Lecture 3.8:
Introduction to Thermoelectric Devices

Learning Objectives
By the Conclusion of this Lecture, You Should be Able to:

1. **List** potential uses for thermoelectric devices and how they play a role in the energy conversion portfolio.

2. **Calculate** the figure of merit for a given thermoelectric material given experimental materials data.

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A Lot of Energy is Converted to Waste Heat Currently

Recovery of 16% of the Rejected Energy Would Cover the Commercial Sector

Estimated U.S. Energy Use in 2009: ~94.6 Quads

Source: LLNL 2010. Data is based on DOE/EIA-0384(2009), August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant “heat rate.” The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-M1-410527

Recovery of 16% of the Rejected Energy Would Cover the Commercial Sector
### Thermoelectric Materials Convert Heat to Electricity

**Thermoelectric Device Schematic**

![Thermoelectric Device Schematic](image)

**Figure of Merit for Properties of Materials**

\[ ZT = \frac{\sigma S^2}{\kappa} T \]

Efficiency Increases with Increasing $ZT$

**Defining the Terms of the Figure of Merit**

<table>
<thead>
<tr>
<th>Seebeck Coefficient $(S)$</th>
<th>Electrical Conductivity $(\sigma)$</th>
<th>Thermal Conductivity $(\kappa)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Describes how much energy the electrons that carry heat have</td>
<td>Describes how easily electrons can move in the material</td>
<td>Describes how easily the flux of heat can move in the material</td>
</tr>
</tbody>
</table>

**Goal is to MAXIMIZE** Electrical Conductivity $(\sigma)$ and Thermopower $(S)$ **while MINIMIZING** Thermal Conductivity $(\kappa)$
**Thermoelectric Devices Emerging Today**

**Multiple Devices Make a Module**

- Heat absorbed
- Substrates
- Thermoelectric elements
- Metal interconnects
- External electrical connection

**Heat rejected**

- Heat absorption
- $p$ $h^+$ $n$ $e^-$
- Heat flow

**Modules Can Be Used in Automobiles**

- Cooled by engine coolant system
- Thermoelectric Generator
- Thermoelectric Modules
- Exhaust Gas

Synder, G. J.; Toberer, E. S. *Nat. Mater.* **2008**, *7*, 105.  
Concept Images by: BMW, Ford, and BSST
Certain Materials Have Better Thermoelectric Properties Than Others

| Material   | Material type | $|S|$ (µV K$^{-1}$) | $\sigma$ (S cm$^{-1}$) | $k$ (W m$^{-1}$ K$^{-1}$) | ZT (T = 298 K) |
|------------|---------------|-------------------|------------------------|--------------------------|----------------|
| ZnO        | Insulator     | 350               | $10^1$                 | 50                       | $\approx 10^{-3}$ |
| Bi$_2$Te$_3$ | Semiconductor  | 200               | $10^4$                 | 1                        | $\approx 1$    |
| Cu         | Metal         | 7.6               | $10^7$                 | 400                      | $\approx 10^{-3}$ |