European Thermodynamics Limited
Intelligent Thermal Management

Thermoelectric actions

By

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Energy Harvesting Network

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Overview

- Company Overview
- Introduction to Thermoelectrics
- Thermoelectrics in Energy Harvesting
- Thermoelectrics : Activities in R&D

- Automotive – Marine:	PD/MT
- RTGs -	ESA
- System level / test -	UoG
- Buildings	innovTEG
- Organic	h2esot
- New device production	KTP - UoC

- Summary

Company Overview

- established 2002
- based in Leicester, UK
- private ownership
- self-funded
- turnover 2012 ~ GBP£3.2m
- 12 staff
- UK SME company

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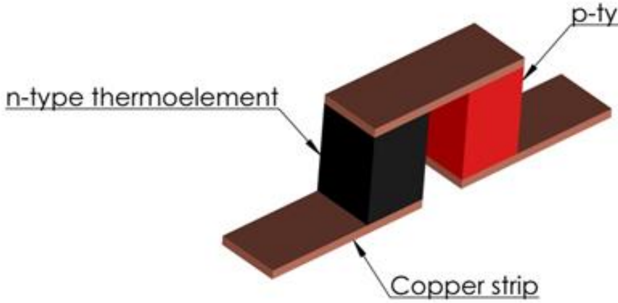
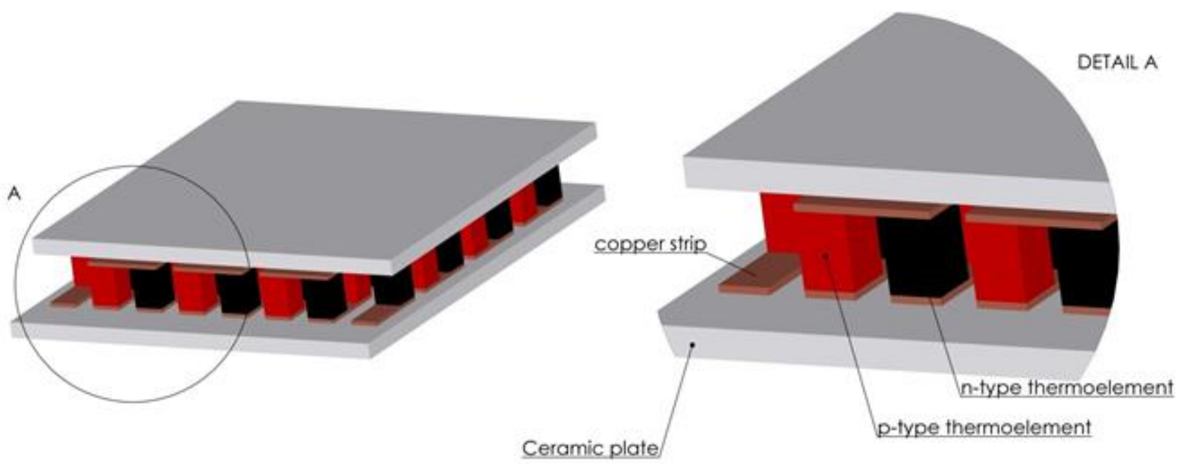
Introduction to Thermoelectrics

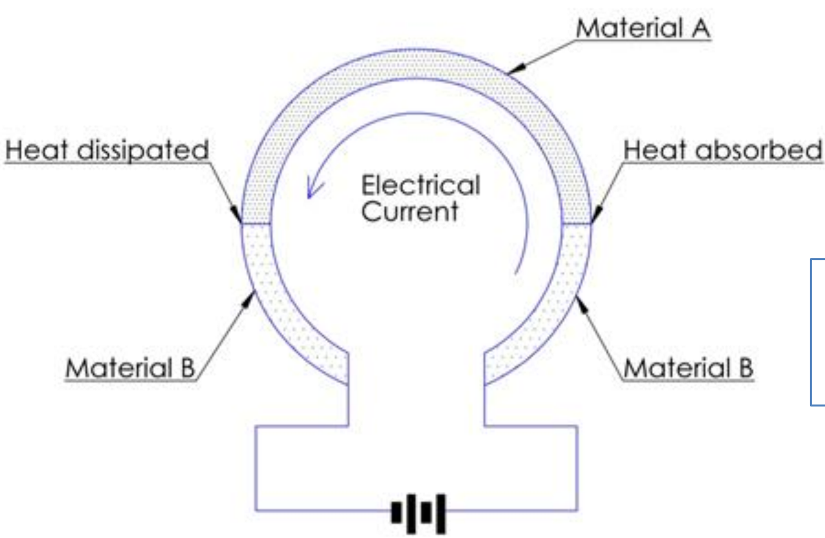
- Solid-state systems of specially tuned semiconductor materials.
- Thermocouple – The Basic Thermoelectric Unit.
- Two dissimilar metals, in electrical contact.
- Units arranged Electrically in series and Thermally in parallel.





Introduction to Thermoelectrics

- Most commonly used for cooling by the Peltier effect: Electronics, Lasers, Car Seats…
- Energy generation uses phenomenon called the Seebeck effect
- Performance comparisons made by dimensionless figure of merit, ZT
- BiTe couple has a peak ZT=1. Effective up to 250-300^{o}C.

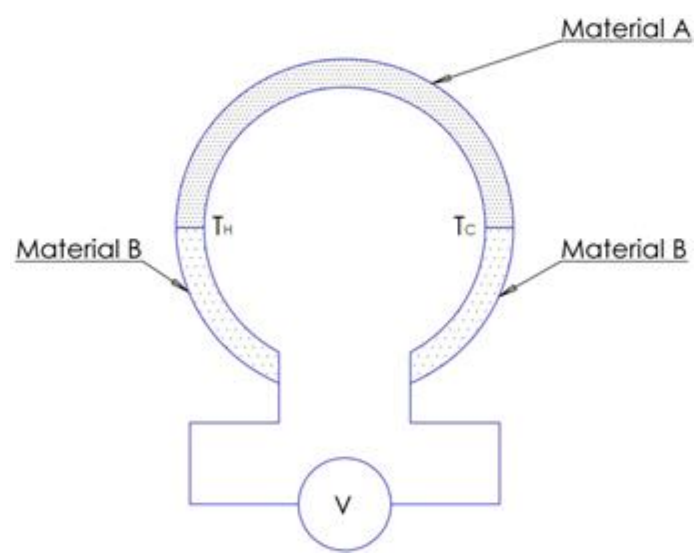


Seebeck Effect

$$V = \alpha_{AB} \cdot \Delta T$$

Figure of Merit

$$ZT = \frac{S^2 \sigma T}{(\kappa_L + \kappa_e)}$$



Thermoelectrics in Energy Harvesting

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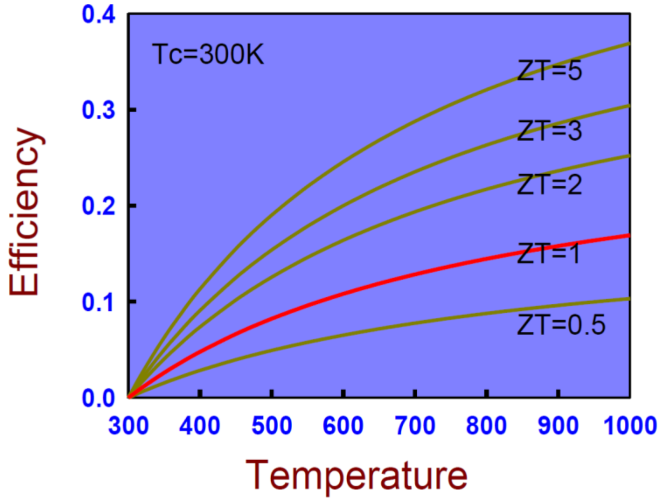
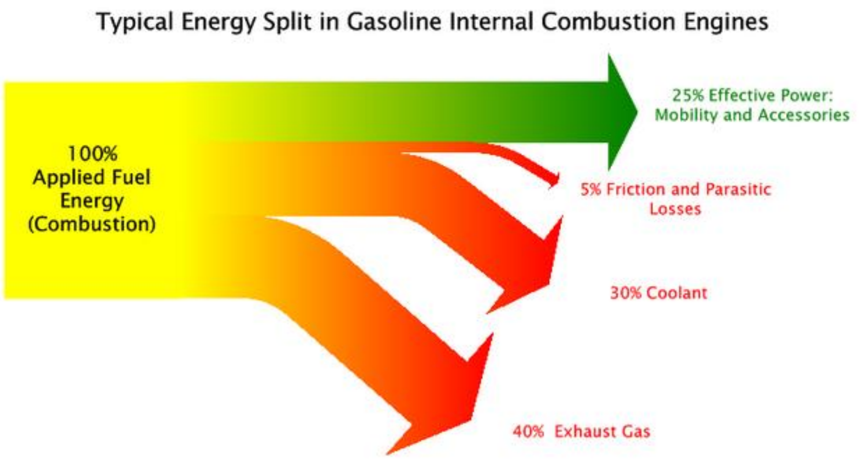
- Motivation:
  - Thermal energy is ubiquitous => Waste heat is also – opportunity.
  - Reliable.
  - Scalable.
  - Developing new materials that are more efficient across all temperatures and more robust for higher temperature ranges could see them used to power/increase efficiency of everyday processes.





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Thermoelectrics in Energy Harvesting

Automotive

- Efforts have been made by consortiums to harvest heat energy from the exhaust line and radiator.
- Aim is to improve vehicle efficiency by offloading alternator.
- Amerigon (now Gentherm) , BMW and Ford achieved 300W on car power.

Thermoelectrics in Energy Harvesting

Wireless EH

- Requirement for compact < 12x12mm
- Low cost, efficiency not prime
- Robust / Long life

•Prefer high voltage output / small delta T

•High density / high number of couples per unit area – low yield
•Traditional module manufacturing techniques – difficult / high ingot and cutting losses

• Typical volume materials cost for small device:
127 couple, 15x15mm – base cost
250degC power generation module 241 couple, 15x15mm – 2.5 x base cost

- High density low cost thermoelectric devices needed for uptake

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Thermoelectrics in Energy Harvesting

Remote Generation

- Heat energy can be converted to electrical power by combustion of fuels in a small portable generator.
- Biofuels – stoves, and biofuel systems, large opportunity for energy harvesting in remote or third world locations
- Global TE designed a power supply for remote sensing (PbTe)
- Developed from military design into terrestrial

ILLUSTRATION: BRYAN CHRISTIE

Thermoelectrics in Energy Harvesting

Remote Generation: Space

- Radioisotope Thermal Generators (RTG)
- Power supply lasts for decades
- Perfect for remote or inhospitable environments
- Space projects have used thermoelectrics for powering of missions since 60s. Harvesting thermal energy from the radioactive material
- Extensive research carried out into PbTe and SiGe for Plutonium based
- Future – Terrestrial applications, powering remote sensors in down-well

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Thermoelectrics in Energy Harvesting

Industrial: Smelting, Power Stations, Incinerators.

- Covers both high temperature and low temperature energy harvesting.
- Furnaces emit a large amount of thermal energy. Harvesting energy from processes will increase efficiency.
- Water from power stations 30-80C unusable. Utilising these heat gradients could lead to even higher efficiencies of power plants.


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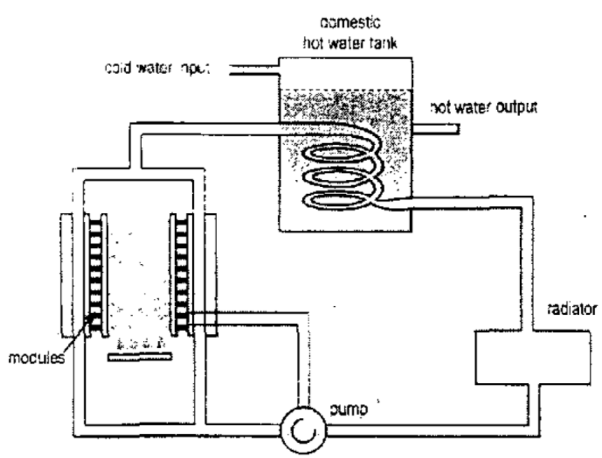
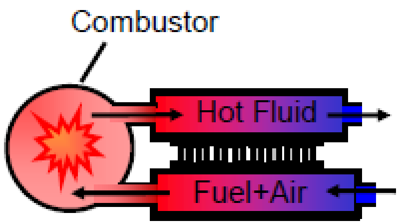
Thermoelectrics in Energy Harvesting

Symbiotic

- Use of a thermoelectric generator as a dual function device i.e. heat exchanger/generator.
- Thermoelectric central heating system. Only needs fuel supply.
- Geo-lab monitors weather at north pole. TE system can produce power for sensors and act as exchanger to heat cabin for electronics.
- Combustor, pre heating of fuel-air mix and generation of power.





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

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R&D Activities – PDMT

Automotive - Marine

POWERDRIVER www.powerdriver.info

- Achieve in excess of 300W on car power. Target 5% improvement.
- Develop novel, environmentally friendly, thermoelectric materials that have optimal working temperatures consistent with the vehicle exhaust gas temperatures.
- Demonstrate on 2L Jaguar XF GTDi. Marine simulation to 5MW engine

Queen Mary University of London
Ben-Gurion University of the Negev
אוניברסיטת בן-גוריון בנגב
dts Exhaust and fuel systems
European Thermodynamics Limited Intelligent Thermal Management
FCT Systeme GmbH FCT Group
Halyard
JAGUAR
thermex Advanced Cooling Technology
RICARDO
intrinsiq materials
tecnalia Inspiring Business
Rolls-Royce

SEVENTH FRAMEWORK PROGRAMME

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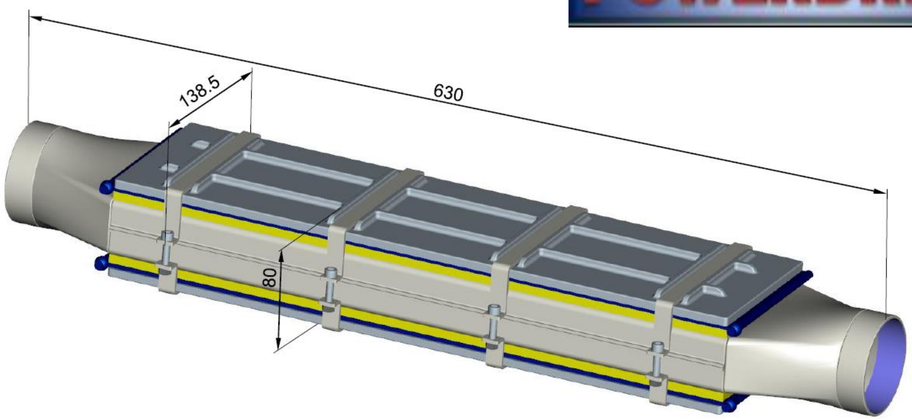
R&D Activities - PDMT

Automotive - Marine

POWERDRIVER

- Thermo-Electric-Generator - Dimension

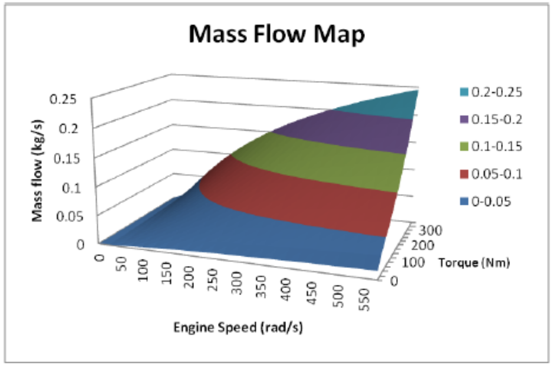


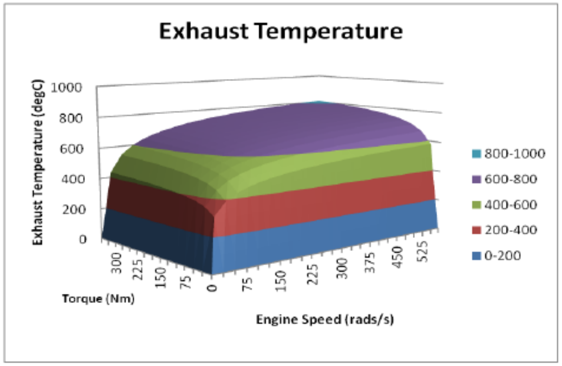
JAGUAR

Halyard

Rolls-Royce

- Temperature and Mass Flow Maps





SEVENTH FRAMEWORK PROGRAMME

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R&D Activities - PDMT

- TE Materials assessment for diesel temperatures in power conversion
- Standard conditions used, optimum pellet arrangement
- Reference: note BiTe solution 0.22 Euros/W (not shown)
- Target additional TEG weight <10kg
- Typical FE savings for NEDC:

(10% TEG eff): 600W ~ 3% , 300W : ~ 2.5%
(5% TEG eff): 600W ~ 1.8% , 300W : ~ 1.5%

Couple Ref	Euro/Watt	Ranking
N01/P01	0.37	5
N01/PO2	0.63	7
N01/P03	0.22	2
N02/P01	0.55	6
N02/P02	1.14	9
N02/P03	0.37	4
N05/P01	0.32	3
N05/P02	0.63	8
N05/P03	0.05	1

Material selection based on LME raw material cost only

SEVENTH FRAMEWORK PROGRAMME

R&D Activities - RTG

Context:

UK Participants in ESA RTG Breadboard Programme

R&D Activities - RTG

Study Objectives

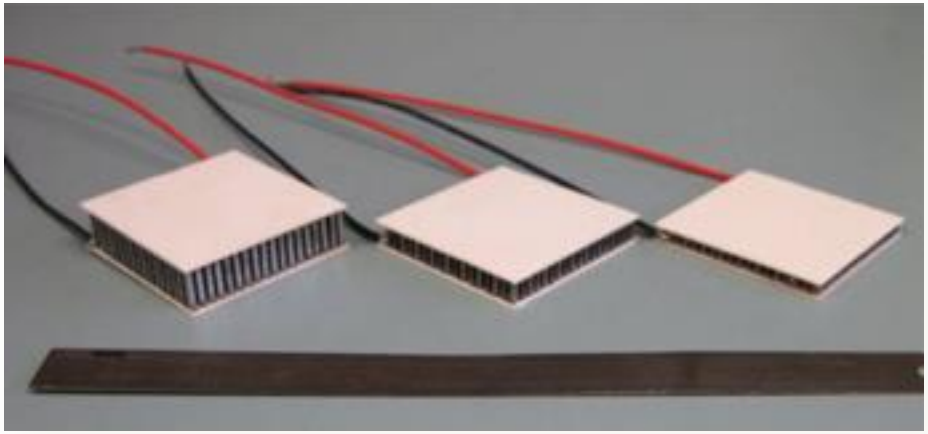
- Develop an initial RTG design for a European RTG development activity.
  - Very low power to 50 W electric for Am-241 based system.
- RTG system for deep space and planetary mission environments.
  - Scalable power output and modular heat source design
- Etl / QMU / UoL address challenges with system arrangement for TEs
- Focus on basic technologies "off the shelf" with emphasis on improving commercial production processes and methods

R&D Activities - RTG

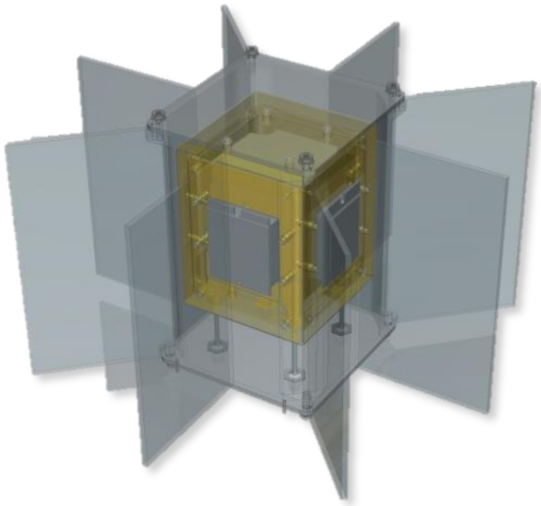
Current Activities

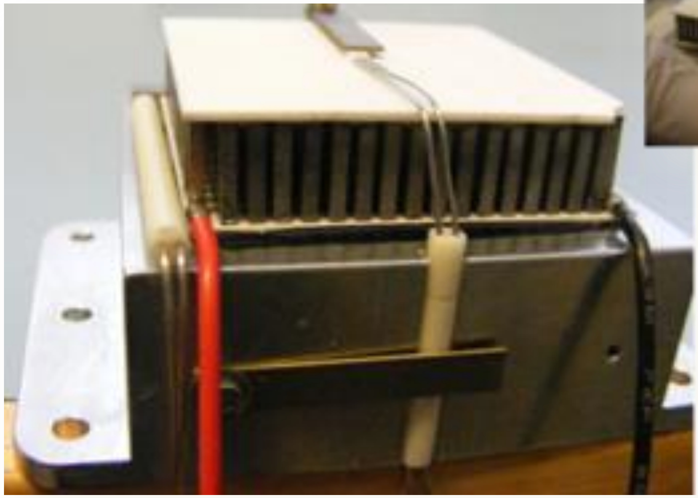
- Prototype RTG system 4%-5%, implying a >5% TEG efficiency.
- System thermal efficiency of 80%.
- Incremental changes to materials for improved performance
- Higher aspect ratio TEGs achieved with Bi_2Te_3 materials
- Improvement in the mechanical properties of Bi_2Te_3
- Exploring the options to improve the thermoelectric properties of Bi_2Te_3 over range of operating temperatures.

R&D Activities - RTG



- BiTe custom devices
- Standard jigs and typical volume methods used.
- “Off-the-shelf” solution





R&D Activities – System level

TEG System and Characterisation

- Collaboration with Professor Andrew Knox , Systems Power and Energy Research – University of Glasgow

  - Thermoelectric characterisation and rig design
  - MPPT electronics development for TSB VIPER
  - Electronics System Architecture research (PD/MT)
  - ‘Adaptive Plant’ project – offer in TSB EH round
  - Combined P&O and extreme seeking Algorithm development, inc Coventry University and ETL

TEG Test Rig

Mechanical Fixture

Water Cooling

Computer Control

Electronic Instruments

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R&D Activities - Buildings

Energy from Buildings: innovTEG www.innovteg.com

- Objective: To produce an innovative very low-cost thermoelectric technology for large-scale renewable solar energy applications.

- Aim is to tailor this material for specific high impact solar thermal harvesting system for construction and built environment (Buildings as power plants), however to become a viable replacement for BiTe for low temperature harvesting and cooling applications.

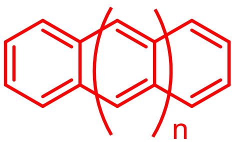
- BiTe approx material cost £70/kg replaced with material cost less than £10/kg

- Sustainable, abundant material replacement

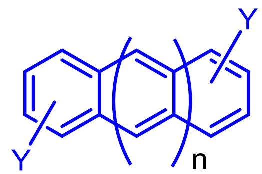
h2esot - Waste Heat to Electrical Energy *via* Sustainable Organic Thermoelectric Devices

Concept

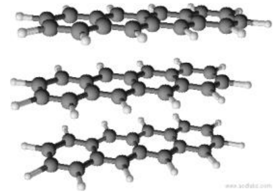
Renewable resources



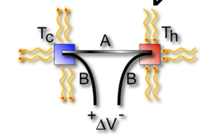
Poly-Acenes



Substituted Poly-Acenes



Crystal Engineering New Organic Materials



Thermoelectric Devices (energy generation)

Scientific Goals	Highly efficient synthesis (readily available starting materials)	purification, deposition	optimisation, characterisation undestanding	device fabrication testing/users
Disciplines required	CHEMISTRY	EXPERIMENTAL PHYSICS	MATERIALS SCIENCE	THEORETICAL PHYSICS / ELECTRONICS

6 Partners, 243 person-months effort, million € 1.26

European Thermodynamics and Universities of Nottingham, Würzburg, Latvia, Moldova, and the Bulgarian Academy of Sciences

More details needed...... www. h2esot.com

....developing additional synergistic links to UK academia & industry

R&D Activities – Organic TE

H2ESOT www.h2esot.com

- Objective: to develop various technologies required for low cost organic thermoelectric devices for low grade heat
- Multi-disciplinary action bringing together considerable resource in a small 3 year FP7 funded FET project.
- Timely, as 2011 nobel prize winner centred around quasi crystals, is one of the core themes of this FET project.
- Led by Professor Simon Woodward, Nottingham University - Chemistry

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R&D Activities – KTPs

KTP-European Thermodynamics & Cardiff University

- Working with Cardiff thermoelectric research group led by Dr.Gao Min.
- Developing mid-high temperature thermoelectric devices.
- Research into materials, joining technology, encapsulation and processes for manufacturing.
- Establish new device manufacturing and production, supporting R&D growth

Knowledge Transfer Partnerships

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

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Summary

- Bismuth Telluride – commercially difficult to displace
  - Energy Harvesting still seems most viable (material cost/abundance for thin film)
  - Higher temperature materials for harvesting – potentially oxides

- Higher performing materials required to displace PbTe (mid-temp region)
- Low cost / scalable replacement to BiTe needed (supporting various studentships)

- Efficiency is not high, but technology proven

- Great importance in developing this technology with high potential, at material, modular and system level.

- Thermoelectric Community in UK is fragmented – need to bring industrial and academic partners together, wide scope for novel technology

- Building 'critical research mass' in organic materials - crucial

- Need to utilise high volume techniques – low labour content to grow and retain jobs

Highly supportive of Prof Paul's microfabrication activities in low-D materials