Solid State Vehicular Generators and HVAC Development

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Arlington, Virginia
May 22, 2009
## Competitive Award Selections
(March 2004 RFP)

<table>
<thead>
<tr>
<th>Awardees</th>
<th>Additional Team Members</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Efficiency Thermoelectric</strong></td>
<td>University of Michigan, University of South Florida, Oak Ridge National Laboratory, and RTI International</td>
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<tr>
<td>General Motor Corporation and General Electric</td>
<td>BSST, LLC.</td>
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<tr>
<td>Michigan State University</td>
<td>Visteon, BMW-NA, Ford</td>
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<td></td>
<td>NASA Jet Propulsion Laboratory</td>
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<tr>
<td></td>
<td>Cummins Engine Company</td>
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<td>Tellurex, Iowa State</td>
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Thermoelectric Modules

Diagram showing the principles of thermoelectric energy conversion:

- **Cooling**
  - Heat rejection
  - p-type
  - n-type
  - Refrigeration

- **Heat source**
  - Heat sink
  - p-type
  - n-type
  - Power generation

Diagram also illustrates elements and connections involved in thermoelectric modules.
**TE materials performance:** Figure of Merit (ZT)

\[ ZT = \frac{\sigma \alpha^2}{(\kappa_e + \kappa_L)} \cdot T \]

- **Electrical conductivity**
- **Seebeck coefficient or thermopower** \((\Delta V/\Delta T)\)
- **Total thermal conductivity**

\[ \sigma \alpha^2 = \text{Power Factor} \]

\[ \sigma = \frac{1}{\rho} = \text{electrical conductivity} \]

\[ \rho = \text{electrical resistivity} \]

Slide courtesy of Oregon State University
Cobalt atoms form a *fcc* cubic lattice.

Antimony atoms are arranged as a square planar rings.

There are 8 spaces for the Sb$_4$ units.

6 are filled and 2 are empty.

\[ \text{CoSb}_3 \ [\text{Co}_8(\text{Sb}_4)_6] \]

Atoms can be inserted into empty sites. Atoms can “rattle” in these sites – scatter phonons and lower the lattice thermal conductivity.

\[ R_x\text{CoSb}_3 \]

Slide courtesy of Oregon State University
Thermoelectric Modules optimized for Thermal Zones

Slide courtesy of General Motors
Highest ZT Achieved in Triple-filled Skutterudites

\[ ZT_{\text{ave}} = 1.1 \]
GM’s Thermoelectric Generator Vehicle: Chevy Suburban

- plenty of space and waste heat

Slide courtesy of General Motors
GM TE Generator on a Chevy Suburban

TEG installed in a rear drive vehicle. GM Suburban

Vehicle interface
- Coolant in (blue)
- Coolant out (red)
- Electric Pwr (yellow)

Exhaust gas bypass

Prototype TEG

DC/DC converter

Slide courtesy of General Motors Corp.
TEG Installed in BMW Series 5 Test Vehicle

Thermoelectric Generator

Courtesy of BSST
Vehicle 530iA at 130 km/h, Exhaust gas back pressure limited to 30mbar at 130km/h

Slide courtesy of BSST
TEG is ideally compatible with Regenerative Braking

Slide courtesy of BSST
Average demand for electric power
Fraction of electricity on total FC.

<table>
<thead>
<tr>
<th>Model</th>
<th>Average Demand (W)</th>
<th>Fraction (%)</th>
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<tbody>
<tr>
<td>116i</td>
<td>190</td>
<td>2%</td>
</tr>
<tr>
<td>530dA</td>
<td>330</td>
<td>3.5%</td>
</tr>
<tr>
<td>750iA</td>
<td>390</td>
<td>4%</td>
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<tr>
<td>BMW Sedans</td>
<td>750</td>
<td>6%</td>
</tr>
<tr>
<td>1000</td>
<td>1000</td>
<td>8%</td>
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</table>

Thermoelectric Waste Heat Recovery.

Slide courtesy of BSST
Zonal TE devices located in the dashboard, headliner, A&B pillars and seats / seatbacks

Slide courtesy of BSST
COP Calculations – Traditional PTC in an EV Plus Enhanced CCS + Zonal Devices

Heating to driver = 500W
Total PTC heating to vehicle = 1200W
PTC COP = 1
CCS heating to driver = 100W
CCS COP = 2.5
Zonal TED heating to driver = 100W
Zonal TED COP = 2.5
Total power used = 1280W
COP Calculations – TE Central HVAC in an EV + Enhanced CCS + Zonal Devices

Heating to driver = 500W

Total TE central HVAC heating to vehicle = 1200W

TE central HVAC COP = 2.5 (assumed)

CCS heating to driver = 100W

CCS COP = 2.5 (assumed)

Zonal TEC heating to driver = 100W

Zonal TED COP = 2.5 (assumed)

Total power used = 560W
**TE applications: heat recovery from exhausted gases**

Reduced Energy Consumption by Massive Thermoelectric Waste Heat Recovery in Light Duty Trucks

**HeatReCar - EU project**

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<tr>
<th>Company</th>
<th>Location</th>
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<tr>
<td>Siemens</td>
<td>Germany</td>
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<tr>
<td>ROM Innovation</td>
<td>France</td>
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<tr>
<td>CRF</td>
<td>Italy</td>
</tr>
<tr>
<td>Bosch</td>
<td>Germany</td>
</tr>
<tr>
<td>Termo-gen AB</td>
<td>Sweden</td>
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<tr>
<td>Fraunhofer IPM</td>
<td>Germany</td>
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<td>Valeo</td>
<td>France</td>
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Slide courtesy of Fiat
**TE applications: distributed energy generation**

**Thermoelectricity for Mobile Systems**

**THERMOBILE - under evaluation**

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<th>Country</th>
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Thank You!