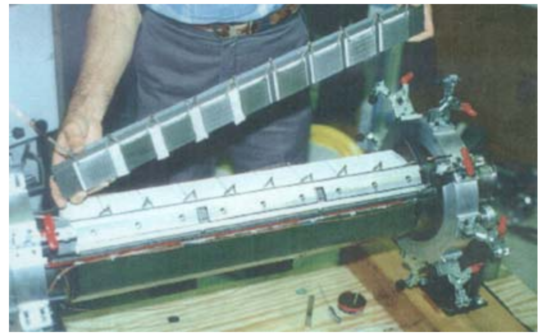
Waste Heat Recovery Systems

1 kW Generator for Diesel Truck
Demonstrated capability to produce 1 kW of electric power from Diesel engine exhaust.



1 kW TEG for Class 8 Truck Under Assembly
Eight arrays, 9 modules per array for a total of 72 HZ-14 modules.

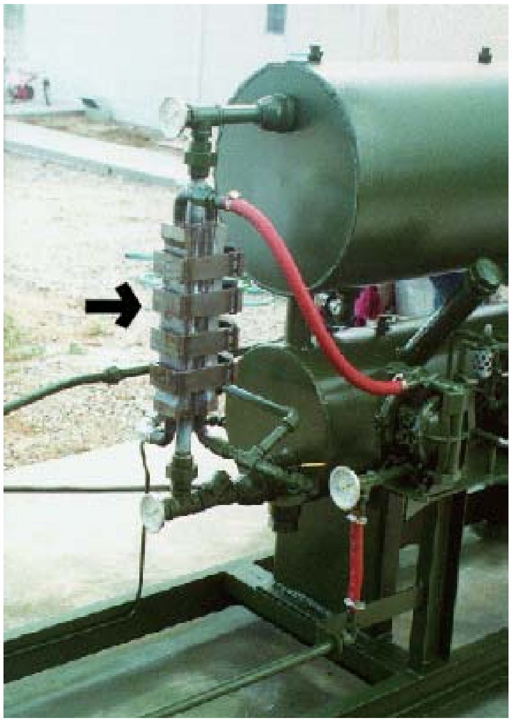
1 kW TEG for Class 8 Truck
TEG being evaluated in test cell and is coupled with 300 HP Diesel engine.

1 kW TEG Installed on a Kenworth Truck
(550 HP Diesel engine) for durability test. TEG passed 543,000 equivalent miles

180 W TEG Modified for Hybrid SUV
Equipped with power management system capable of charging 300 V battery pack.

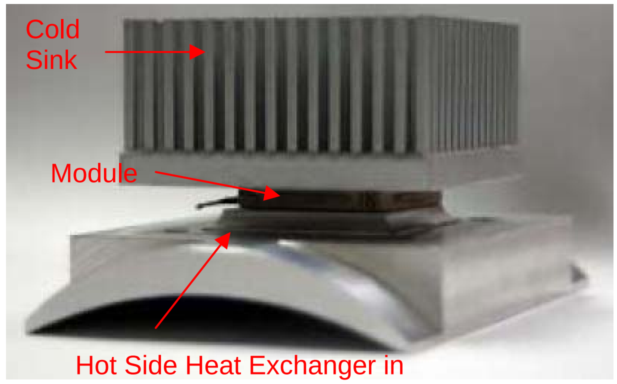
330 W TEG for GM 1999 Sierra Pickup Truck
Equipped with power management system to charge 12 V and 42 V batteries. Suitable for light trucks and passenger vehicles.

Waste Heat Recovery Systems



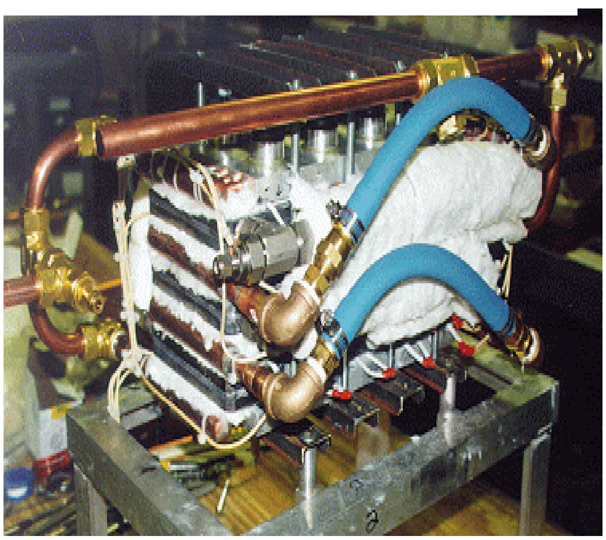
Power From Waste Heat in Natural Gas Production Field

The only source of electricity at the spot. TEG assembled from six HZ-14 modules. Produces 60 W of electric power that is adequate to run the glycol recovery system.



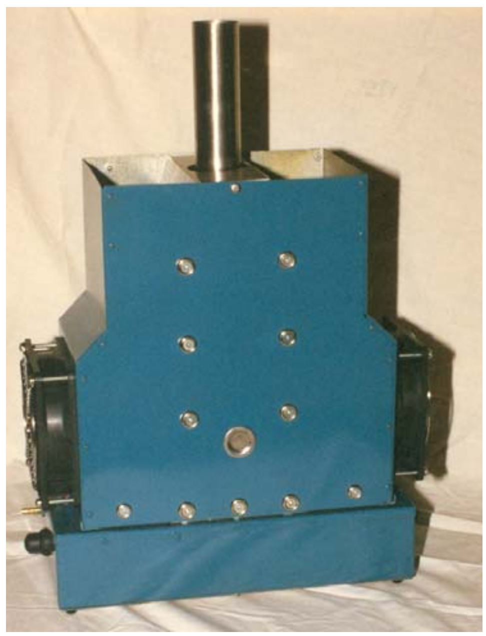
Clamp-on Thermoelectric Generator

Hot side is held against heat source (*e.g.,* steam line) for powering wireless sensors. Also suitable for recovering waste heat from engine exhaust and powering vehicle components.



Waste Heat Recovery From Burning Garbage

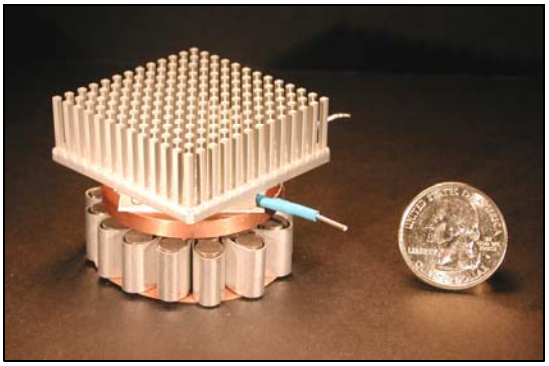
500 Watt at 50 V TEG uses hot oil from the garbage burning plant.
Assembled with 32 H Z-14 modules

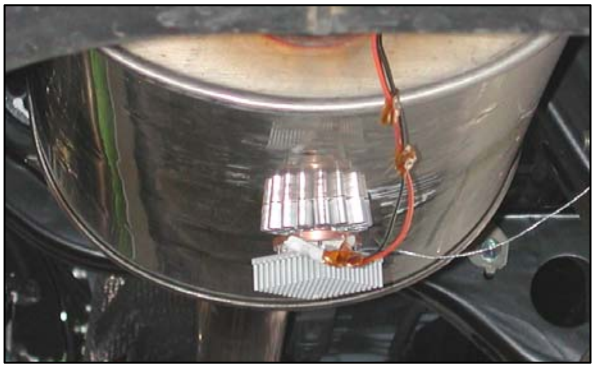


20 W Demonstration Generator

Assembled from two HZ-14 modules. Driven by gas or liquid fueled camping stove burner. Can supply electric power for lighting, changing batteries, power cell phones, radio, communication devices, sensors, *etc*.

Waste Heat Recovery Systems





QuickSnap® Thermoelectric Device for Tracking Vehicles

The QuickSnap® Thermoelectric Device produces ½ W during freeway driving and it can be attached to a car muffler in two seconds using high temperature magnets. The shiny muffler surface shows a mirror image of the device.

Self-Powered Appliances

Woodstove Stack Generator
The stove is equipped with two HZ-14 modules and two DC fans. TEG produces 20 W of net electric power and electricity to drive the fans. The stove produces heat for cooking and space heating, hot water and electricity

Pellet Stove for Cabins with no Electricity
The stove is equipped with 2 HZ-14 modules that supply electricity to DC fan, pellet supply device and controls. DC fan cools TE modules and enhances connective heat transfer.

Self-Powered Appliances

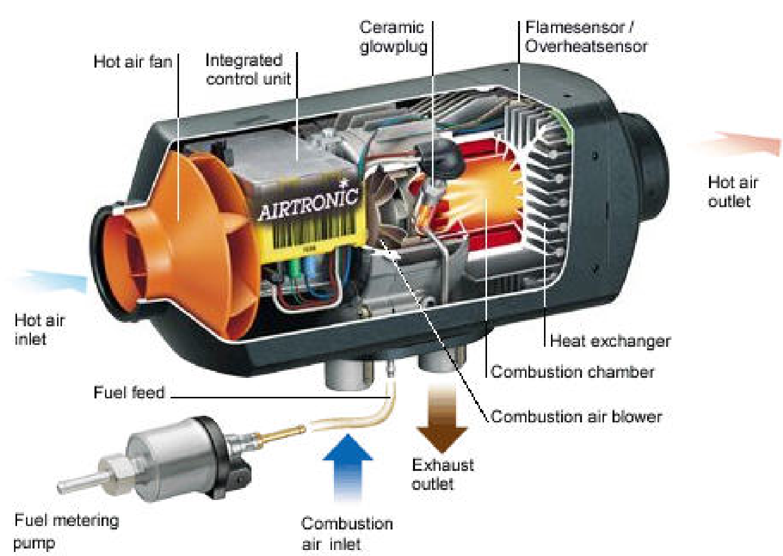
Self-powered Home Central Heating Unit
Cogeneration device 84,000 Btu/hr that simultaneously produces hot water for home hydronic heating system and electric power (80 W) from TEG that runs the heater burner and controls.

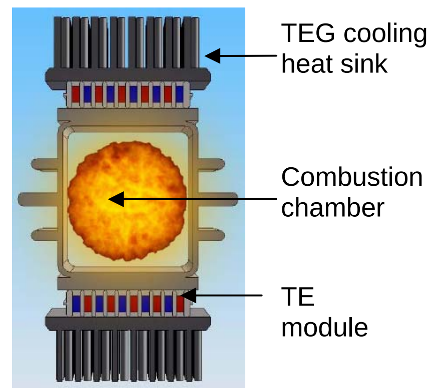
Self-powered Fireplace
Equipped with 2 HZ-9 modules and a DC fan.

- Eliminates needs for hard wiring or use of battery
- Enhances space heating efficiency
- Saves fuel

U.S. Army Self-powered Field Feeding System Prototype
TEG (not shown) is integrated below water tank. TEG generates sufficient amount of electricity to drive the system and re-charge a start-up battery. Self-powering eliminates need for Diesel generator and reduces weight, volume and fuel consumption. Ready-to-eat meals are loaded into the water tank and are heated to 90-100°C.

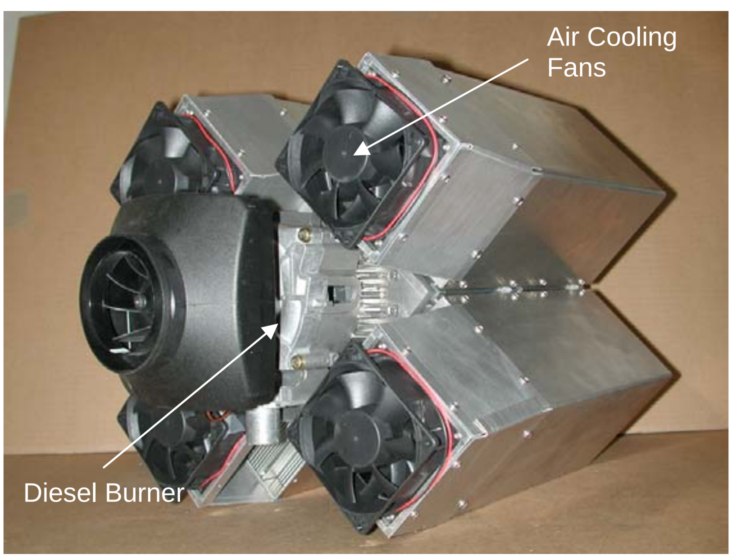
Self-Powered Appliances

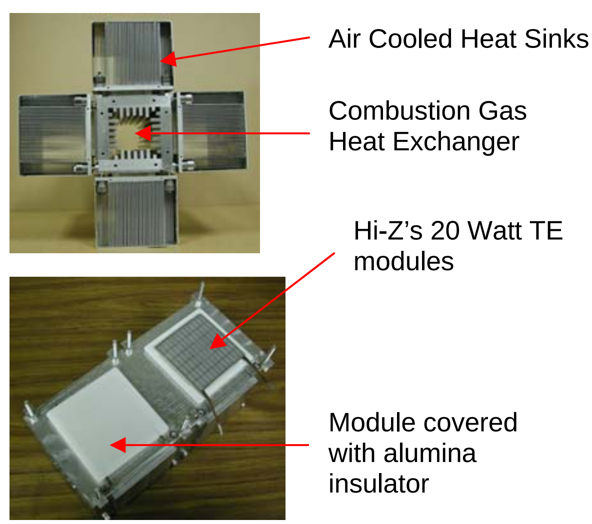




Conceptual Design of a Self-powered Space Heater

DC driven truck space heater was modified to generate electricity to operate in self-powered mode. Requires 21.5 W for steady state operation. TEG produces 25 W, enough power to run burner and charge car battery.

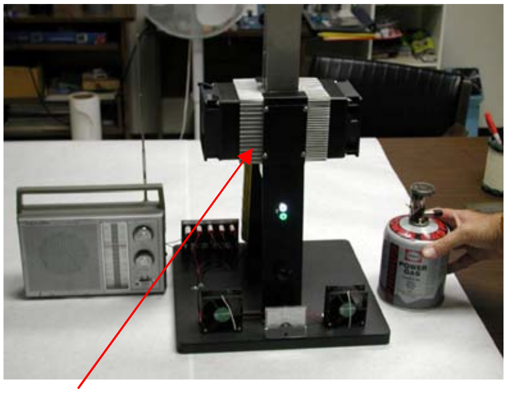




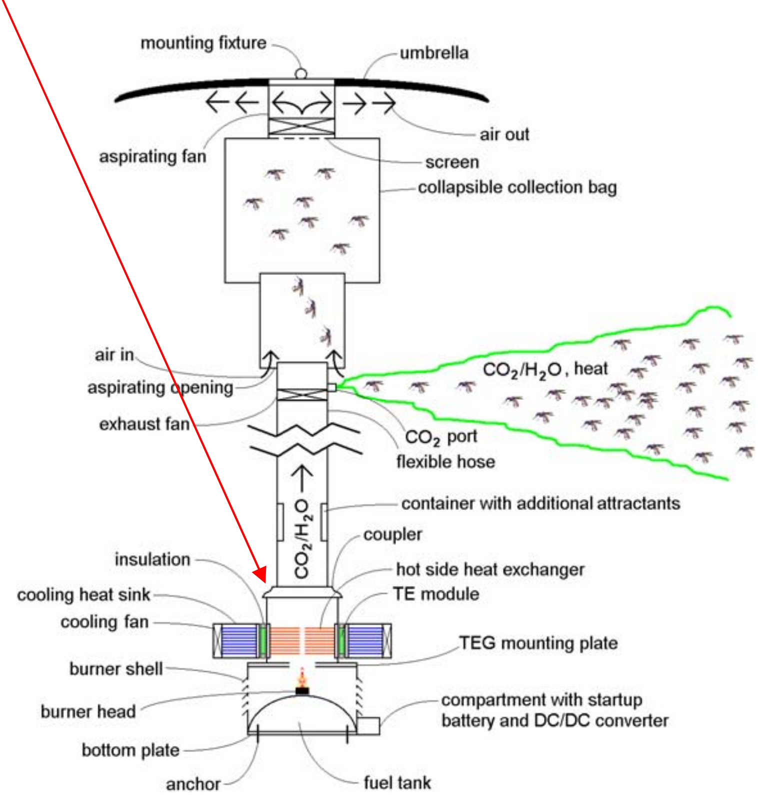
Portable Thermoelectric Generator

Generator uses 8 HZ-20 modules to generate 160 W gross power output and a 110 W net power with parasitic power used for combustion fuel pump, combustion air fan and fans to cool thermoelectric modules. Generator fits in 21 in. long by 15 in. diameter space envelope.

Thermoelectric Generators



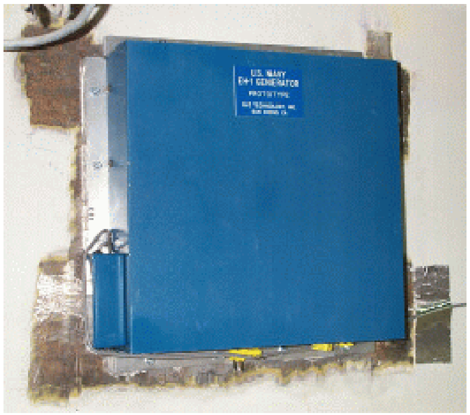
Small 3W to 4W TEG capable of operating with different fuels, including Diesel, JP, propane, butane, *etc*.
Power source to charge mosquito trap batteries, power/charge cell phones, sensors, data collection and transmission systems, light sources, *etc*. TEG demonstrates capability of simultaneously powering two cooling fans, two external fans, two LED illuminators (total 14 LEDs) and Hi-Z Logo (34 LEDs)



Self-powered Mosquito Trap uses Small TEG Power Generator (3 W to 4 W)

The system was developed for the U.S. Army in cooperation with John W. Hock Company. A thermoelectric generator assembled with 2 HZ-2 modules supplies a mosquito trap with the required amount of electric power (about 2W) to run an aspirating fan and a light bulb and 2 TEG cooling fans (2 W). It also produces surplus electric power (about 1.45 W) that can be used for additional lighting, battery charging, *etc*. The system can operate on various heat sources including logistics fueled burners and gas burners. Burner exhaust contains CO_2 and water vapor that are used for mosquito attraction. The standalone TEG can be used as a small (3 W to 4 W) generator capable of powering communication devise, cell phones, battery chargers, lighting, or other needs. The TEG can be scaled up to produce 30 W to 40 W of electric power.

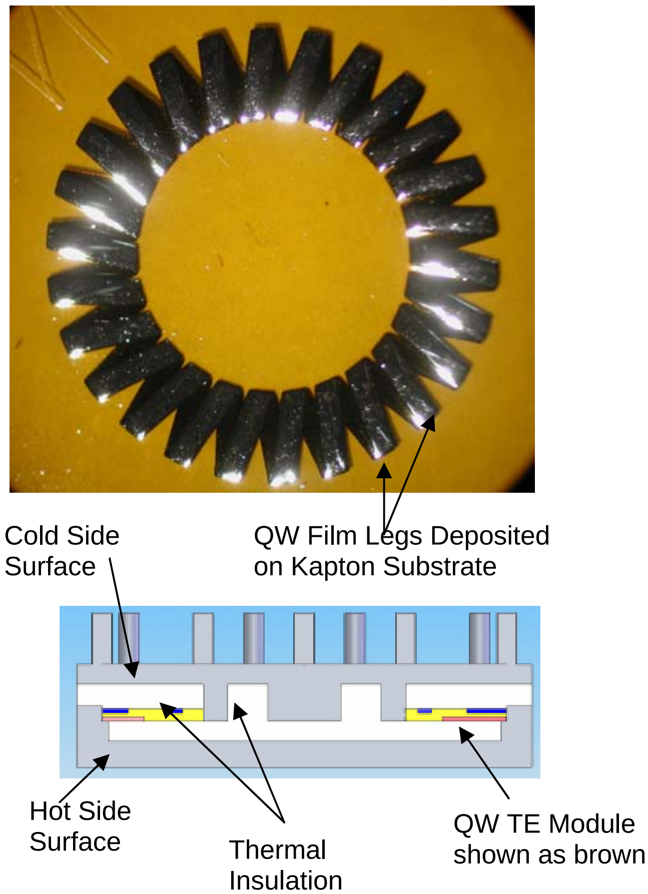
Thermoelectric Generators

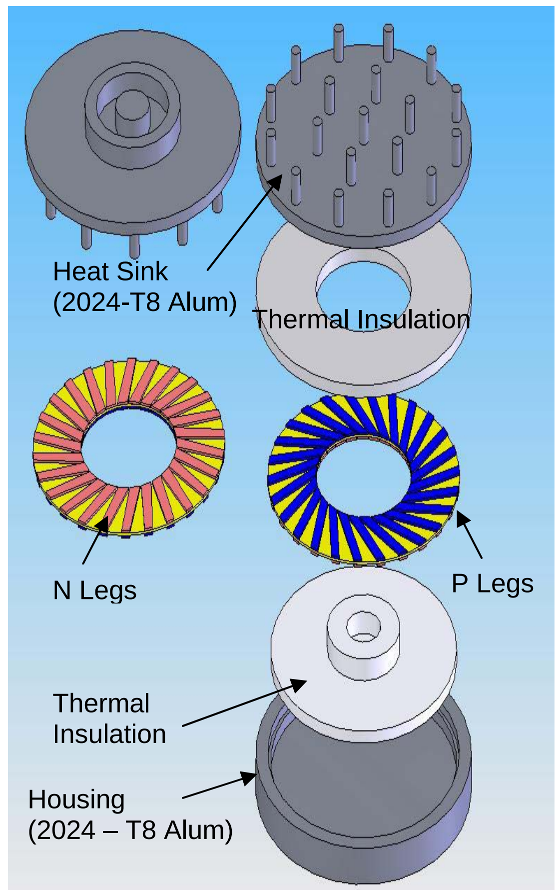


Infinite Battery for Data Sensing and Transmitting System

Generating power for U.S. Navy from ambient shipboard temperature differences of 5°C. Generator uses 9 0.070 inch thick milliwatt modules in series and produces 3 mW at 3.1 V DC output.

1 Inch OD Quantum Well TE Module During Fabrication





Provides power for wireless sensors:

- 5 mW at 3 V using 40°C ΔT from ship interior thermal environment

Modules can be stacked and connected in series to yield higher output powers

Generator:

- 1 in^2 footprint, ½ inch height, 7.4 g weight

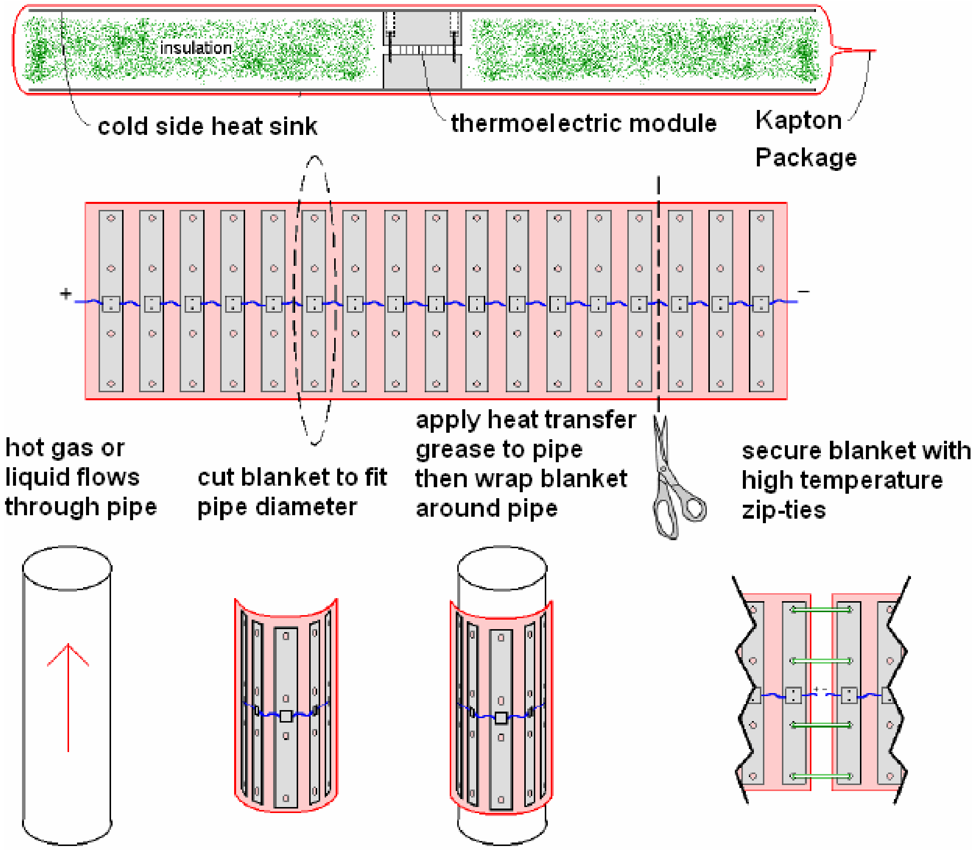
Thermoelectric (TE) Module:

- 66.8 μm thickness, 0.05 g weight

Thin Film Legs:

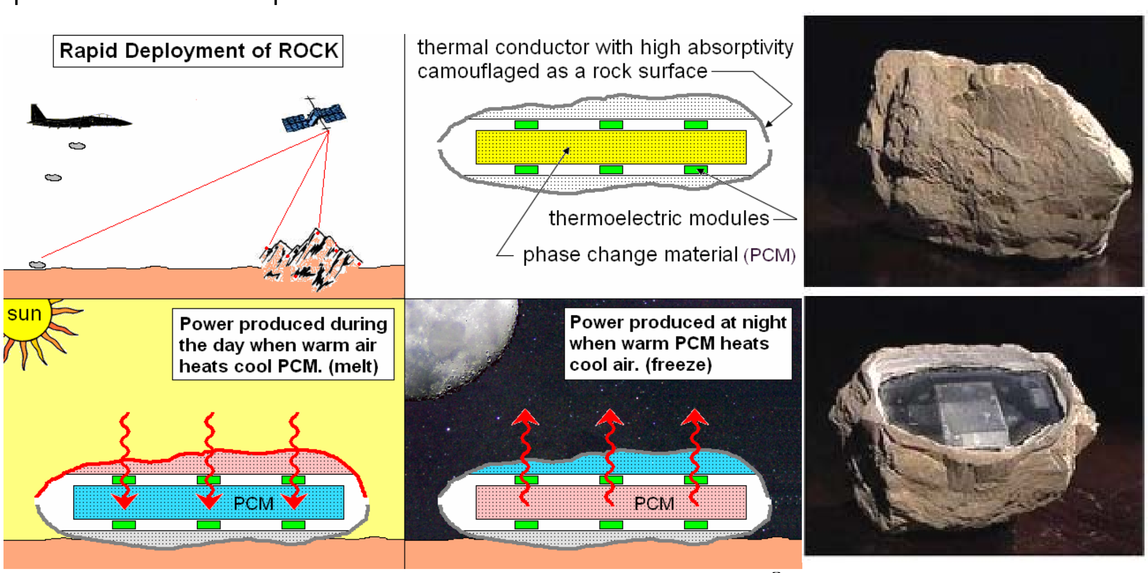
- 800 alternating Si and SiGe layers 100 Å *(10 nm) thick on both sides of Kapton substrate

Thermoelectric Generators – Conceptual Designs



Thermoelectric Blanket® for Powering Wireless Sensors

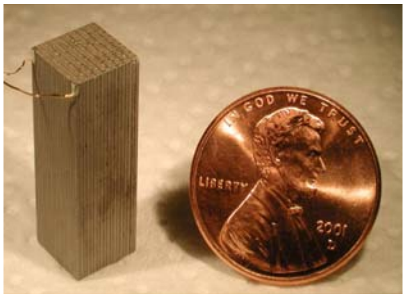
America's power producers and industrial sectors continuously vent 1,000,000 MegaWatts of heat into the environment. Pipes are the most common conduit in which waste heat is transferred to the environment. Hi-Z's Thermoelectric Blanket® is a low-cost, easy to use, universal device for converting hot pipe heat into electrical power!



Thermoelectric Energy Harvesting® ROCK

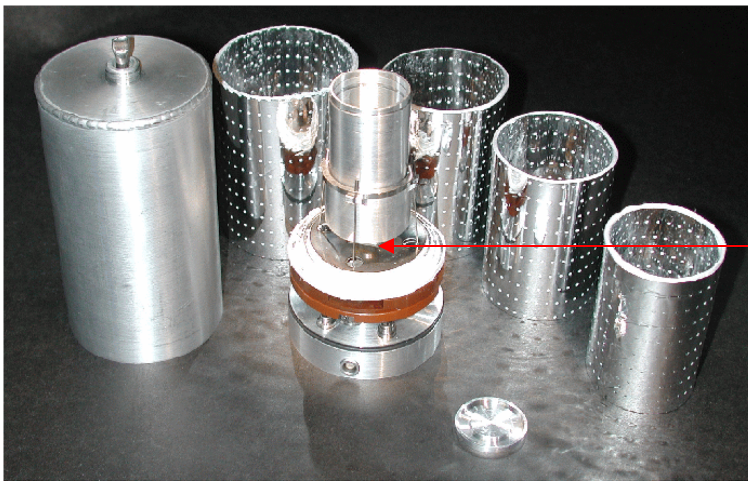
The Thermoelectric Energy Harvesting Rock® uses a phase change material to store energy from warm air during the day, and releases this energy at night. During each daily cycle heat passes through a thermoelectric module so power is produced. It could be used to power hidden devices such as sensors (disguised as rocks) for remote pipelines!

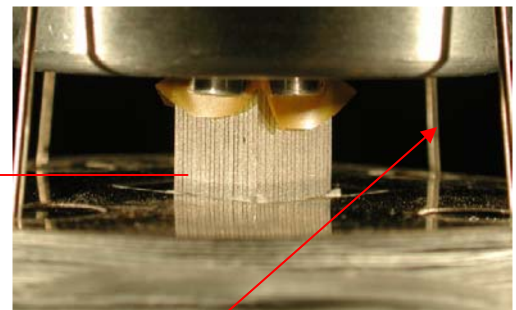
MilliWatt Thermoelectric Generator for Space and Terrestrial Applications



40 MilliWatt Module

A 0.070 inch thick slice of the 40 mW module produces 500 mW at a ΔT of 225°C or 4 mW at ΔT 20°C.



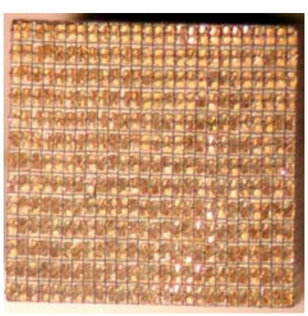


40 mWatt module held in compression between heat source and cold sink with titanium wires

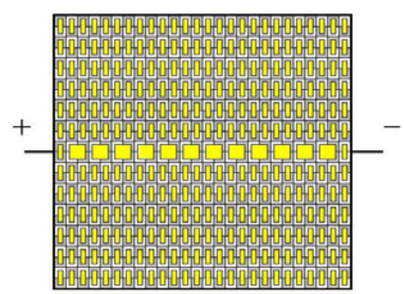
Thermoelectric Generator for NASA Space Applications

Generator produces 40 mW of power at 6 V using a 1 W_t radioisotope heating unit and uses a Bi_2Te_3 thermoelectric module consisting of an 18 x 18 array of 15 x 15 mil N and P legs. Preliminary tests indicate the generator can survive > 500 Gs at 1 msec. An advanced version of the module is a 26 x 26 array and each leg is 0.010 in. x 0.010 in. x 0.9 in. and has redundant circuitry.

Half Watt Thermoelectric Module

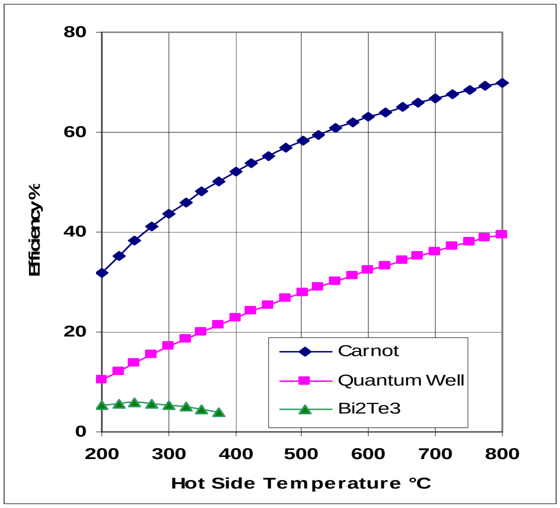


Actual Module
Each gold tab joins an N & P leg. Leg size is 0.028 in. x 0.028 in. x 0.6 in.

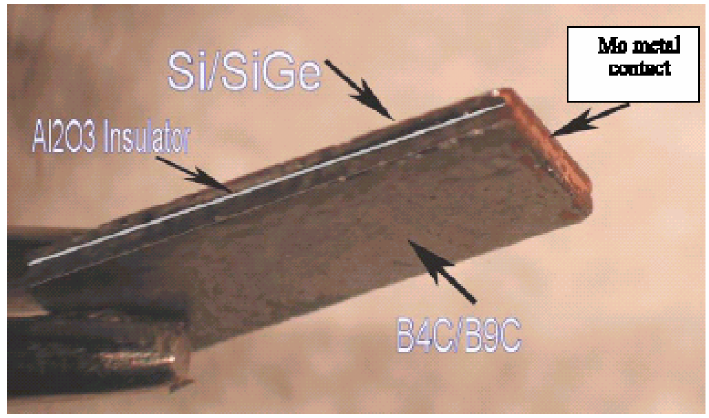


Schematic showing the joining of the redundant (gold squares) circuitry in a ½ W module

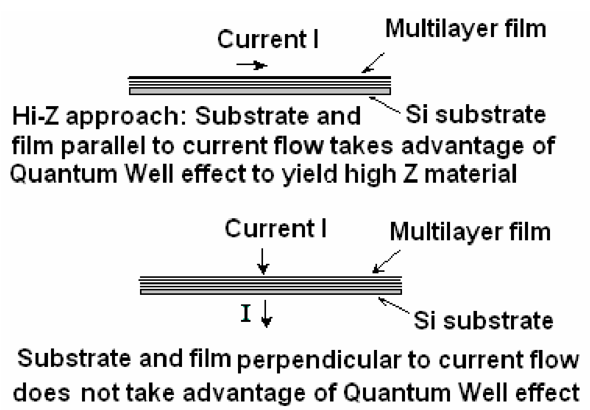
High Efficiency, High Temperature Quantum Well Thermoelectric Materials for Power Generation from Vehicles and Industrial Waste Heat Recovery

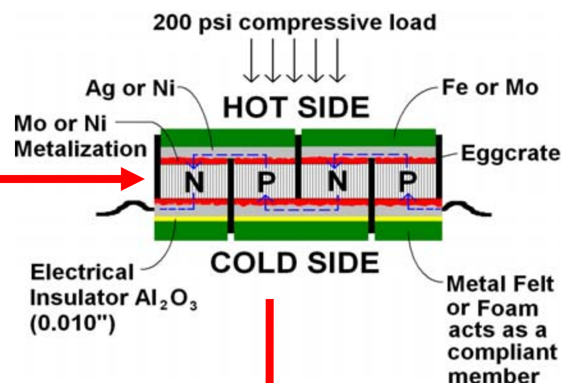


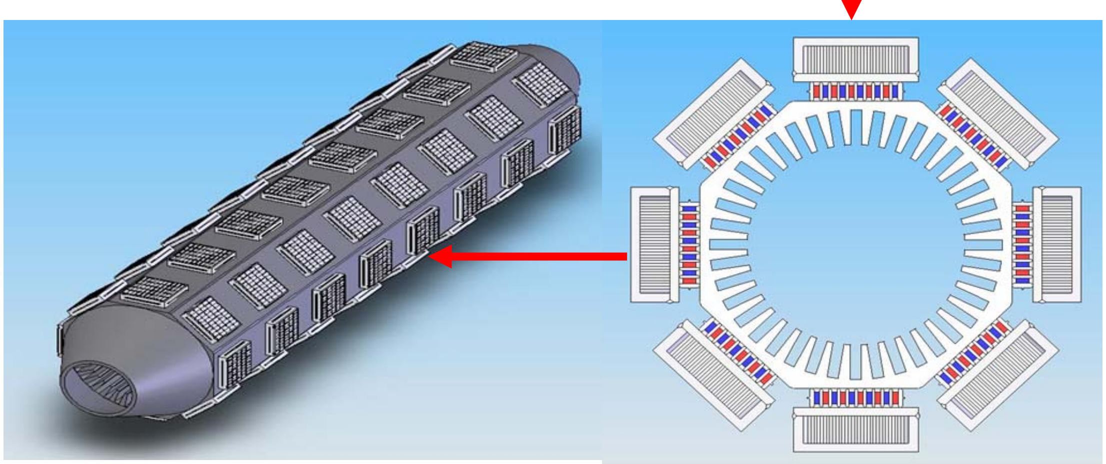
Quantum Well thermoelectrics provide larger (3X) efficiency over current Bi_2Te_3 alloys, and with N-type Si/SiC and P-type B_4C/B_9C exceed 50% of Carnot limit at higher temperatures.



Quantum Well of N type Si/SiGe and P type B_4C/B_9C couple has operated over 2500 hours with stable performance



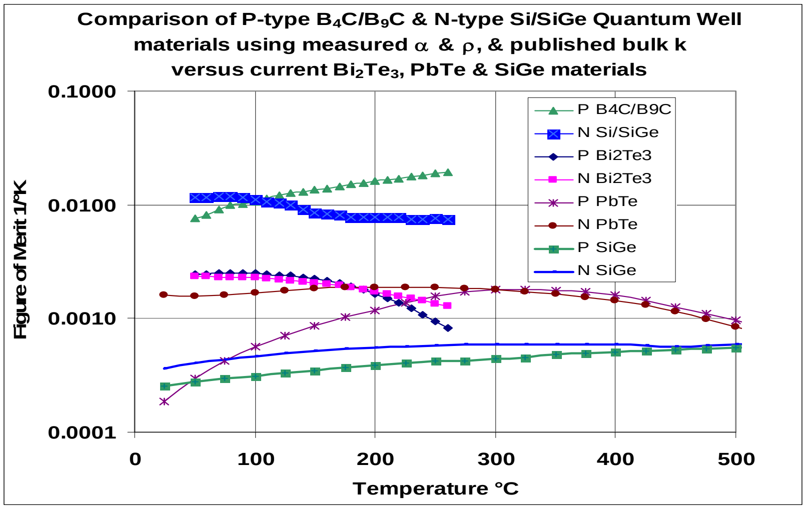




Quantum Well TE from Films to Module to Generator

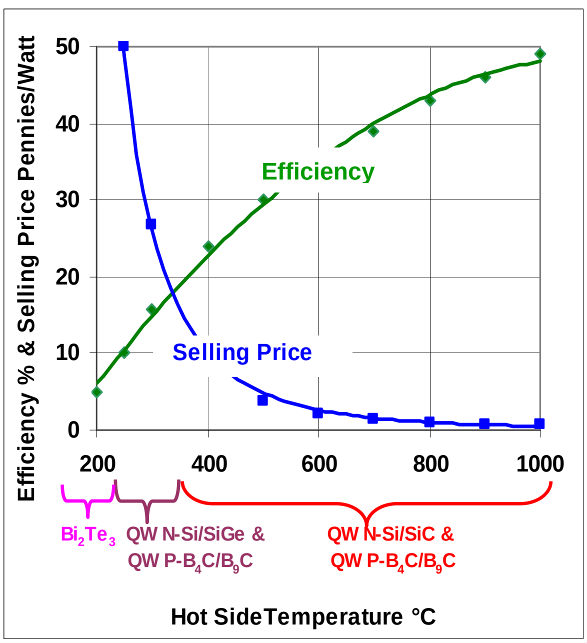
Hi-Z approach has films on substrate parallel to heat and electrical current flow to give higher Seebck voltage and thermoelectric figure of merit (efficiency). TE module contains films and forms building block of thermoelectric generator.

Quantum Well Materials are the Best Performing Thermoelectrics, Can be Fabricated With Automated Machines in U.S. and Have Low Raw Materials Cost That Will Lead to Very Low Selling Price per Watt



Highest Performing Thermoelectric Materials
Quantum Well thermoelectrics have significantly higher thermoelectric figure of merit than any other thermoelectric material and P-type boron carbide figure of merit is increasing with temperature

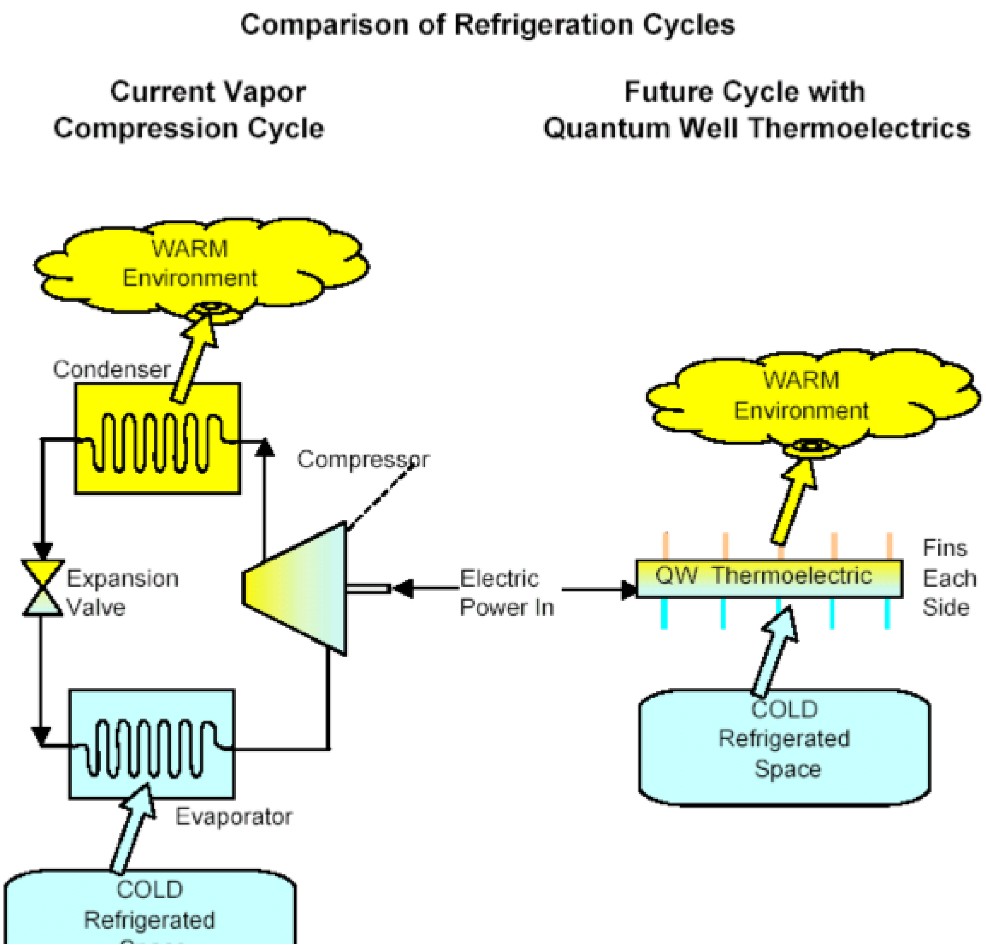
Automated Fabrication of Quantum Well Materials
New Quantum Well Sputtering Machine at Hi-Z
The new AJA batch coater has a 34 inch diameter chamber that processes up to six (6) 8-inch wafers or nine (9) 6-inch wafers to increase output by 100x



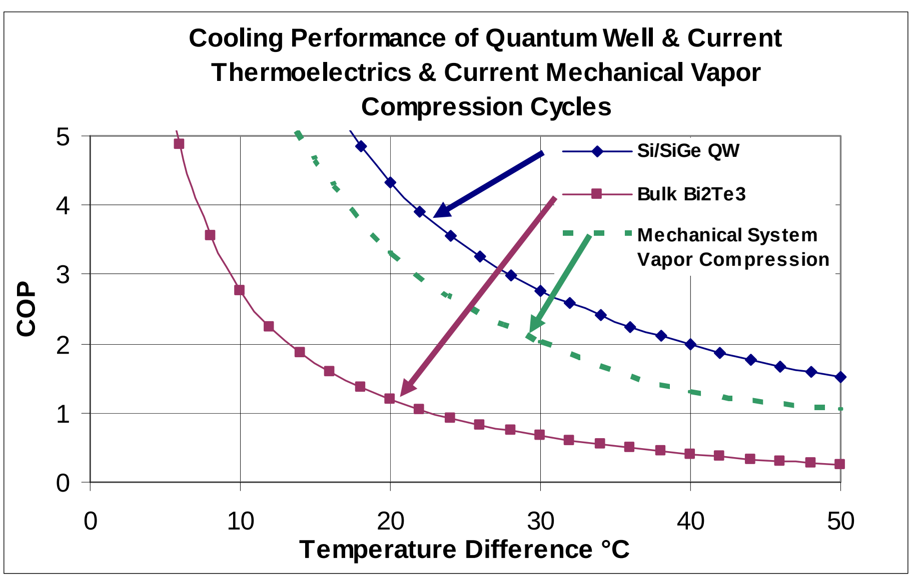
Selling Price per Watt will Compete With Mechanical Equipment
Quantum Well raw materials costs are >10X lower than current Bi_2Te_3 alloys. Results derived from DOE Phase I Study July 2005. Quantum well material engines will be able to replace gasoline and Diesel engines based on

- Efficiency
- Selling price

Cold side is 100°C



Quantum well thermoelectrics reduce complexity of current refrigeration cycle with no environmentally unsafe coolants and can be packaged for many geometries.



Quantum well thermoelectrics have large coefficient of performance that competes with mechanical vapor compression cycle.