PROSPECTS FOR BROADENED USE OF THERMOELECTRICS IN THE AUTOMOTIVE VEHICLES

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1. Abstract.

Very large strides have been made recently in the performance of solid-state thermoelectric systems, due directly to substantial efficiency gains at the system level and through the development of heterostructure materials. Such systems may have advantage over today's HVAC and temperature-control systems within the next several years. Direct conversion of electric power hold the promise of weight savings, system simplicity and distributed, efficient temperature control. As a result, solid-state conversion systems are projected to become serious contenders for waste power recovery in vehicles. The characteristics and performance requirements to meet present and projected usage for specific applications are discussed. Requirements for achieving these targets are analyzed.

Present and near term vehicle applications include small, on-board refrigerators and Amerigon's seat cooling and heating systems. Amerigon's product is given as an example of a TE product that has exhibited very good consumer acceptance, through a direct increase in personal comfort. Manufacturers have adopted the technology since it increases consumers perceived performance of current HVAC systems, and reduces vehicle energy consumption by decreasing HVAC power demand.

2. Background

Extraordinary advances have been made in the performance, efficiency and cost of thermoelectric devices for cooling, heating, and power generation systems. These advances have given thermoelectrics, along with efficient thermal management systems, the potential to key the next wave of advances in the automotive industry, particularly in HVAC systems and later for waste power recovery. In the past few years the technology, used in military and aerospace applications since the early 1960's, has become cost-effective for mass production. It is of specific interest for automotive applications, an industry with sales of over 50 million units annually.

Research Triangle Institute (RTI) and MIT researchers have independently identified and tested new thermoelectric materials fabricated to form engineered heterostructures. By concentrating on the basic characteristics that govern the performance of energy conversion in thermoelectric materials, both groups have created new nanostructure materials that exhibit nearly double the thermodynamic efficiency of standard materials. The technology is expected to become commercially available in the next two to four years.

Additional performance gains have been made through design improvements of the total thermoelectric system. Utilization of heat pipes and higher thermal conductivity fluid systems, as well as design optimization for a given system, have shown gains in efficiency of up to 10%, and the potential exists for gains of an additional 20%.

At BSST we have taken yet another approach by focusing on the thermodynamic cycle of the thermoelectric device. We have developed and tested thermoelectric systems with measured efficiency gains between 100% and 140%. BSST's technology is additive to the new materials and system concepts previously mentioned; in the near future it will be possible to manufacture thermoelectric devices four times as efficient as today's standard.

3. Thermoelectrics in Automobiles

The movement in thermoelectric technology has come at a most opportune time to meet critical emerging needs of the automotive industry. The continuing trend toward vehicle electrification, through automation of components and the replacement of mechanical sensors with electrical equivalents, will continue to grow in the future. Even core vehicle systems are becoming electrified, with many companies already producing electric or hybrid vehicles as a result of government-enforced emissions requirements and the need to reduce fuel consumption. The solid-state thermoelectric devices are electricity-based, therefore compatible with the new vehicle propulsion systems, including high efficiency, low emission diesel engines, as well as hybrids and fuel cells. In addition, the devices satisfy many other important needs in the automotive industry: they typically have very few moving parts, which make them simple, reliable and quiet; they are lightweight, and they are recyclable.

Advances in thermoelectrics allow the technology to be a strong contender as medium and long-term replacements for the present and proposed automotive fluid-based HVAC systems. Amerigon's Climate Control Seat™ (CCS™) system, discussed in the next section, uses thermoelectric devices to provide supplemental heating and cooling comfort through the seat. Similarly, a new wave of thermoelectric devices may act in direct unison with the HVAC system to reduce power consumption, or as auxiliary HVAC units in larger vehicles such as vans and campers. A strong possibility also exists of using thermoelectric devices to replace the entire HVAC system. Based on detailed models, thermoelectric HVAC systems are projected to be smaller and lighter than the fluid-based systems now used. They could be introduced first in the small diesel vehicles common in Northern Europe, and then in the next generation electric and hybrid vehicles, not only for space savings, but also for reduced weight and improved fuel efficiency.

The size of thermoelectric devices allows them to be distributed at advantageous locations within the vehicle to provide spot heating and cooling. A small unit could be placed in a vehicle's headliner for face heating/cooling. Studies have shown this to be an effective method of increasing perceived thermal comfort in humans. Other potential uses of thermoelectric devices include defroster/demister units for mirrors and windows, on-board refrigerators, heated and cooled cup holders, and temperature regulating devices for control modules.

Thermoelectric devices are not limited to heating and cooling functions. When mounted to a heat source, such as the exhaust system, or the radiator of a vehicle, the devices are also capable of extracting electrical power from the waste heat generated by the engine. This could be very advantageous to electric and hybrid vehicles as it would allow the mechanical energy produced to be used almost exclusively to power the drive train.

While the CCS has created a niche in the automotive market for thermoelectric devices, there are barriers to more complete market entry. The efficiency and power density of today's units must increase in order to fit within the tightly-monitored vehicle power budgets. Costs are also uncertain due to a small manufacturing base and small market. (Amerigon, after only two years of production, is projected to become the world's largest commercial user of thermoelectric devices in 2003.) Finally, the reliability and durability, mandatory for automotive manufacturers, is still unproven in the larger systems envisioned.

Potential uses for thermoelectrics in vehicles can be categorized in terms of the level of performance of the thermoelectric materials and the advantage derived from the BSST thermodynamic cycle. The performance of a thermoelectric material is defined in terms of a figure of merit, ZT, for the material. Present materials have ZT of up to 1.0; the RTI and MIT materials under development have ZT between 1.6 and 2.4. Efficiency is just slightly less than proportional to ZT, so that any future improvements that result in higher values will lead to further performance gains. Figure 1 presents a summary of significant possible applications for thermoelectrics in vehicles. Components and systems that can utilize thermoelectrics are evaluated by the ZT required for competitive performance. The value of the figure of merit is indicated by ZT1 for a ZT=1, and so on. The description “BSST” indicates where the BSST cycle is utilized. Rankings are noted by “possible” if the capability of the thermoelectric system is projected to be marginal, “OK” if it is comparable to existing systems, and “+” if it is expected to be superior.

Cooling	**ZT1**	**ZT1 + BSST**	**ZT2**	**ZT2 + BSST**	**ZT4 + BSST**
Seat cooler/heater	OK	+	+	+	+
Refrigerator/cup cooler/heater		OK	OK	+	+
Personal climate control		OK	OK	+	+
Defrost/demist		OK	OK	+	+
Quiet/auxiliary HVAC (campers/vans/trucks)		OK	OK	+	+
HVAC (small diesels)		OK		+	+
HVAC (hybrid/electric/fuel cell vehicles		Possible	Possible	+	+
HVAC system replacement (cars/trucks)				OK	+
Sensor Controls					
Temperature/heat flux sensors	OK		+	+	+
Humidity sensors			+	+	+
Electronic component cooling/control	Possible	OK	+	+	+
Power Generation					
Exhaust gas power recovery				OK	+
Radiator/engine heat power recovery				OK	OK
Co-cycle generation				Possible	OK

Figure 1

The Figure shows that significant prospects for thermoelectrics should exist with ZT2 materials and the BSST cycle, and still more applications are enabled if ZT4 could be achieved.

.4. Case Study

Amerigon’s CCS system has led the way for the use of thermoelectrics in the automotive industry, and interest continues to grow. The system, which mounts in the seat frame, adds to perceived performance of the vehicle’s HVAC system, while reducing the power load required for the overall system.

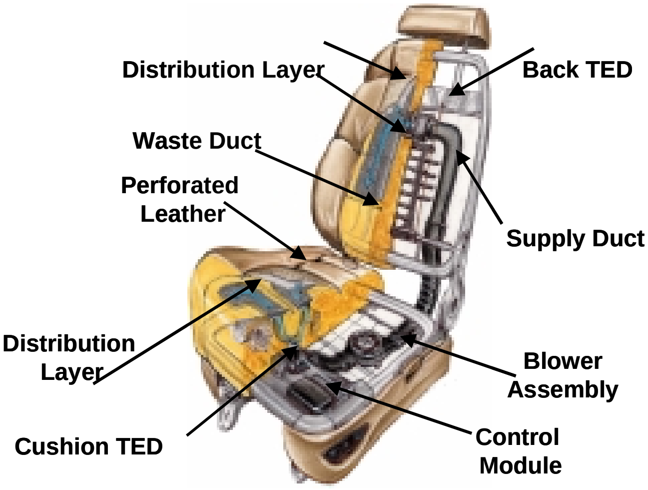

Figure 2

Ford, Nissan and Toyota offer CCS systems in current production vehicles; several other automotive manufactures are at work with Amerigon to release their first CCS vehicles. Figure depicts historic usage and projects future usage through 2004.

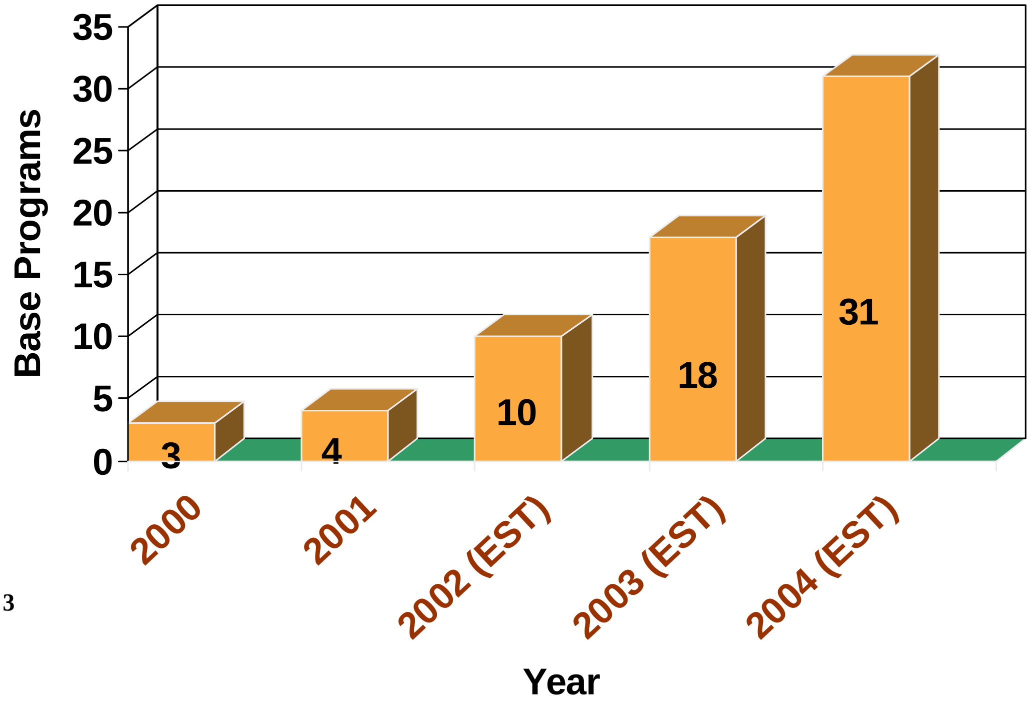

Figure 3

The Company estimates thirty-one vehicle platforms will be using the CCS system by the end of 2004.

Figure 4

The CCS system is configured around two thermoelectric assemblies, one each in the seat cushion and back. The assemblies produce either hot or cold airflow to the seat depending on the polarity of the applied voltage regulated through an electronic control unit. The airflow is generated by an electric blower also mounted to the seat, and is routed through heat exchangers in contact with the thermoelectric device. The conditioned air is then routed through channels molded in the seat foam. Distribution materials contained in the seat trim, including perforated leather, transport the conditioned air to the occupant. The system can be controlled by the occupant to one of several temperature settings in either the heating or cooling modes. A switch is typically used for control, although the CCS controller will accept many different types of input, including outputs from the vehicle’s HVAC control system.

Figure 3

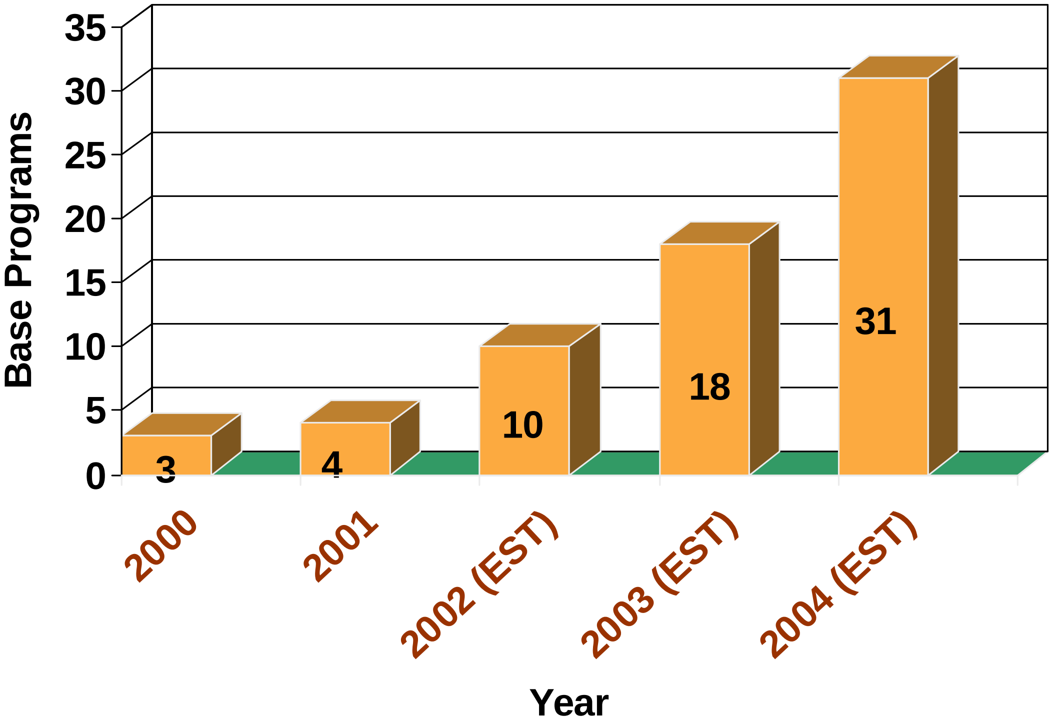

Figure 4

Thee CCS^{TM} system is based around two thermoelectric assemblies, located in the seat cushion and back.

Figure 5

The assemblies produce either hot or cold temperatures, depending on the polarity of the applied voltage regulated through an electronic control unit. Air, produced by an electric blower also mounted to the seat, is routed through ducts and blown through heat exchangers in contact with the thermoelectric device. The conditioned air is then routed through channels molded in the seat foam. Distribution materials contained in the seat trim, including perforated leather, are used to condition the occupant. The system uses active set-points and can be controlled by the occupant to one of several temperature settings in either heat or cool mode. A switch is typically used for set-point control, although the CCS controller will accept many different types of input, including outputs from the vehicle's HVAC control system.

5. Summary

With advances in materials and the thermodynamic cycles, many potential applications in vehicles appear attractive for conversion to thermoelectric technology. Amerigon's CCS, a distribu5ted cooling and heating system, supplements standard HVAC systems in vehicles today, and provides a case study for the uses of thermoelectrics in the automotive industry. Today, other applications, including complete HVAC systems, electronic component thermal management, sensors of various types, demisting, refrigerators and other systems are candidates. Power generation from waste heat sources could be another very important application of the complete electrical system integration proposed in future vehicles. Just as electronics have replaced mechanical control sensing and display systems, there is now the prospect that solid-state thermoelectric systems will find favor over present mechanical cooling, heating and temperature control systems.

6. References