Advancing Thermoelectric Battery Technology for Sustainable Energy Storage

To combat greenhouse gas emissions, the production of electricity using fossil fuels is being replaced by sustainable energy sources such as solar or wind. These energy sources require energy to be stored so it can be available when needed. Storage of energy is traditionally done using batteries based on chemical storage. These chemicals are obtained through mining and other methods that have negative environmental impacts. Storing energy thermally rather than by using chemicals offers easily scalable and environmentally friendly battery storage. The development of a practical thermoelectric battery could revolutionize energy storage.

Thermal energy is starting to be used for energy storage. A recent thermal storage project in Finland is the world's first "sand battery" and can store heat at 500 ^{o}C for months at a time. (Purtill, 2022). One of the major advantages of this type of storage is that the storage medium (sand) is low-cost and environmentally friendly. This project utilized 100 tons of sand stored in a 7-meter steel container that was connected to the power grid using off-peak low-cost electricity to heat the sand using resistive heating. The output of the sand battery can be used to drive steam turbines to generate electricity, or the heat can be used directly for domestic heating requirements.

The Department of Energy (DOE) in the United States has launched the "Energy Storage Grand Challenge," which is a comprehensive program to accelerate the development, commercialization, and utilizing of next-generation energy storage technologies ("Energy Storage Grand Challenge"). A subprogram area of this challenge is for "Thermal Energy Storage Technologies", focused on the research, development, demonstration, and deployment (ROD&D) for building applications. ("Thermal energy storage"). Thermal storage is a key component of our energy storage systems of the future and an exciting area of research.

While thermal energy storage can deliver heat directly for building use, it is desirable to be able to use the stored heat energy and convert it back to electrical energy for general use in the building. In this concept, thermal energy storage acts like a traditional battery, charging from an electrical energy source (such as a sustainable source like solar or wind) and discharging when needed. The “charging” phase of the thermal storage would consist of heating a storage medium (such as sand or phase change material); this can be done using electricity through resistive heating. Also needed in the “charging” phase is the ability to cool another medium (such as water) to its freezing temperature to obtain a maximum temperature differential (ΔT). Typical large-scale methods for cooling use compressors and a gas that cools via expansion. A small-scale method can use the Peltier effect through a thermocouple junction of two dissimilar metals when a voltage is applied. One side of the junction cools, and the other heats. Commercial thermoelectric cooler (TEC) modules exist that are used for such devices as portable refrigerators and laboratory cooling. A TEC uses the Peltier effect to move heat from one side of the device to another, creating a temperature differential between the two sides. A study (Shi et al., 2023) shows the usage of Peltier devices to cool water.

Large-scale solutions for converting thermal energy to electrical energy would use a steam turbine or Stirling engine to drive a generating unit. For smaller scale uses, a thermoelectric generator can be constructed using Peltier devices operating in reverse mode, where a temperature differential is provided across the TEC module and a voltage is generated through the Seebeck effect. This voltage can be used to generate electricity for home use.