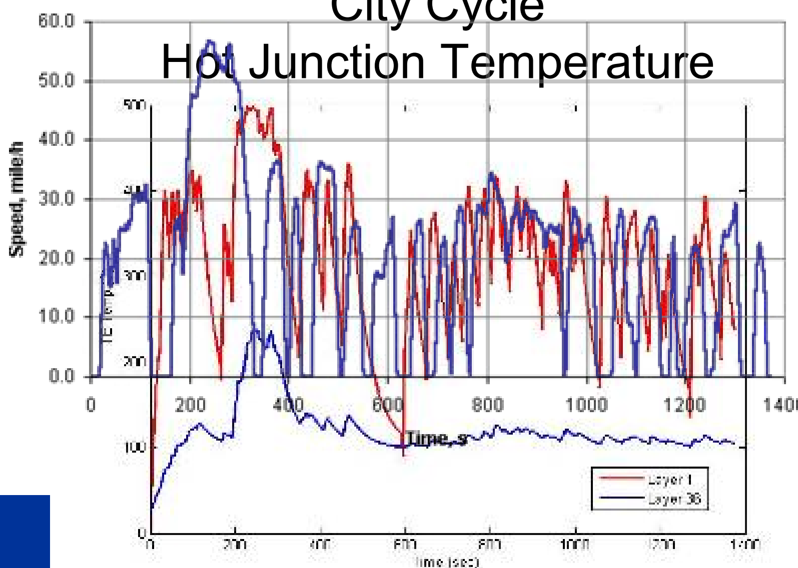
City Cycle Power



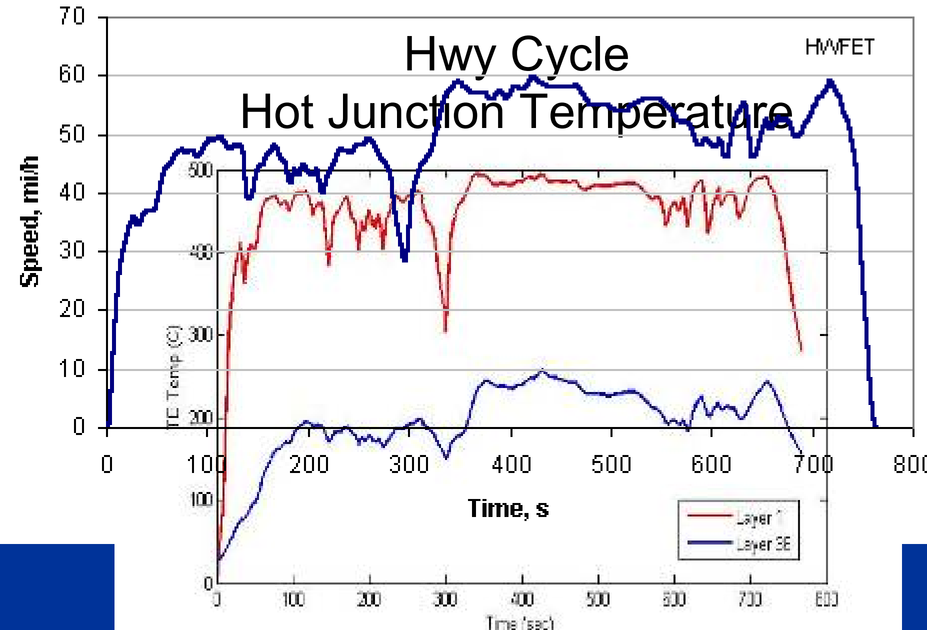
Hwy Cycle Power



City Cycle
Hot Junction Temperature



Hwy Cycle
Hot Junction Temperature



Implications of Design Study

	Current Design	Mid-Term Design
Material Performance (ZT)	0.97	1.7
Heat Transfer Losses	40% $T_{hot, junction}$ = 180 – 250°C	20% $T_{hot, junction}$ = 350 – 420°C
TE Mass	1.6 kg	1.1 kg
Interfacial Resistance	2 $\mu\Omega$-cm^2	0.5 $\mu\Omega$-cm^2
% Conversion Efficiency	4.8 % T_h: 215°C, T_c: 90°C	14.4 % T_h: 385°C, T_c: 90°C
Power Generated – M/H EPA Cycle (Watts)	90 / 350	240 / 1000
Fuel Economy Improvement	1.5%	5%-7% (est.)

Thermoelectric HVAC

Objective:

Identify a technical and business approach to accelerate the deployment of light-duty automotive TE HVAC technology, maintain occupant comfort, and improve energy efficiency.

Timeline:

Selected for award negotiation in December 2008

Award approved September 29, 2009

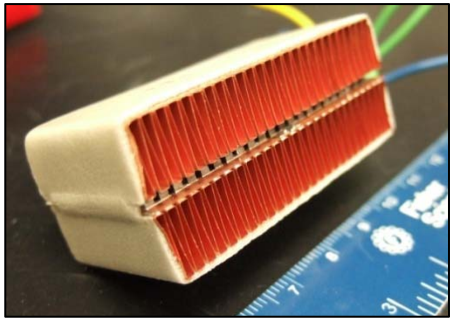
4 phase, 3 year project timeline

Major Deliverable:

Demonstration vehicle delivered at end of phase 4

TE HVAC Project Targets

- Accelerate development of TE heat-pump modules and systems
- Augment or replace need for A/C Compressor and PTC-based heating
- Improve fuel economy and associated GHG emissions vs current production HVAC technology
- System Coefficient-of-Performance Targets:
  - COP > 1.3 for cooling
  - COP > 2.3 for heating



- Reduce power consumption of A/C compressor by >33%
- Target commercial introduction between 2012 – 2015
- Develop and test a distributed TE HVAC vehicle system
- Deliver a demonstration vehicle to DOE for further independent verification of system performance and efficiency for 1 – 5 occupants

Summary & Conclusions

- Future vehicle CO_2 requirements makes TE WHR more technically challenging. However, the need for continued improvements in powertrain efficiency make WHR a likely prospect.
- Electrification of vehicles creates opportunity for Thermoelectric HVAC and Thermal Management.
- Increased systems efficiency, lower system costs, and robust design will be important for introduction of TEs into future vehicles
- Scale-up of TE material, module, and device manufacturing is a crucial step in the industrialization of thermoelectric-based systems
- Continued cooperation and collaboration between government, academia, and industry is crucial to fully realizing the potential of thermoelectrics

Acknowledgements

Thanks to the Department of Energy for their partnership support.

In particular, thanks to John Fairbanks at DOE-EERE and Carl Maronde at NETL.