

# Thermoelectric material is world's best at converting heat waste to electricity

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Northwestern University scientists have developed a thermoelectric material that is the best in the world at converting waste heat to electricity. This is very good news once you realize nearly two-thirds of energy input is lost as waste heat.

The material could signify a [paradigm shift](#). The inefficiency of current thermoelectric [materials](#) has limited their commercial use. Now, with a very environmentally stable material that is expected to convert 15 to 20 percent of [waste heat](#) to useful electricity, thermoelectrics could see more widespread adoption by industry.

Possible areas of application include the [automobile industry](#) (much of gasoline's [potential energy](#) goes out a vehicle's tailpipe), heavy manufacturing industries (such as glass and brick making, refineries, coal- and gas-fired [power plants](#)) and places where large [combustion engines](#) operate continuously (such as in large ships and tankers).

Waste heat temperatures in these areas can range from 400 to 600 degrees Celsius (750 to 1,100 degrees Fahrenheit), the sweet spot for thermoelectrics use.

The new material, based on the common semiconductor lead telluride, is the most efficient thermoelectric material known. It exhibits a thermoelectric figure of merit (so-called "ZT") of 2.2, the highest reported to date. Chemists, physicists, material scientists and mechanical engineers at Northwestern and Michigan State University collaborated to

develop the material.

The study will be published Sept. 20 by the journal *Nature*.

"Our system is the top-performing thermoelectric system at any temperature," said Mercouri G. Kanatzidis, who led the research and is a senior author of the paper. "The material can convert heat to electricity at the highest possible efficiency. At this level, there are realistic prospects for recovering high-temperature waste heat and turning it into useful energy."

Kanatzidis is Charles E. and Emma H. Morrison Professor of Chemistry in Northwestern's Weinberg College of Arts and Sciences. He also holds a joint appointment at Argonne National Laboratory.

"People often ask, what is the energy solution?" said Vinayak P. Dravid, one of Kanatzidis' close collaborators. "But there is no unique solution—it's going to be a distributed solution. Thermoelectrics is not the answer to all our energy problems, but it is an important part of the equation."

Dravid is the Abraham Harris Professor of Materials Science and Engineering at the McCormick School of Engineering and Applied Science and a senior author of the paper.

Other members of the team and authors of the *Nature* paper include Kanishka Biswas, a postdoctoral fellow in Kanatzidis' group; Jiaqing He, a postdoctoral member in Dravid's group; David N. Seidman, Walter P. Murphy Professor of Materials Science and Engineering at Northwestern; and Timothy P. Hogan, professor of electrical and computer engineering, at Michigan State University.

Even before the Northwestern record-setting material, thermoelectric

materials were starting to get better and being tested in more applications. The Mars rover Curiosity is powered by lead telluride thermoelectrics (although its system has a ZT of only 1, making it half as efficient as Northwestern's system), and BMW is testing thermoelectrics in its cars by harvesting heat from the exhaust system.

"Now, having a material with a ZT greater than two, we are allowed to really think big, to think outside the box," Dravid said. "This is an intellectual breakthrough."

"Improving the ZT never stops—the higher the ZT, the better," Kanatzidis said. "We would like to design even better materials and reach 2.5 or 3. We continue to have new ideas and are working to better understand the material we have."

The efficiency of waste heat conversion in thermoelectrics is governed by its figure of merit, or ZT. This number represents a ratio of electrical conductivity and thermoelectric power in the numerator (which need to be high) and thermal conductivity in the denominator (which needs to be low).

"It is hard to increase one without compromising the other," Dravid said. These contradictory requirements stalled the progress towards a higher ZT for many years, where it was stagnant at a nominal value of 1.

Kanatzidis and Dravid have pushed the ZT higher and higher in recent years by introducing nanostructures in bulk thermoelectrics. In January 2011, they published a report in *Nature Chemistry* of a thermoelectric material with a ZT of 1.7 at 800 degrees Kelvin. This was the first example of using nanostructures (nanocrystals of rock-salt structured strontium telluride) in lead telluride to reduce electron scattering and increase the energy conversion efficiency of the material.

The performance of the new material reported now in Nature is nearly 30 percent more efficient than its predecessor. The researchers achieved this by scattering a wider spectrum of phonons, across all wavelengths, which is important in reducing thermal conductivity.

"Every time a phonon is scattered the thermal conductivity gets lower, which is what we want for increased efficiency," Kanatzidis said.

A phonon is a quantum of vibrational energy, and each has a different wavelength. When heat flows through a material, a spectrum of phonons needs to be scattered at different wavelengths (short, intermediate and long).

In this work, the researchers show that all length scales can be optimized for maximum phonon scattering with minor change in electrical conductivity. "We combined three techniques to scatter short, medium and long wavelengths all together in one material, and they all work simultaneously," Kanatzidis said. "We are the first to scatter all three at once and at the widest spectrum known. We call this a panoscopic approach that goes beyond nanostructuring."

"It's a very elegant design," Dravid said.

In particular, the researchers improved the long-wavelength scattering of phonons by controlling and tailoring the mesoscale architecture of the nanostructured thermoelectric materials. This resulted in the world record of a ZT of 2.2.

The successful approach of integrated all-length-scale scattering of phonons is applicable to all bulk [thermoelectric materials](#), the researchers said.

**More information:** The paper is titled "High-Performance Bulk

## Thermoelectrics With Hierarchical Architecture."

Provided by Northwestern University

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