TECHNOLOGY REQUIREMENTS FOR SOLID STATE POWER CONVERSION

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BSST

Develops and produces advanced TE Systems for heating, cooling, temperature and power generation applications

TE contractual relationships with Northrop Grumman, RTI, Visteon and others

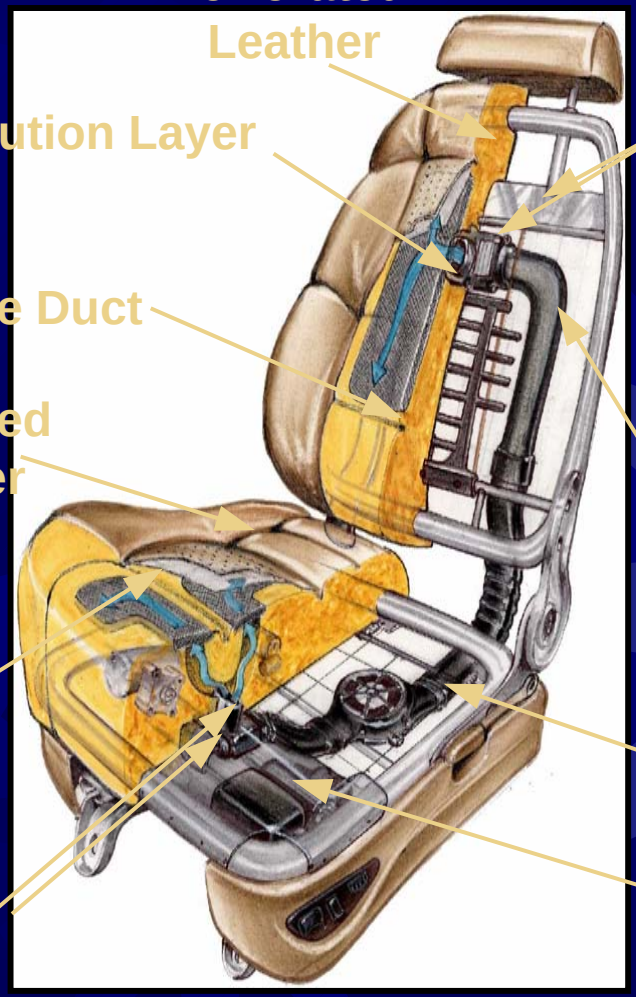
Subsidiary of Amerigon Incorporated

- World's largest commercial user of TEs
- Currently supplying TE-based climate control systems to Ford, General Motors, Nissan and Toyota
- Production in California, Mexico and China

TE Portable Coolers

Climate Control Seat™ (CCS™) System Vehicle Application

Production CCS Assembly



Water Cooler/Heaters

Existing TE Based Consumer Products

Established	Technology First Available	Start of Volume Sales
Portable Coolers	1960	Late 1980s
Cooled & Heated Car Seats	1960	Late 90s
Home Water Cooler/Heaters	1960	Late 90s
Laser Diode Coolers	1960	Late 90s
Wrist-Watch Power Generators	≈ 1980	2000

Why So Slow?

Initial markets were speculative, small and ill-defined

Performance, cost and design tools were not adequate for identifiable, large-scale applications

But today…

- The technology is advancing rapidly on all critical fronts
- Solid-state cooling, heating and power generation are globally known technologies with wide application
- New applications are being identified at a rapid rate
- Today's competitive global business climate will not allow a repeat of the glacial pace of the past

… the swift win races.

Technical Gates of Solid-State Systems

Material

- Figure of merit is main criterion
- Availability, stability and durability

Operating Cycle

- Determines system-level performance
- Varies with application

Output Power Density

- Influences form, size and weight
- Strongly impacts costs

Development Tools

- Defines device design and capability
- Availability for target component & system design
- Ability to interact with existing design processes

Manufacture Infrastructure

- Cost and schedule predictability
- Source selection and qualification

Material Capability

ZT is the definitive figure of merit for thermoelectric materials. Other related solid-state technologies have comparative measures.

ZT Value	Cooling/Heating	Power Generation
0.7 – 1.0	Available worldwide	Available
1.3 – 1.5	Expected within 2 years	Available for prototype development
1.8 – 2.4	Possible within 4 years	Possible within 2 years
2.5 +	Uncertain	Uncertain

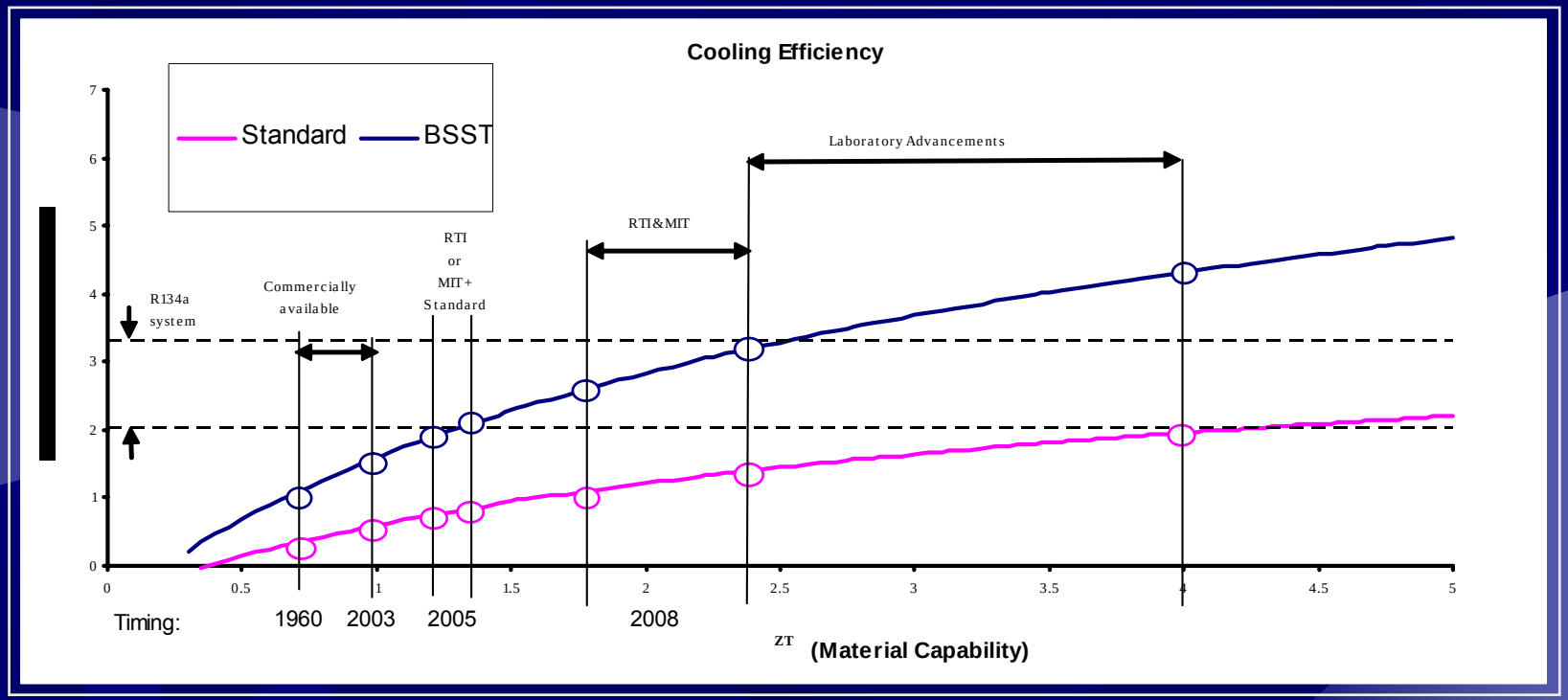
Operating Cycles

Advanced cycles have been studied that exhibit 2x the performance of standard cycles for power conversion from fluid streams

The cycles are suitable for important high volume applications, including:

- Air conditioning
- Heat pumping
- Electronic cabinet and related cooling
- Environmental temperature control
- Waste power recovery

TED Performance Roadmap



Power Density

Cooling/Heating:

- Lower power density standard modules are available worldwide
- A factor of 10 – 20 cost reduction to about $5 – 10 per kilowatt of thermal cooling output is required for HVAC and other large scale temperature control applications

Power Generation:

- Present designs are directed to specialized, low volume usage, with very high per watt cost. TE components are not standardized. Need costs of $10 – 25 per kilowatt of electrical power output.

Development Tools

Production Design Level	Supported Technology	
	Standard Cycle	Advanced Cycle
Low volume module-based design	Widely available	Very limited, proprietary models for cooling, heating & temperature control
High volume module-based designs	Limited design guidance No CAD-integrated package availability	Very limited, proprietary models for HVAC, electronics cooling
Low volume custom design	Proprietary models for internal use by module suppliers and design service providers	Limited to very few proprietary suppliers
High volume integrated designs	Some limited proprietary application-specific tools	A few proprietary, application-specific tools No fully developed packages

Manufacturing Infrastructure

Standard TE modules broadly available worldwide

- Mainly manual module fabrication
- Many concepts for semi-automated assembly under evaluation
- Cost, quality and performance are predictable

Low volume standard material and custom shapes are available worldwide

- Limited manufacturing infrastructures
- Cost and performance are predictable

Low volume custom fabrication

- Available worldwide- aerospace roots
- Costs generally quite high, limiting markets

High volume custom fabrication

- Manufacturing infrastructure under development by very few sources
- Highly proprietary, not easily accessed

Key Technology Drivers

Technology	Enables	Potential Market Impact
ZT of 2	. Electronic chip cooling	. Low $ billions
Advanced cycles	. Home, industry, vehicle supplemental cooling/heating	. Low $ billions
ZT of 2+ Advanced cycle	. Home, industry, vehicle HVAC . Electronic enclosure/other industrial system thermal management . Industry vehicle waste power recovery	. High $ billions . Low $ billions . Medium $ billions
Broadly available design tools	. Accelerates product introduction . Creates opportunities for as yet unidentified products	. Speeds market entry & penetration . Adds new markets
10- Fold (minimum) power density increase	. Required for all of the applications noted above	. Covered above

Summary of Support Requirements

Facilitate the development and early utilization of:

- Practical material systems exhibiting a ZT of at least 2 that have a path to cost effective mass production
- Advanced cycle, high ZT material and high power density modeling tools
- TE material technology development leading to interfacial resistance of about 10^{-7} Ω/cm^2 (10^{-6} for power generation)
- Demonstration programs for solid-state cooling, heating & power generation systems that are projected to offer cost effective performance superior to existing technology

Concluding Remarks

There are good prospects that solid-state power conversion technology will start the process of disrupting and eventually displacing existing mechanical technology in significant market sectors, as did solid-state electronics half a century ago.

This technology revolution could lead to substantial markets and global competitive advantage, while having significant positive societal impact on pollution and energy consumption.

We, by our choice of career paths and good fortune, are at the leading edge as this revolution unfolds.