Energy Harvesting

An EPSRC Funded Network

EPSRC

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Thermoelectric Energy Harvesting

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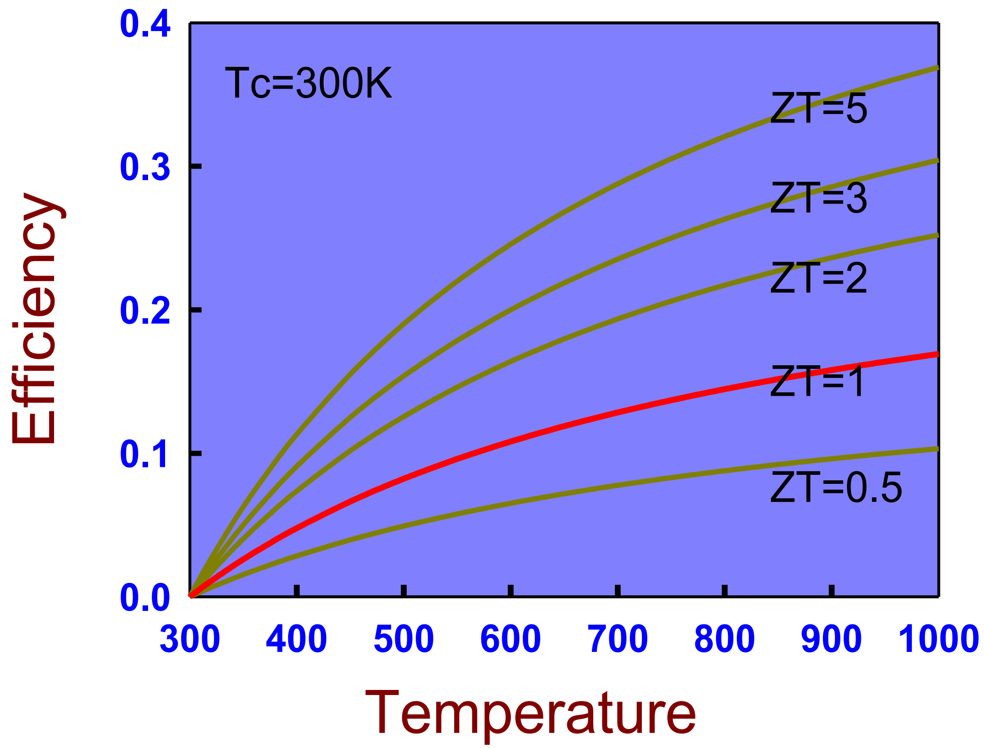
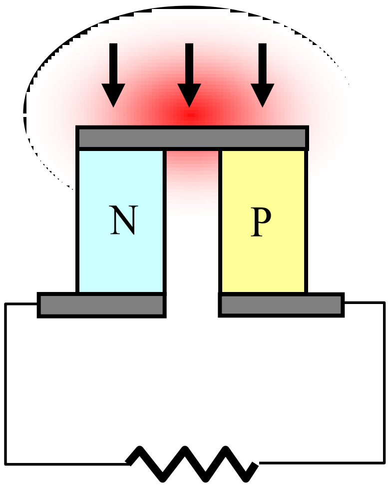
Outline

- Characteristics of Thermoelectric Devices
- Suitability for Energy Harvesting Application?
- Recent R&D efforts and Opportunities

Conversion Efficiency of Thermoelectrics



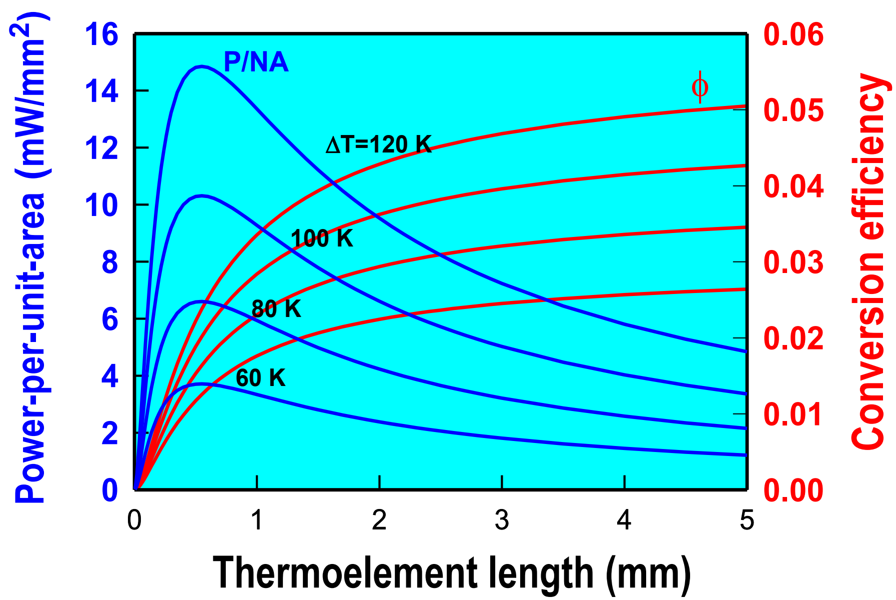


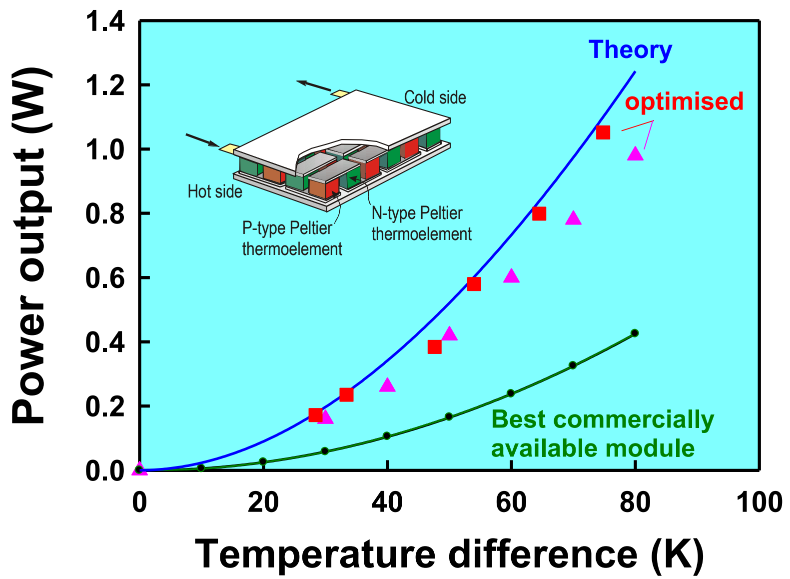
$$ZT = \frac{\alpha^2 \sigma T}{\lambda}$$

- The conversion efficiency is still *relatively low* compared with conventional (mechanical) heat engines.

- The most efficient materials are semiconductor alloys based on Bi_2Te_3 (300K), PbTe (550K) and SiGe (1100K).

Power Output and Optimization



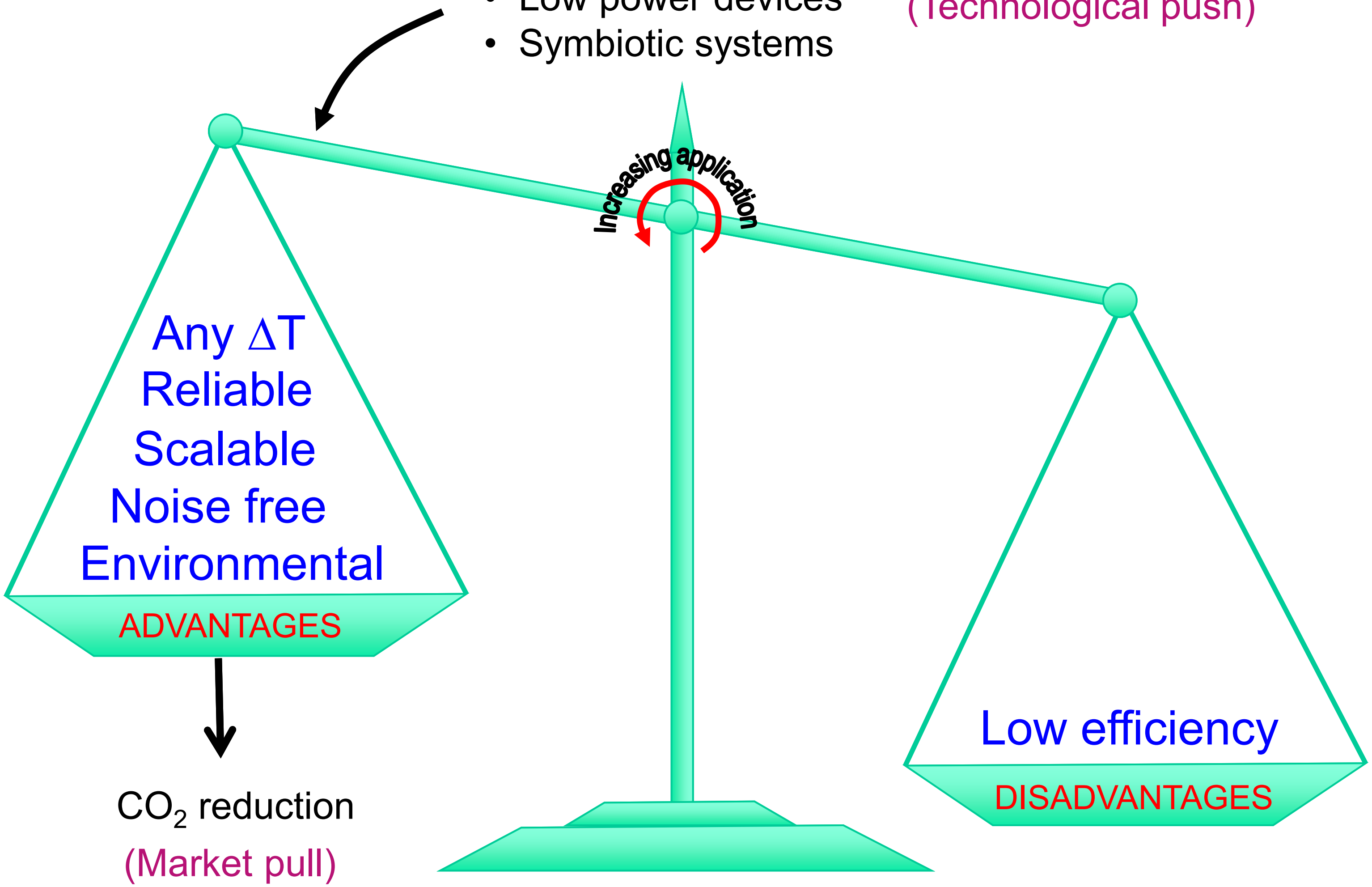


- Power-per-unit area can be improved (at expense of a slight reduction in conversion efficiency.
- 0.1 W/cm^2 has been achieved at ΔT=100K, resulting in a cost of £2/W
- 10 mW/mm^2 (i.e., 1 W/cm^2) may be achievable at ΔT=100K.

Is Thermoelectrics Economically Viable?

- Waste heat recovery
- Low power devices
- Symbiotic systems

(Technological push)

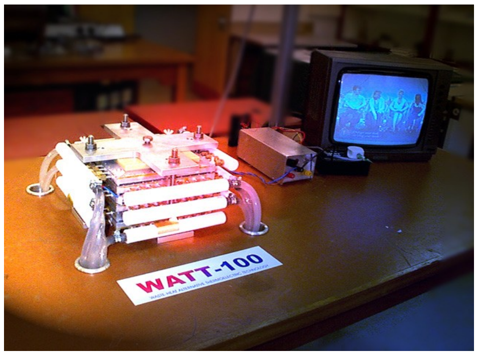


CO_2 reduction

(Market pull)

Thermoelectric Waste Heat Recovery

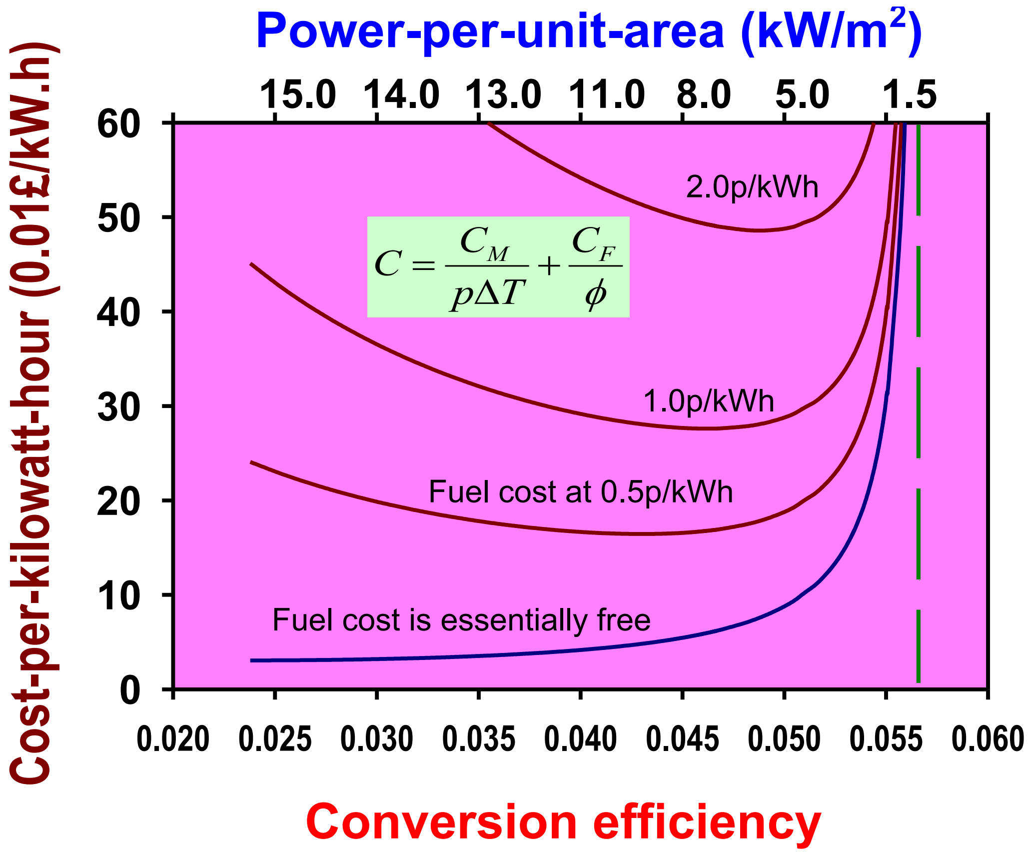
Hot Water TEG



T_h = 85 °C, T_c = 15 °C

P = 80W, η = 3.0%

Cardiff University, 1999



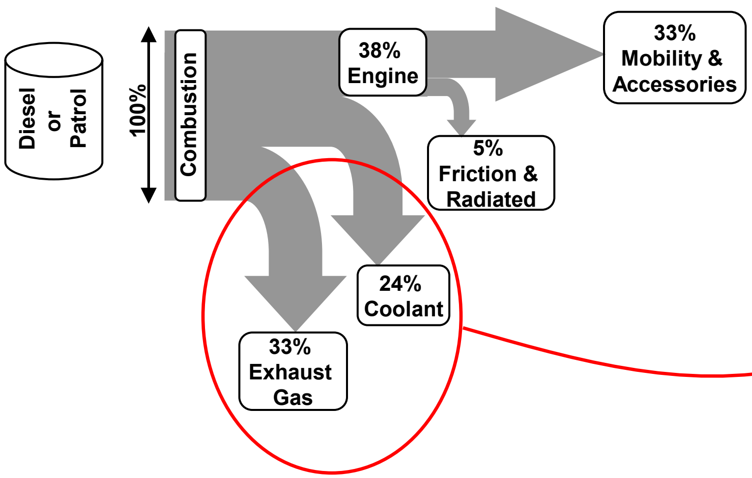
When thermal input is free, the system should be optimized to obtain a large power-per-unit-area (as long as sufficient heat dissipation can be achieved).

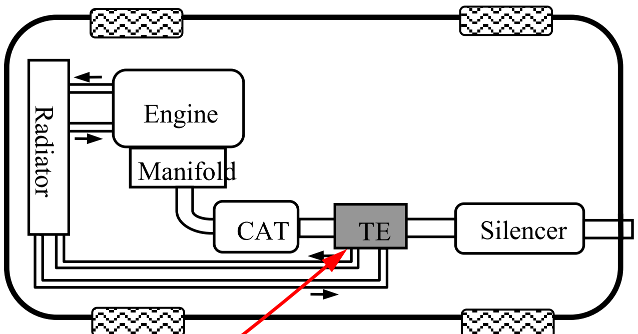
Theoretically, *£0.04/kWh* is achievable.

Demonstrating Fuel Economy Benefit of Exhaust Energy Recovery

Sept 2010 — March 2011

- TE materials — Herriot-Watt
- TE Modules — Cardiff
- System Integration — Loughborough





Current status:

$P_{max} < 200W$

$\eta_{max} < 5\ \%$

Desirables:

$P_{max} > 800W$

$\eta_{max} > 10\ \%$

http://www1.eere.energy.gov/vehiclesandfuels/pdfs/deer_2006/session6/2006_deer_fairbanks.pdf

World wide activities

- **BMW**, BSST, VISTEON, MARLOW, ,,,
- **GM**, GE, VIRGINIA TECH, ORNL, ,,,
- **NASA-JPL**, MICHIGAN, TELLUREX, ,,,
- **PRATT&WHITNEY**, UNITED TECH, .,,,
- **SIEMENS,** FIAT, BOSCH, IPM,...
- **CHALMERS,** ,KHT, VOLVO...
- **RENAULT**, VOLEO, NEXTER, ...
- **KOMATSU,** TOYATO, NISSAN, ,,,

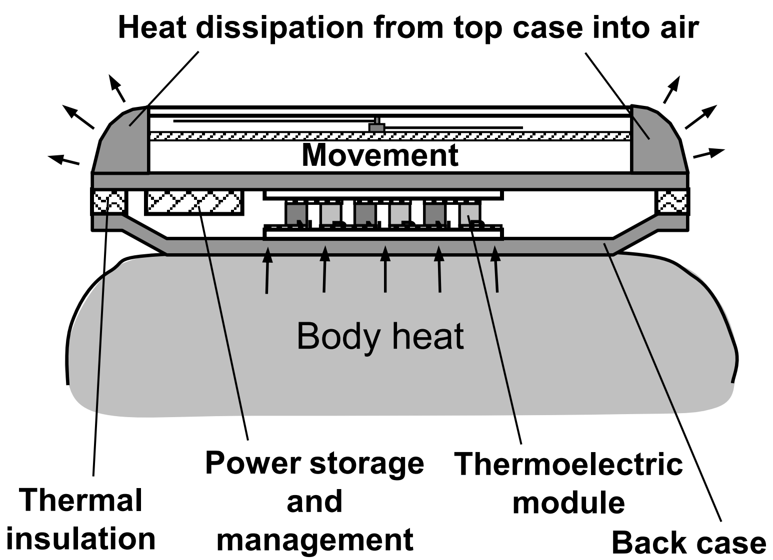
Energy Harvesting from Body Heat

Thermal energy from human body: ~ 6 mW/cm^2

Conversion efficiency at ΔT=5K: ~0.3% (not a problem!)

P ~ 20 μW/cm^2

Quartz Watches: ~40 μW



Seiko (45μW), Citzen (14μW)

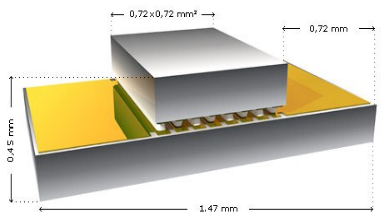
In order to obtain an operating voltage of 1.5 V, over 2000 pairs of Bi_2Te_3 thermocouples are required.

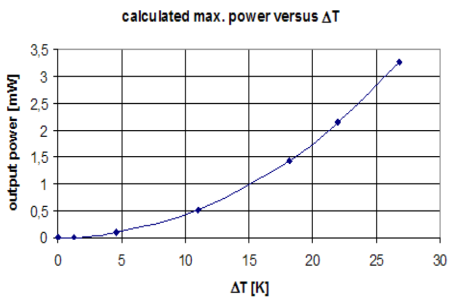
very costly using conventional module fabrication technology

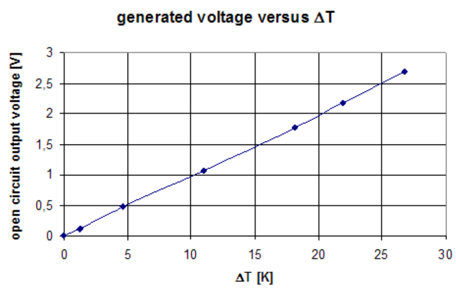
Energy Harvesting for Low Power Electronics

Recent progress: Modern wireless sensor modules require only ~100 μW

Micropelt

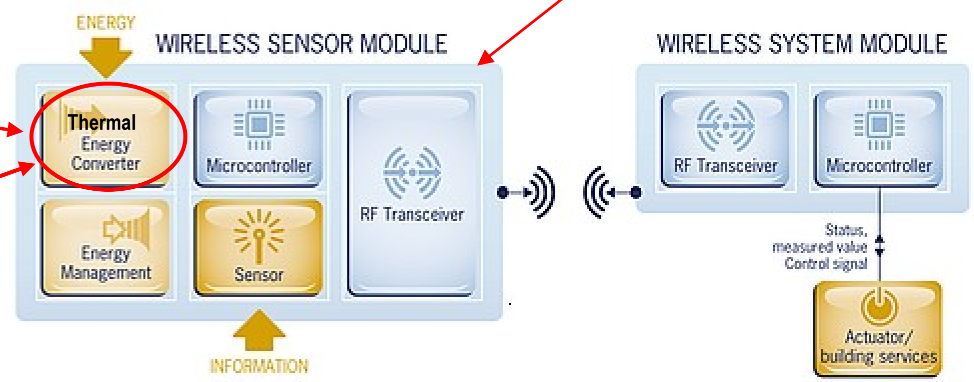






http://www.micropelt.com/

Voltage requirement: 3V

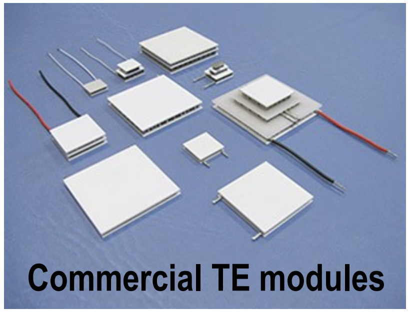


EnOcean

3 V

20 mV

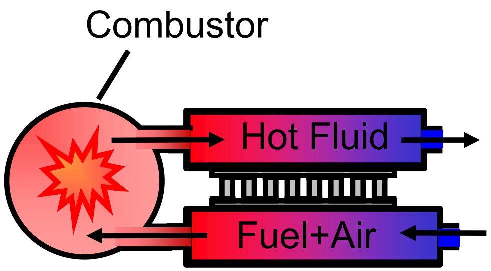
Ultra low power DC/DC converter



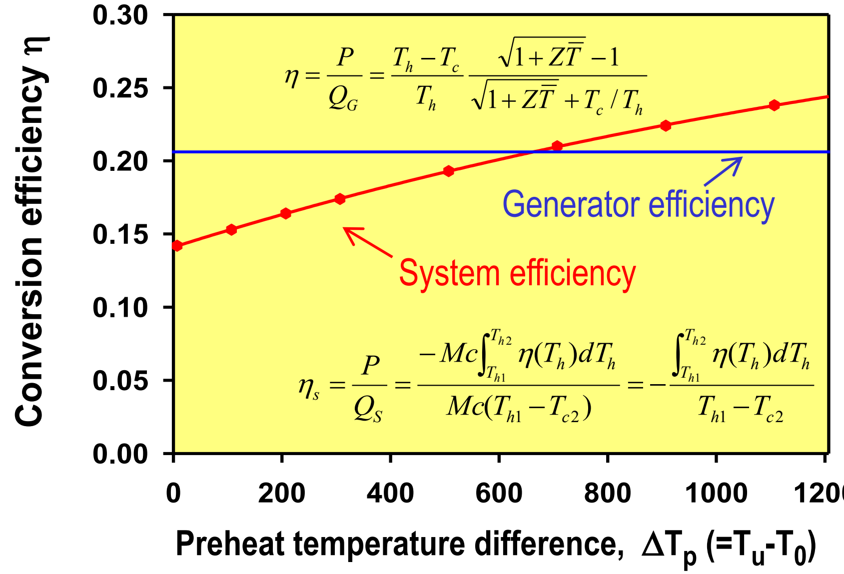
Commercial TE modules

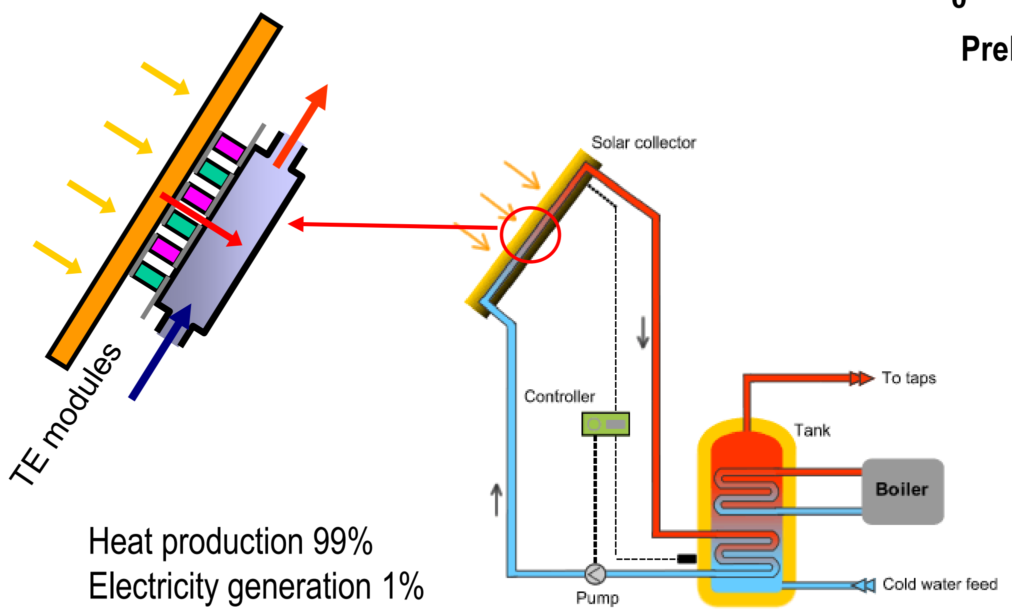
http://www.enocean.com/en/energy-harvesting-wireless/

Symbiotic Use (CHP) of Thermoelectrics for Pre-heating



- TE system efficiency increased;
- Fuel efficiency increased;
- Lean – fuel combustion possible





Heat production 99%
Electricity generation 1%

1kW heat system → 10W electric power for pump and controls – autonomous.

Thermoelectric Energy Harvesting Opportunities

Waste Heat Recovery

- Vehicle exhaust heat
- Geothermal heat
- Hot water from steel plant
- Incinerator
- Subsea oil wells

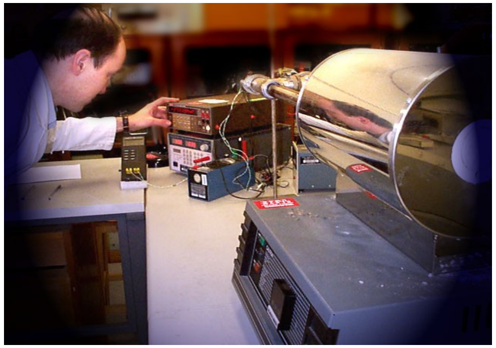
Low Power Electronics

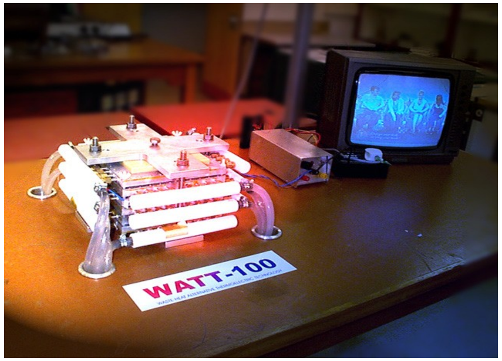
- Wireless sensors
- Medical sensors on Smart textile
- Aircraft health & safety monitoring

Symbiotic Systems (CHP)

- Solar water heating system
- Central heating system
- Biomass stoves
- Mosquito trap

Research Activities at Cardiff Thermoelectric Laboratory





Current Research Projects

- Nanostructured energy harvesting thermoelectrics based on $MgSi_2$ (*FP7*)
- Thermoelectric solar water heating systems (*Overseas funding*)
- Demonstrating fuel economy benefit of exhaust recovery (*EPSRC*)
- Self-powered mosquito trap based on thermoelectric harvesting (*KTP*)
- Preparation and characterization of Ti_xO_{1-x} thin films (*Overseas funding*)
- Heavy-fermion/superconductor tunneling refrigerator (*EPSRC*)
- Develop a novel ZT measurement technique (*Overseas funding*)

Preparation/Measurement Facilities

- Crystal growth / Hot-pressing / Mechanical-alloying
- Thermal co-evaporator for Bi2Te3 thin films
- PPMS for thermoelectric properties (2K-400K)
- Infrared Microscope for micro-scale thermal profile
- Seebeck-resistivity system (300K-800K)
- Laser flash thermal diffusivity system (300K-1000K)
- DSC 200 for specific heat (77K-650K, Natzsch)
- Hall coefficient system (300K-1000K)