Automotive Fuel Efficiency Improvement via Exhaust Gas Waste Heat Conversion to Electricity

2009 Thermoelectrics Application Workshop

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September 30, 2009

Presentation Outline

BSST background

The CO_2 Challenge and Technology Options

BSST's waste heat recovery program overview:

- Progress and achievement to date
- Current status

Next steps

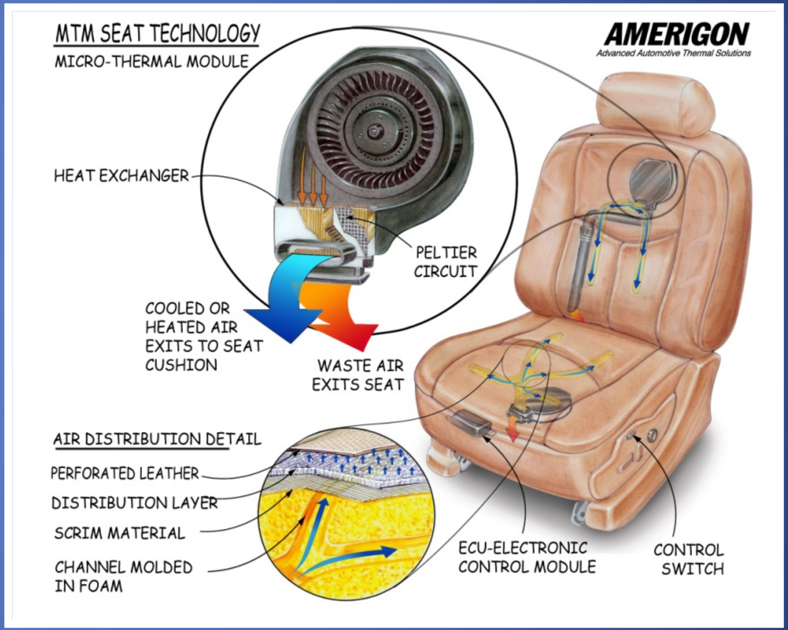
BSST Background

Subsidiary of Amerigon (NASDAQ- ARGN)

Working to expand the usage of thermoelectric technology beyond seat heating and cooling and in doing so reduce CO_2 emissions and conserve energy

Corporate parent, Amerigon, has fielded over 9 million TE devices (4 ½ million seat systems) to the automotive industry

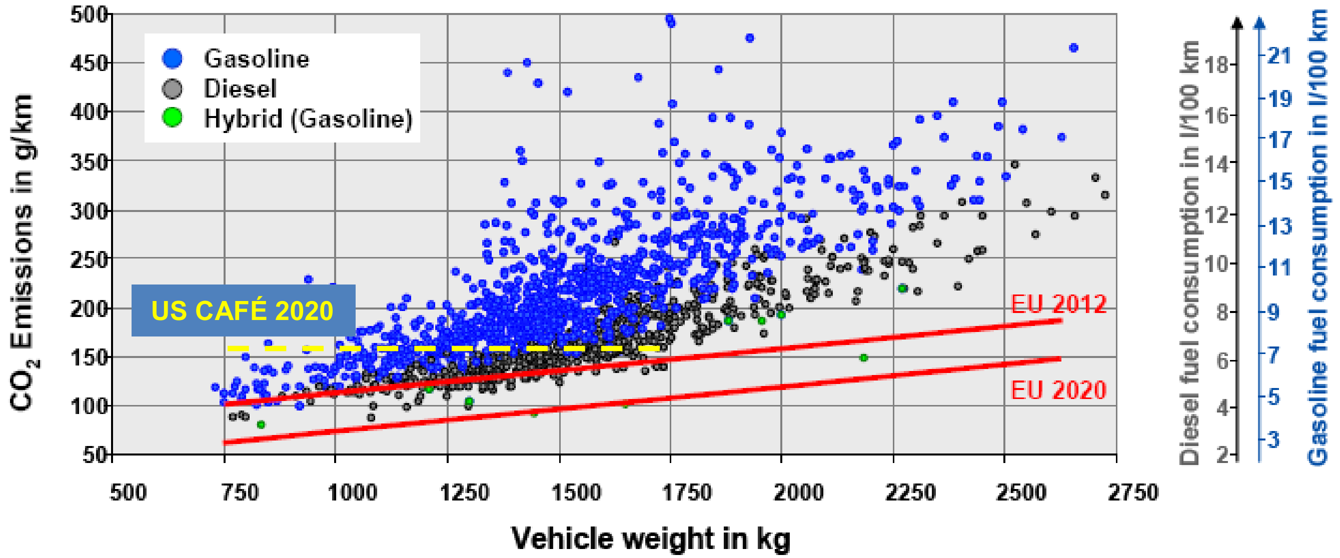
Offices in Irwindale, California and Northville, Michigan with worldwide regional offices



The CO_2 Challenge

The Challenges of the Automotive Industry

CO_2 Emissions of Current Vehicles



→ More than 80% of the actual vehicles are too high in CO_2 emissions
→ From 2015, OEMs have to pay a fee of 95 € per vehicle and gram CO_2 for exceedings

→ Eco-innovations could increase the average CO_2 limit of an OEM up to 7 grams!

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Source: IAV GMBH, D. Jaensch, ICT 2009

CO_2 Reduction: Technology Options

Baseline: Overhead Cams, 4-Valve, Fixed Timing, Roller Finger Follower	Fuel Consumption Reduction %		Retail Price Equivalent, Est.		
	Range	Average	Low	High	RPE Avg
TE waste heat recovery system	5-10	7.5	$500	$1,000	$750
Camless valve actuation	5-10	7.5	$280	$560	$420
Engine supercharging and downsizing	5-7	6	$350	$560	$455
Continuously variable transmission	4-8	6	$140	$350	$245
Integrated starter/generator (idle off-restart)	4-7	5.5	$210	$350	$280
Intake valve throttling	3-6	4.5	$210	$420	$315
Cylinder deactivation	3-6	4.5	$112	$252	$182
Variable compression ratio	2-6	4	$210	$490	$350
Automatic shift/manual transmission (AS/AMT)	3-5	4	$70	$280	$175
Vehicle weight reduction (5%)	3-4	3.5	$210	$350	$280
Multivalve, overhead camshaft (2-V vs. 4-V)	2-5	3.5	$105	$140	$123
Engine friction reduction	1-5	3	$35	$140	$88
Five-speed automatic transmission	2-3	2.5	$70	$154	$112
Variable valve timing	2-3	2.5	$35	$140	$88
Electric power steering	1.5-2.5	2	$105	$150	$128
Automatic transmission w/aggressive shift logic	1-3	2	-	$70	$70
Six-speed automatic transmission	1-2	1.5	$140	$280	$210
42-V electrical systems	1-2	1.5	$70	$280	$175
Variable valve lift and timing	1-2	1.5	$70	$210	$140
Aero drag reduction	1-2	1.5	-	$140	$140
Engine accessory improvement	1-2	1.5	$84	$112	$98
Improved rolling resistance	1-1.5	1.25	$14	$56	$35
Advanced CVTs - allows high torque	0-2	1	$350	$840	$595
Low-friction lubricants	1	1	$8	$11	$10

Source: Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards”, copyright 2002 by the National Academy of Sciences.

BSST DOE WHR Program

BSST team partners include BMW, Ford and Visteon

The Program includes five phases- currently in its fourth phase which culminates with integration and test of the WHR system with a 6-cylinder BMW engine at NREL in Q4 ‘09. In Phase 5, the WHR system will be installed and tested in BMW and Ford vehicles in the 1st half of 2010.

BMW has developed a comprehensive bumper to bumper computer performance model using Gamma Technologies GT Cool. The model incorporates a BSST developed Matlab Simulink TEG model

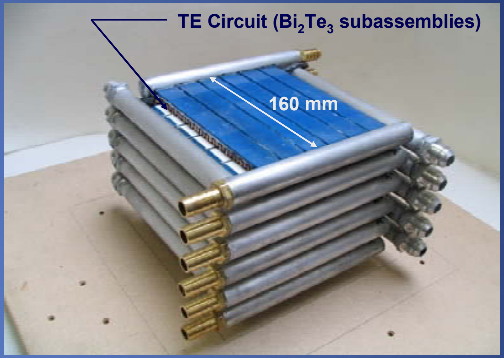
Ford has performed computer modeling to analyze hybrid vehicle TEG performance and has supported interface characterization via their Physical Sciences Laboratories

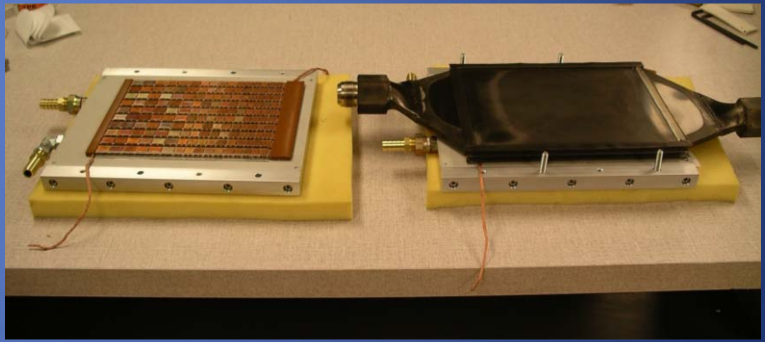
Visteon has provided heat exchangers and power control/conversion electronics in conjunction with Virginia Tech.

BSST DOE WHR Program

Achievements to date include:

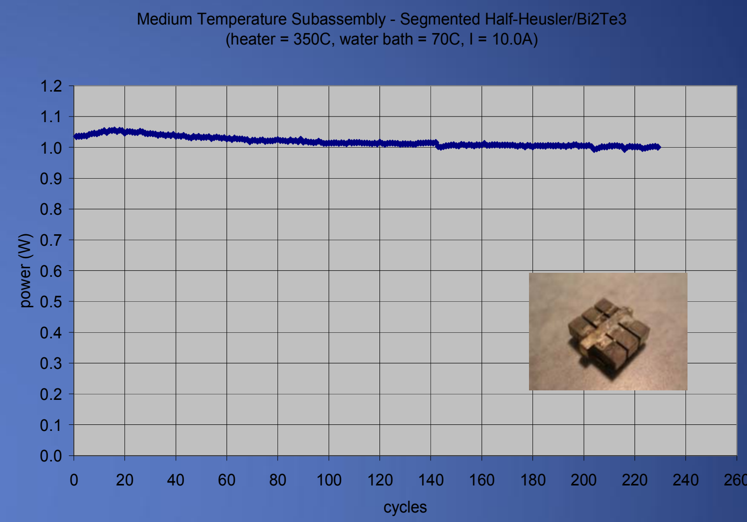
- Fractional and full scale BiTe TEG build and bench test providing over 500 watts of electric power
- Fractional scale high temperature TEG using Half Heusler material providing over 120 watts of electric power
- Thermal cycling of TE subassemblies to demonstrate long-cycle fatigue and to prove interface systems
- Power Control System design, build and test demonstrating over 95% conversion efficiency for TEG power to the vehicle buss
- Bumper to bumper vehicle fuel efficiency modeling that incorporates system parasitics and provides a means for evaluating system trade-offs.

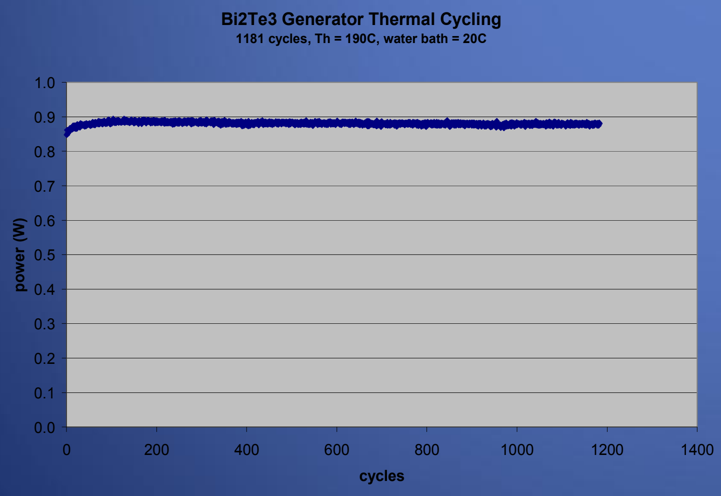


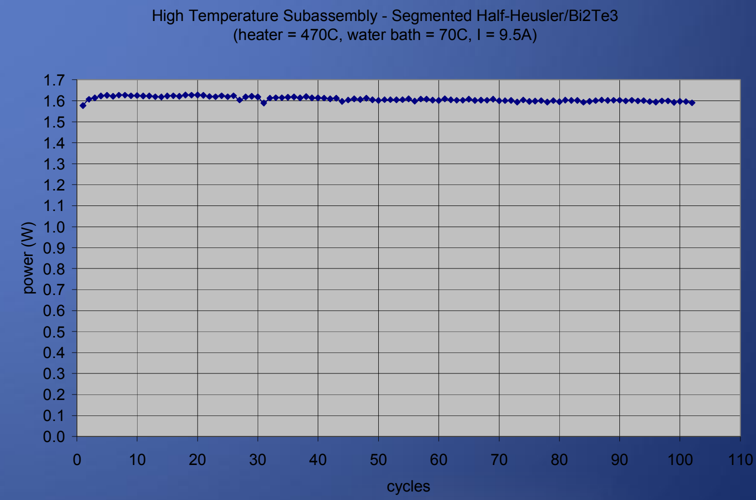


Thermal Cycling of TE Subassemblies

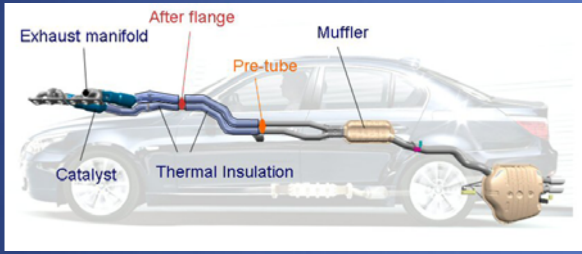
TE Subassemblies were thermal cycled to evaluate long cycle fatigue performance

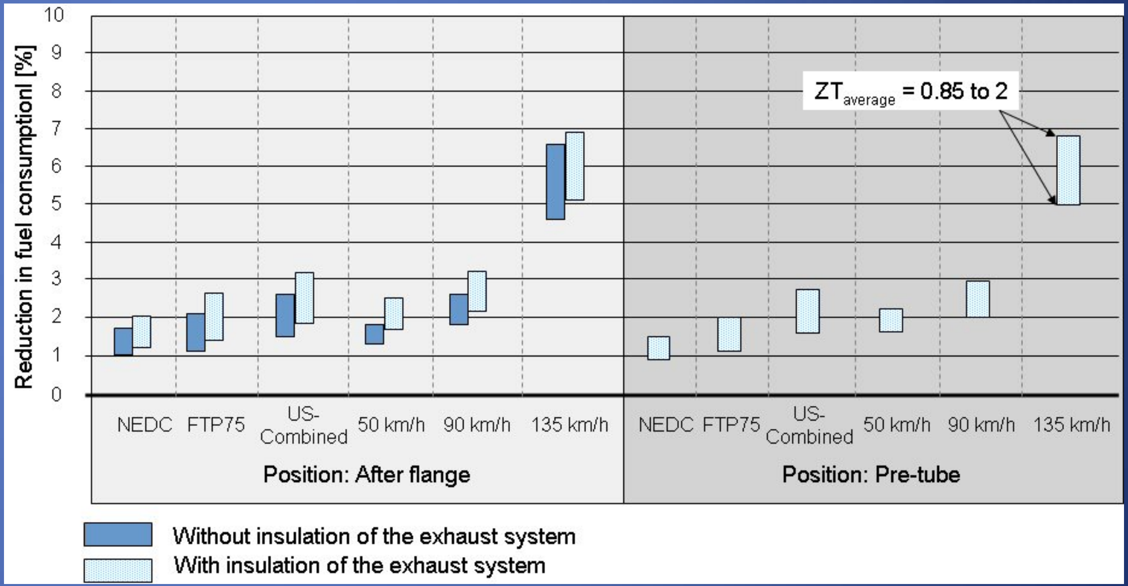






BMW Predicted Fuel Efficiency Improvement





Courtesy of Andreas Eder, BMW Group

Single Cylinder TEG Testing

Source: Ford Motor Company, Clay Maranville

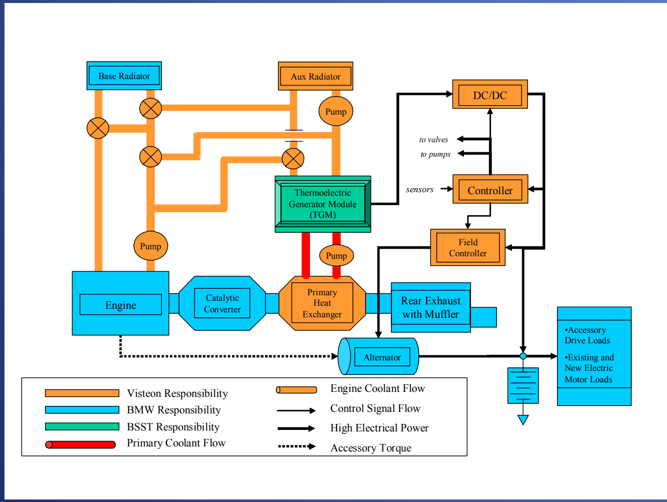
TEG Installation

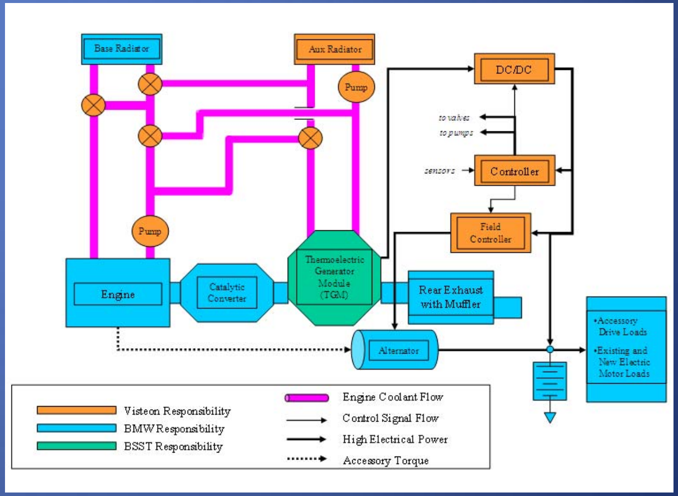
Engine Installed in Dyno

BSST DOE WHR Program

Major design changes:

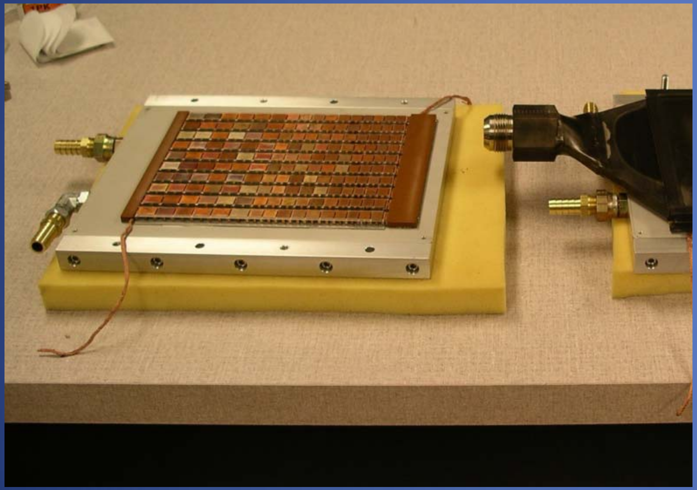
- At the system level the secondary loop removed in favor of a direct, and simpler, heat transfer system.
- At the TEG level, the planar design evolved to a coaxial design with internal bypass arrangement



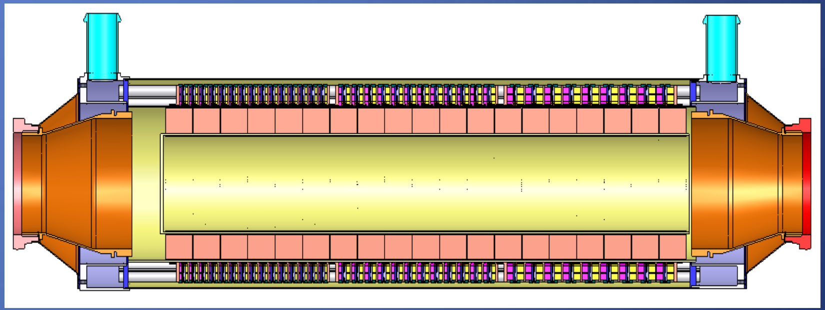


BSST DOE WHR Program

Phase 3 Planar TEG



Phase 4 Cylindrical TEG



Cross Sectional View of Preproduction Waste Heat Recovery TEG

The Path to 10% Fuel Efficiency Improvement

The path 10% FE improvement requires:

- Incorporation of advanced TE materials with a ZT of 2 (proof of concept for a path to ZT = 2 has been demonstrated by OSU/MSU);
- Improvement in electrical contact interface properties to reduce parasitic losses;
- Optimization of vehicle systems to integrate the TEG into the vehicle powertrain and electrical network;
- Development of optimal system control schemes;
- Positioning of the TEG at the catalytic converter outlet to substantially increase exhaust gas enthalpy extraction.

Next steps

Phase 4:

- Fractional cylindrical TEG build and test: 15 October
- Full scale TEG build and bench test (BSST): 15 November
- NREL dynamometer test (BMW engine with full scale cylindrical TEG): mid- December

Phase 5:

- Build and bench test of two TEGs at BSST: Jan 15 2010
- Installation and test of TEGs in BMW and Ford vehicles: late Q1/ early Q2 2010

Acknowledgements

The following people and their organizations are acknowledged for their support of this work :

John Fairbanks, US DOE

Carl Maronde, NETL

Mihal Gross ,The Office of Naval Research

Andreas Eder, the BMW Group

Clay Maranville , Ford Motor Company