Thermoelectrics Applications Workshop

Del Coronado Hotel
San Diego, CA
September 29-October 2, 2009

An Overview of Thermoelectric Waste Heat Recovery Activities in Europe

Mike Rowe

School of Engineering Cardiff University

European Sources of Research Funding

- **European Community**

  Seventh Framework Programme of the European Community

  Total budget EURO 50,521 million, divided among specific programmes. Cooperation programme is EUR 32,413 million.

  The present call FT7 is the first to include thermoelectrics. Typical project budget within the call is EUR 4.5-5.0 million for a 40 month duration project.

- **National**

  Consortia lead by industrial motor manufacturer such as Volvo, Renault etc. typical budget EUR 20 million per annum. National government research awards such as UK Science Research Council maximum EUR 3-4million up to 60 month duration.

- **Local Enterprises**

  Joint university /city/ local company projects typically EUR 50,000-200,000 over one to two years

European funded project 2008-2011

HeatReCar

Waste heat recovery in Light Duty Trucks

OBJECTIVE

- **"Design a thermoelectric generator (TEG) that can be installed in a combustion engine vehicle and produce 3 kW electrical power under full load conditions and 1-2 kW under partial load conditions.“**

PARTICIPANTS

- **Siemens AG – Germany**
- **ROM Innovation – France**
- **Centro Ricerche FIAT – Italy**
- **Robert Bosch GmbH – Germany**
- **Fraunhofer IPM – Germany**
- **Valeo – France**
- **Termo-Gen AB – Sweden**

Budget 4-5 Million Euros ($ 5.7-7.1M)

AWHR in Sweden

Foundation for Strategic Environmental Research MISTRA-E4
E4-Mistra is a joint research initiative between academic and industrial partners:
2006-2009 (20M annually)

Partners

- Chalmers University of Technology
- Royal Institute of Technology
- Uppsala University
- Höganäs AB
- Termo-Gen AB
- Volvo Technology AB

Application in a light truck. Two different concepts towards developing new efficient high and low temperature thermoelectric materials

Phonon-glass-electron-crystal (PGEC)---------germanium based Clathrates

Nanostructured bismuth telluride

French Regional Cluster Project

The RENOTER project, coordinated by Renault Trucks, is a French Cluster Project involving several regions

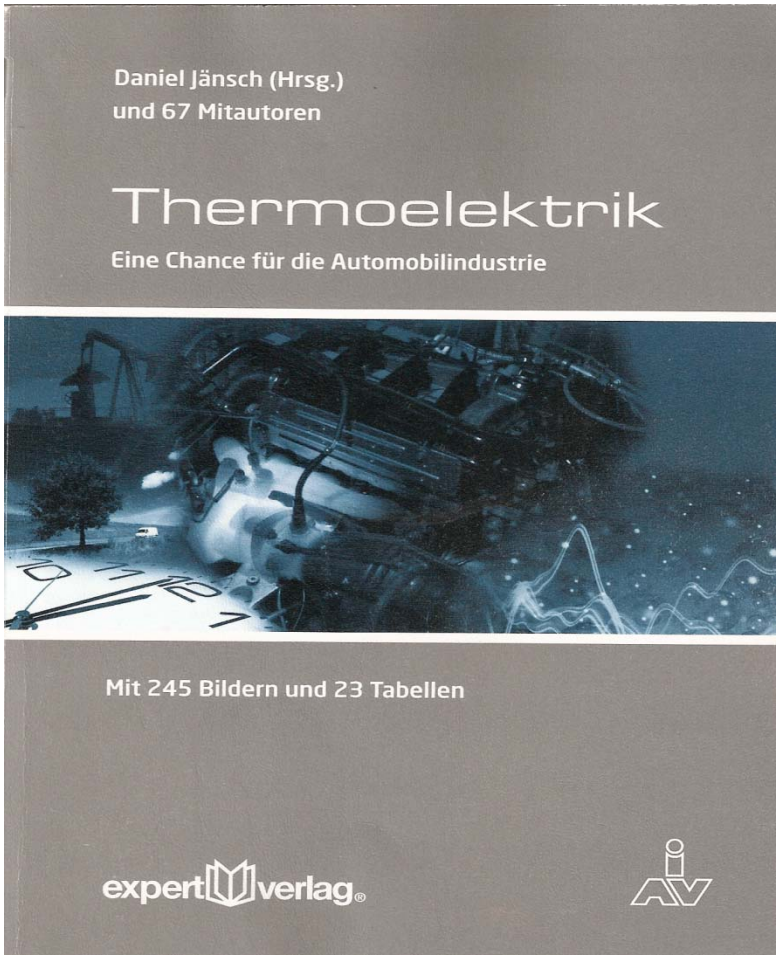
The project aim is to apply thermoelectrics to thermal engines (trucks, cars and military vehicles) in order to reduce their fuel consumption

Generator production is due to be launched in 2014.

participants

- **Renault Trucks,**
- **Renault,**
- **Valeo,(Volvo France)**
- **Nexter System,**
- **Sherpa Engineering**
- **CRISMAT,**
- **LPM (Nancy Material Physics Laboratory)**
- **UM2 (University of Montpellier).**

‘Thermoelectrics an Opportunity for the Automobile Industry’



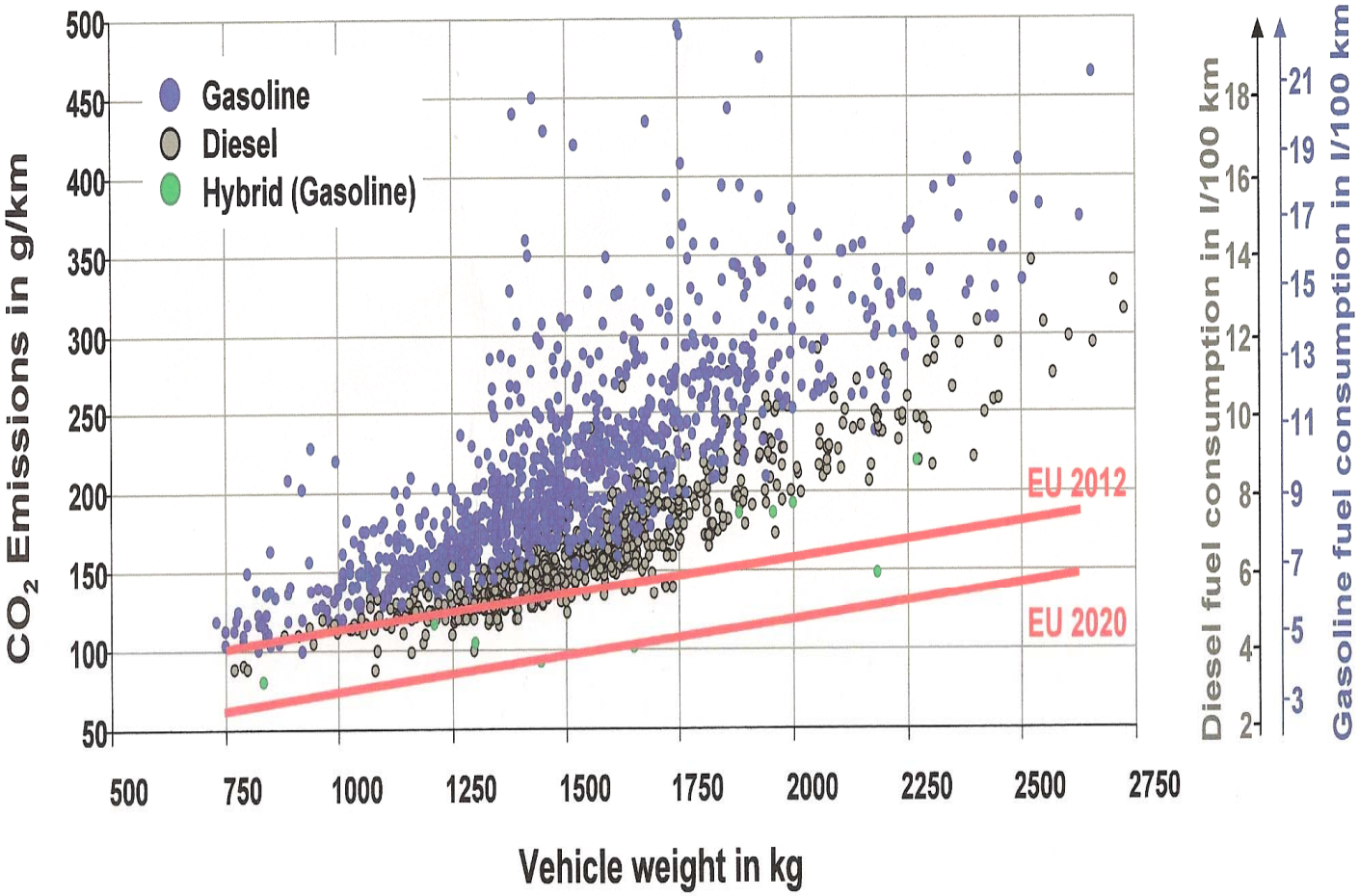
*A conference devoted entirely to automobile thermoelectrics

*Attended by almost 250 Scientists and Industrialists

* 23 scientific presentations

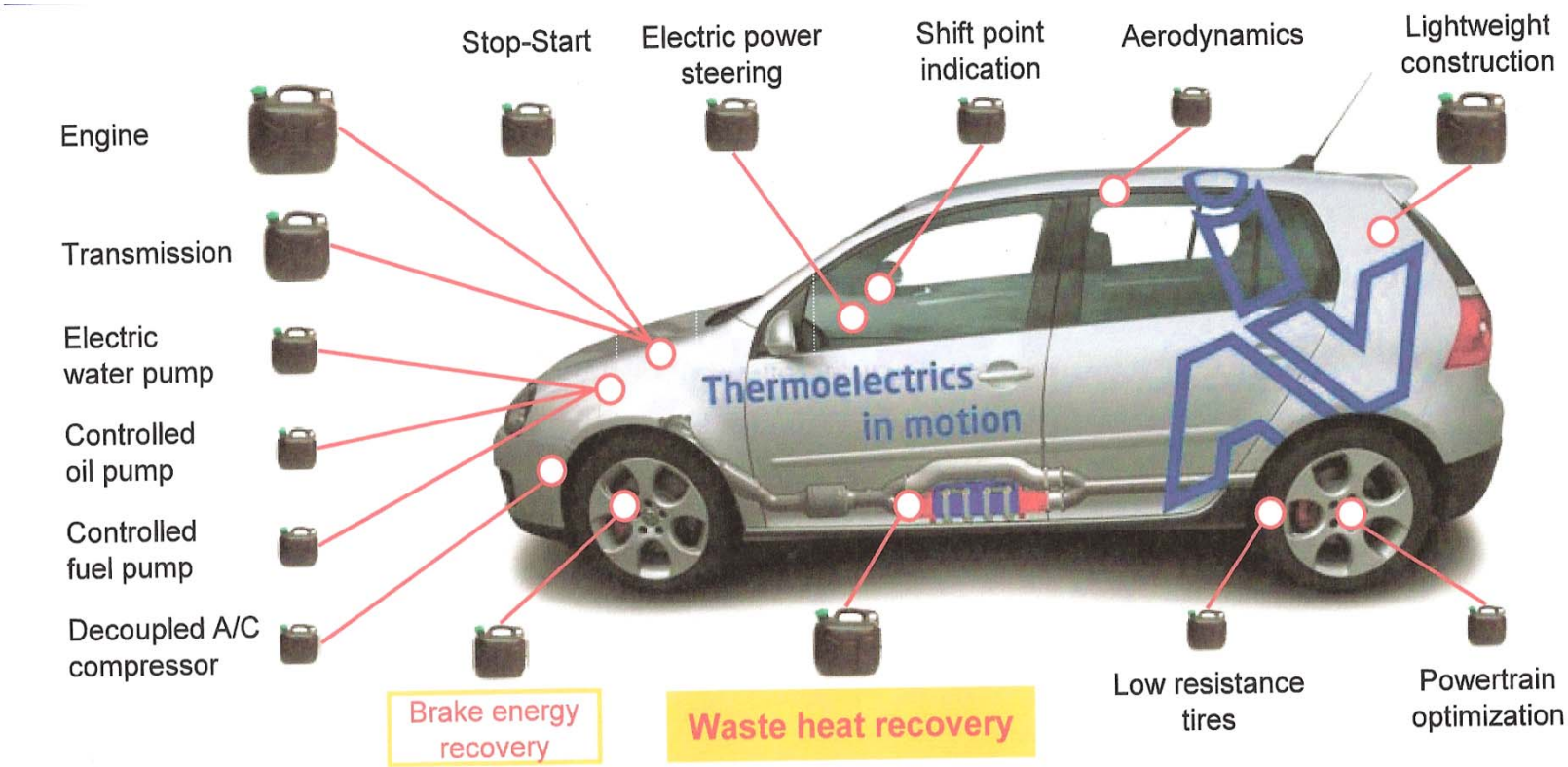
*Two automobile demonstrations

Challenges to meet CO_2 emissions legislation



Potential areas to reduce CO_2 emissions

- Thermoelectrics is one of many measures to reduce CO2 emissions



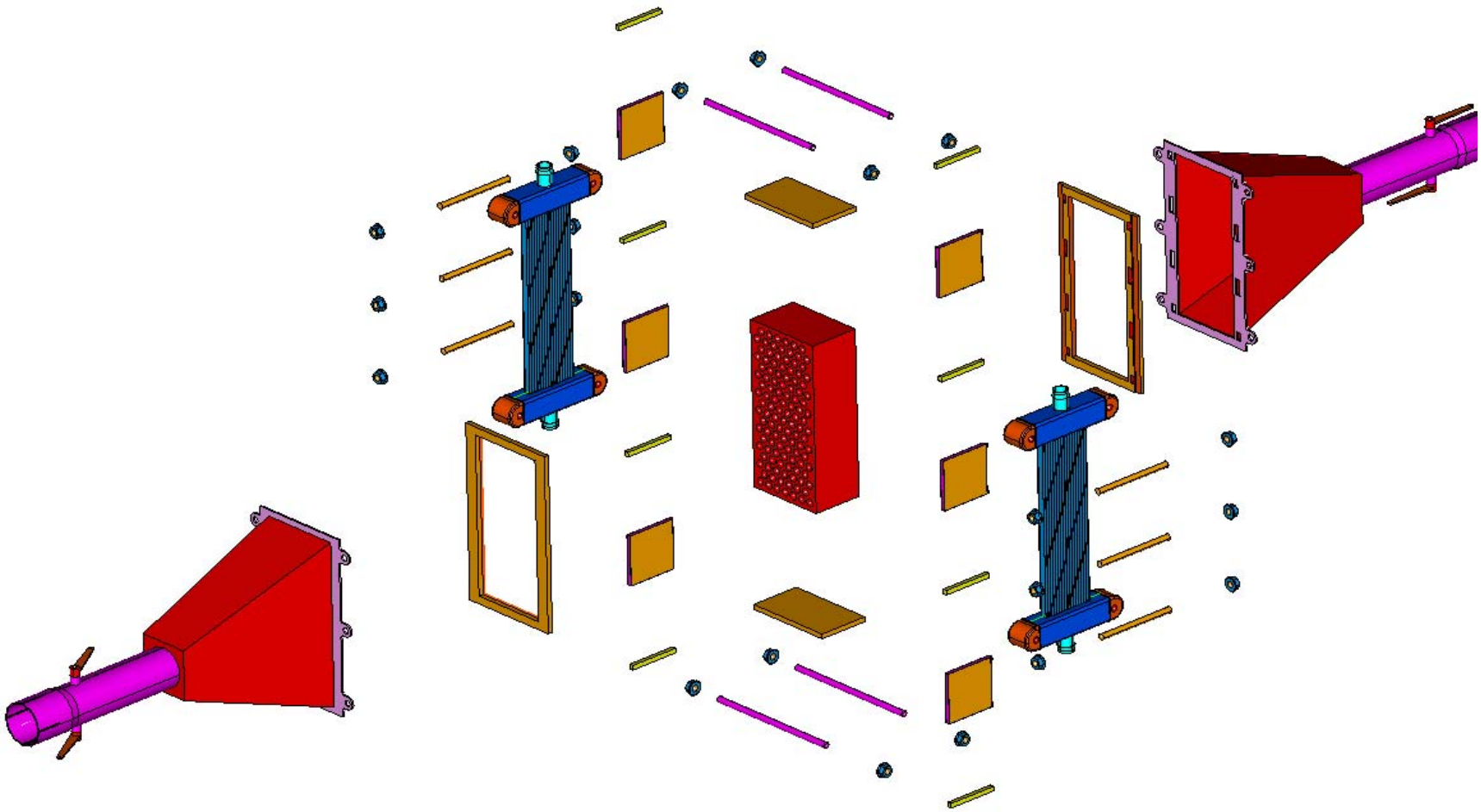
Automobile Thermoelectric Generator (ATG) Demonstrations

Two vehicles with TGs attached at the meeting

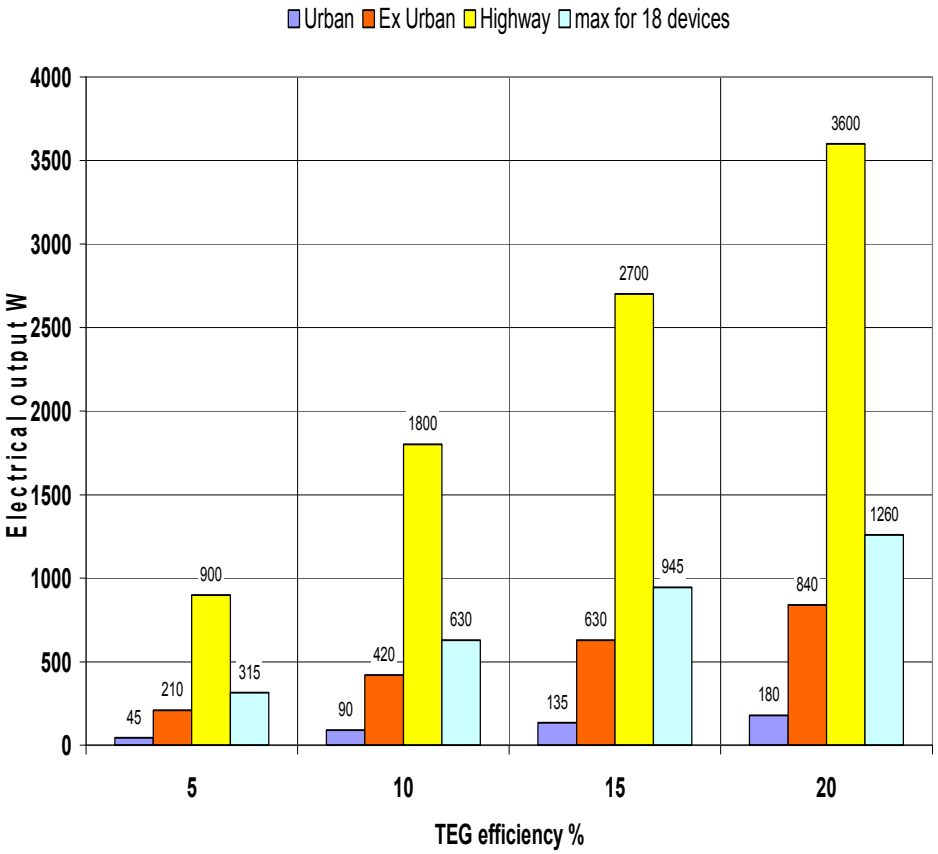
* BMW. This was operational with an electrical output of 200W(e). More than 12000km had been clocked up on highway driving . Conference attendees were able to book a test drive at the meeting.

* Volkswagen. This was a demonstration vehicle being presented by the conference organisers AIV and was not shown operating although a mock-up displayed the thermoelectric generating principles.

Exploded view of bench test design



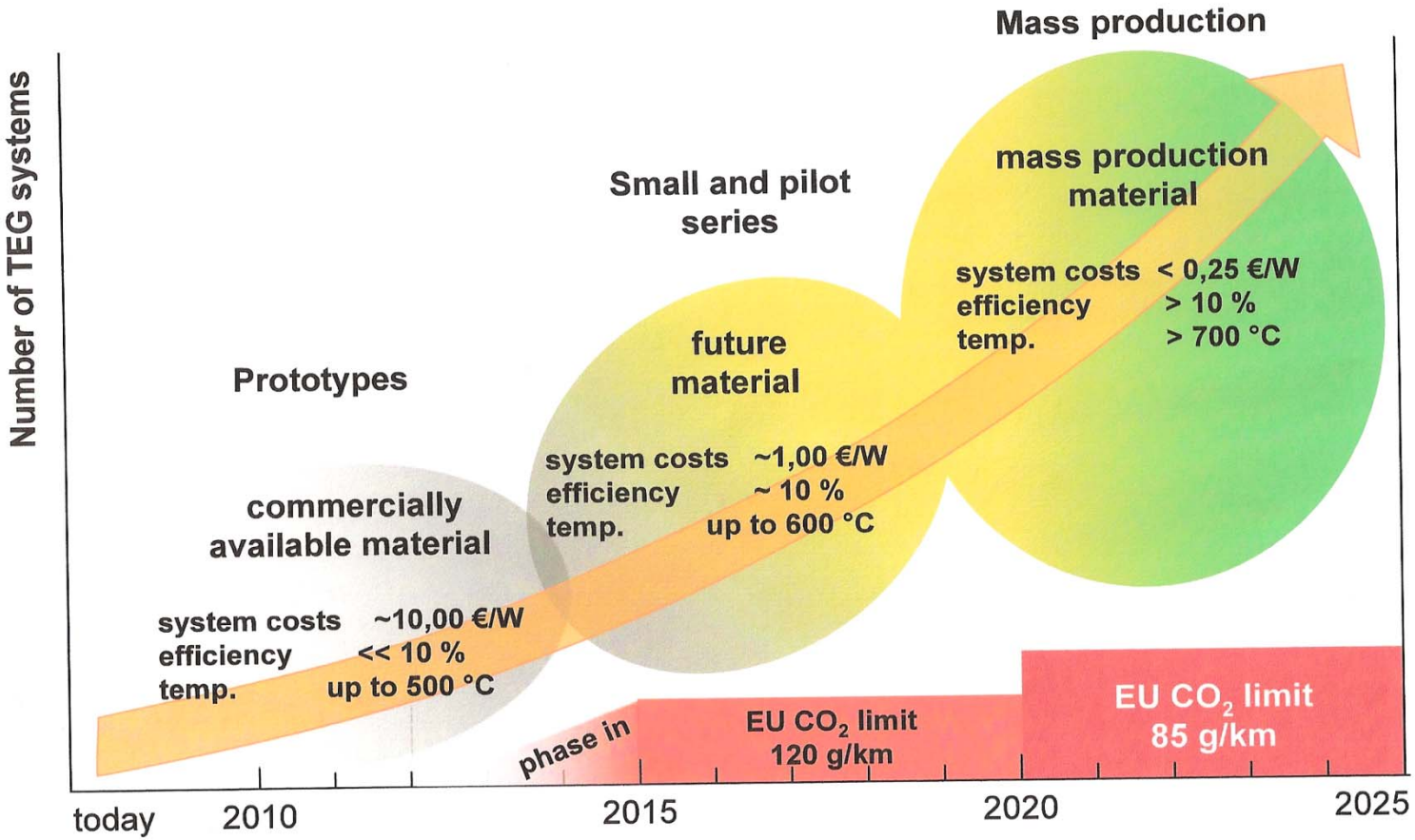
The electrical output achieved under different driving conditions



Power required to compensate generator weight.

The generator's weight imposes a load equivalent to around 12W/kgm on the engine Assuming the device weighs 10kgm. This plus the weight of the pump requires that around 200W must be generated before showing a fuel consumption benefit.

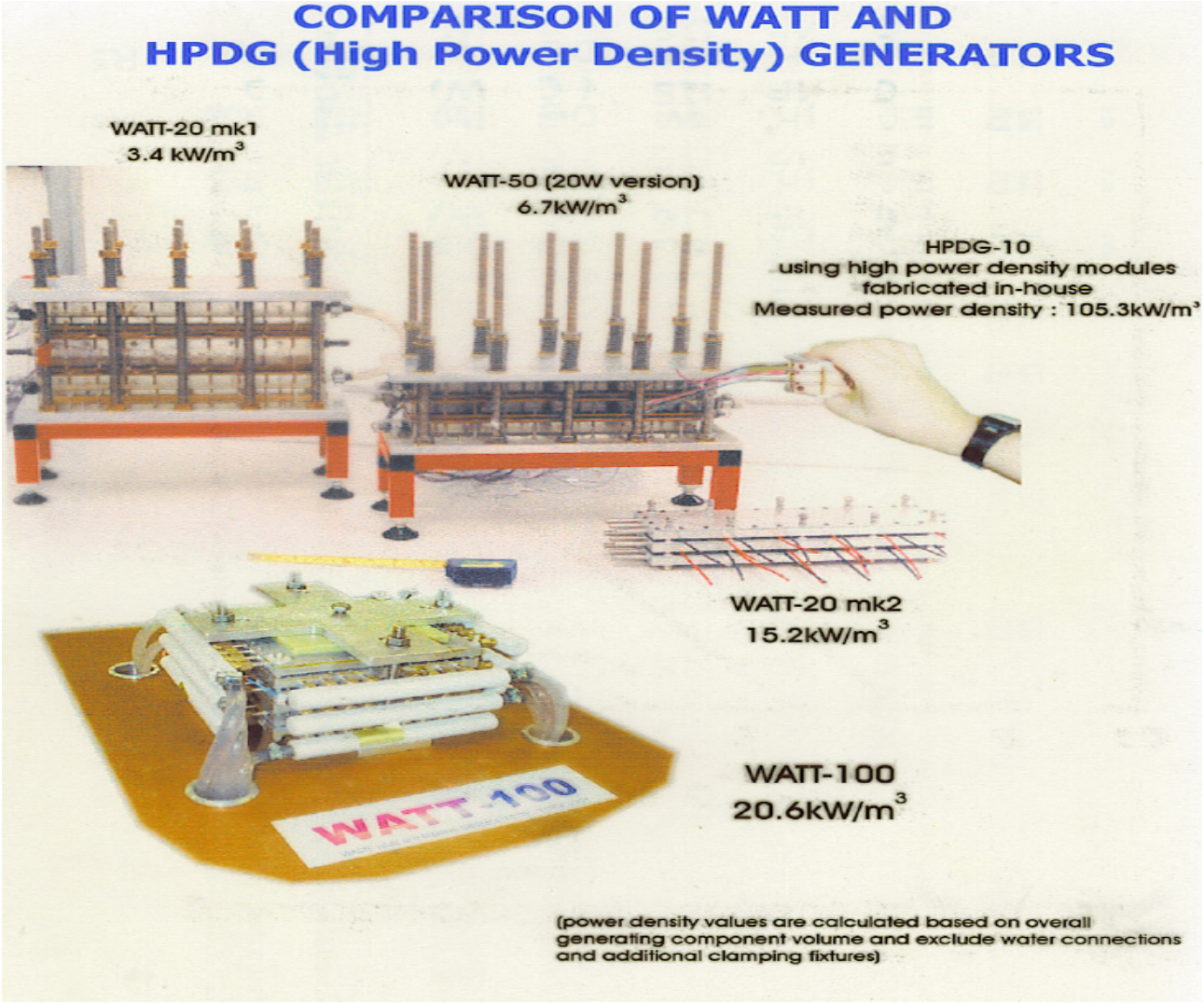
Market Requirements Roadmap for TEG Systems



Low temperature waste heat recovery

- 1993 Cardiff/Osaka project to use thermoelectrics to generate hydrogen gas using waste warm water.
- Led to demonstration of 100W(e) low temperature waste heat recovery technology at Kyoto Summit on global warming
- Redundant oil wells-collaboration with Norwegian Institute for Energy Technology
- Steel plants-collaboration with ARCELOR-MITTAL Spain

Development stages of a 100W(e) high power density waste heat recovery thermoelectric generator

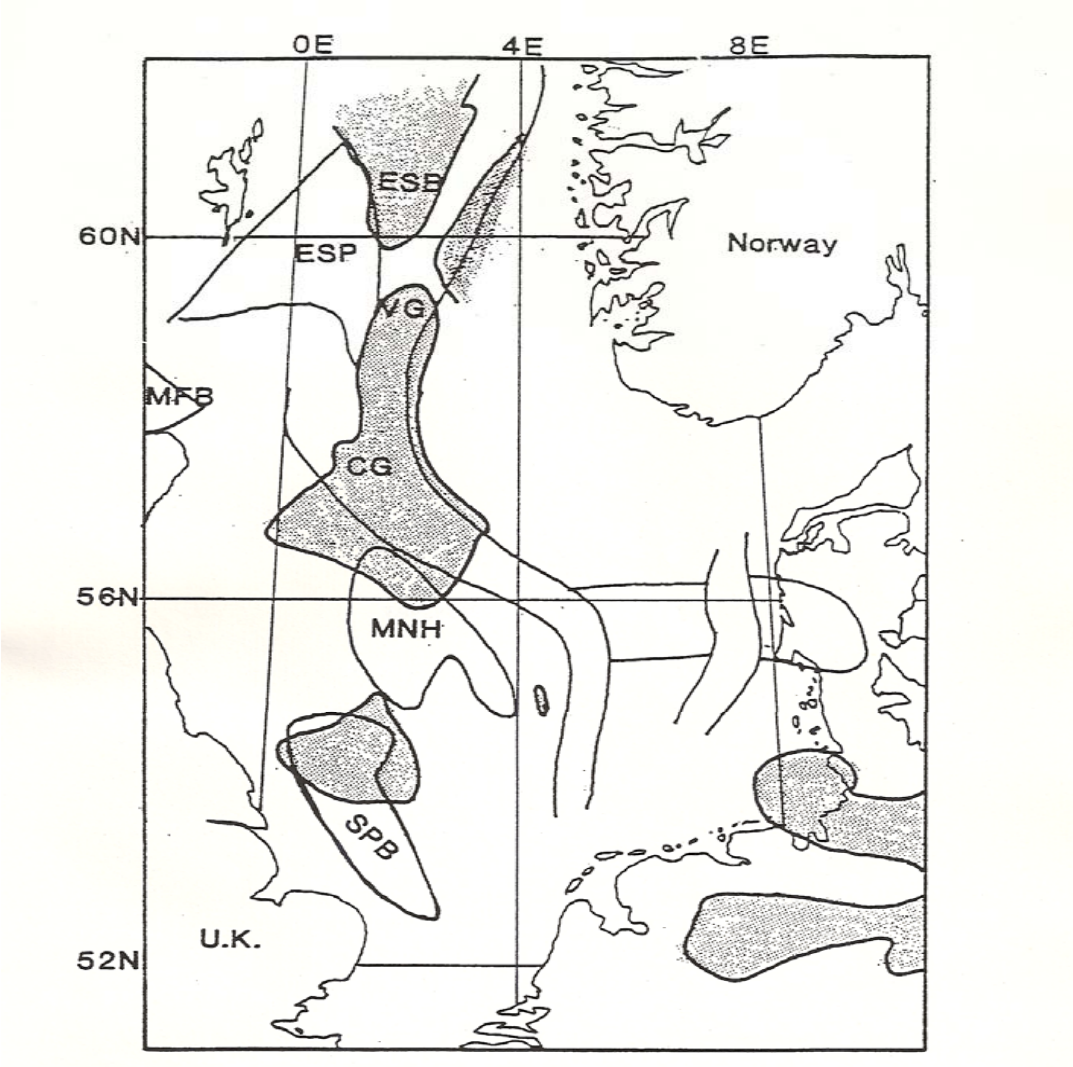


Typical North sea oil platform162 units to be decommissioned

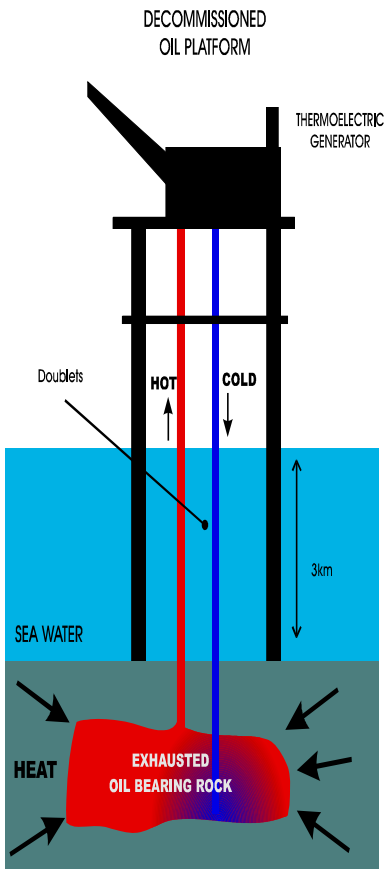
Advantages of Marine Geothermal Thermoelectric Generation

- Constant supply of heat
- Potentially endless energy available
- Contained in a large heat reservoir
- Existing heat extraction facilities
- Control over heat flow
- Choice of heat source temperatures

Shaded areas rock temperature of 200C at less than 6km.



Schematic North Sea Oil Platform



Doublet flow 4000 litres a minute
Hot water at>80C, cold at <10C
Power generated 10MW(e) per platform.
Transmission cost to mainland problematic

Continuous casting modern steel strip mill

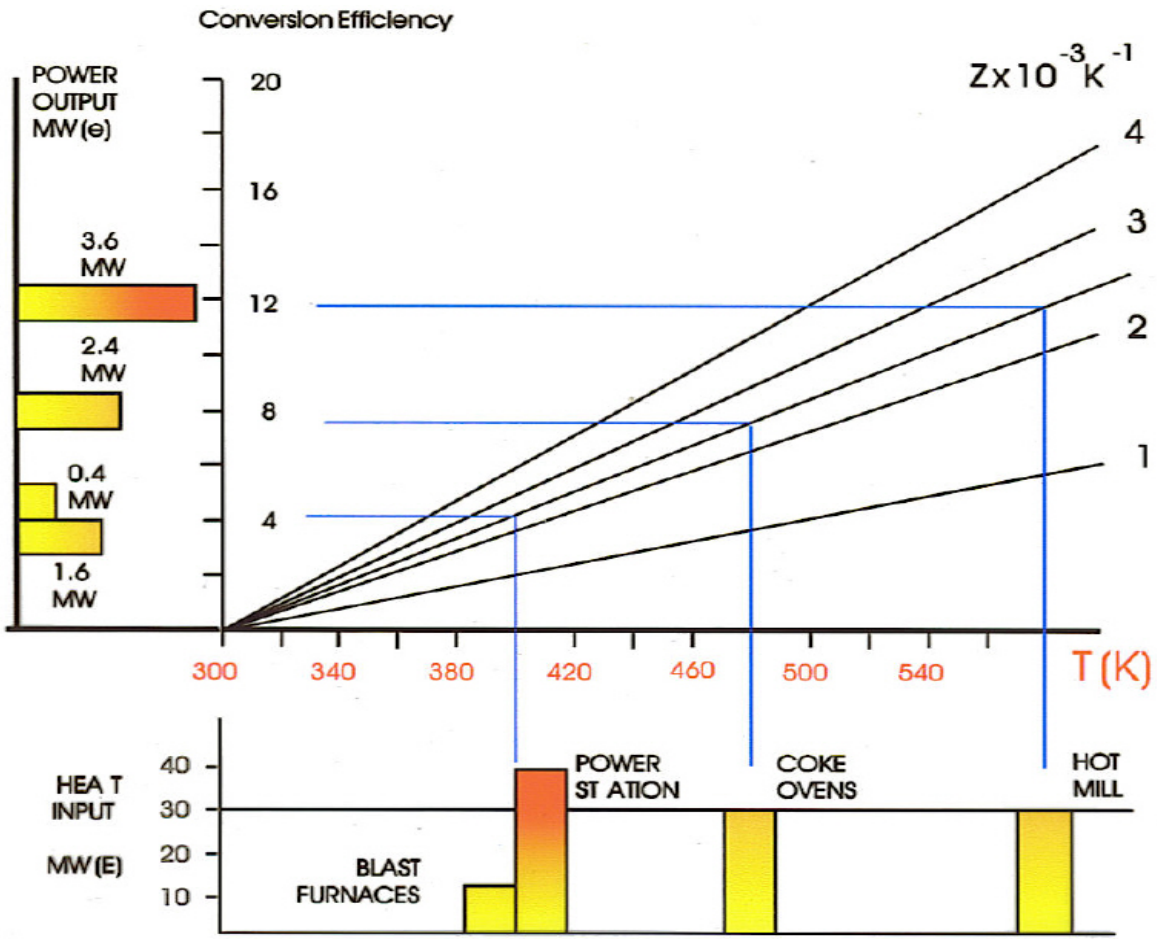
Heat Recovery From small Steel Plant

- Constant supply of warm water at 90C
- Hot mill 3.6 MW(e)
- Coke ovens 2.4 MW(e)
- Power station 0.4 MW(e)
- Blast furnace 1.6 MW(e)
- Location of thermoelectric generator before cooling towers potentially provides around 8MW(e) on- site power

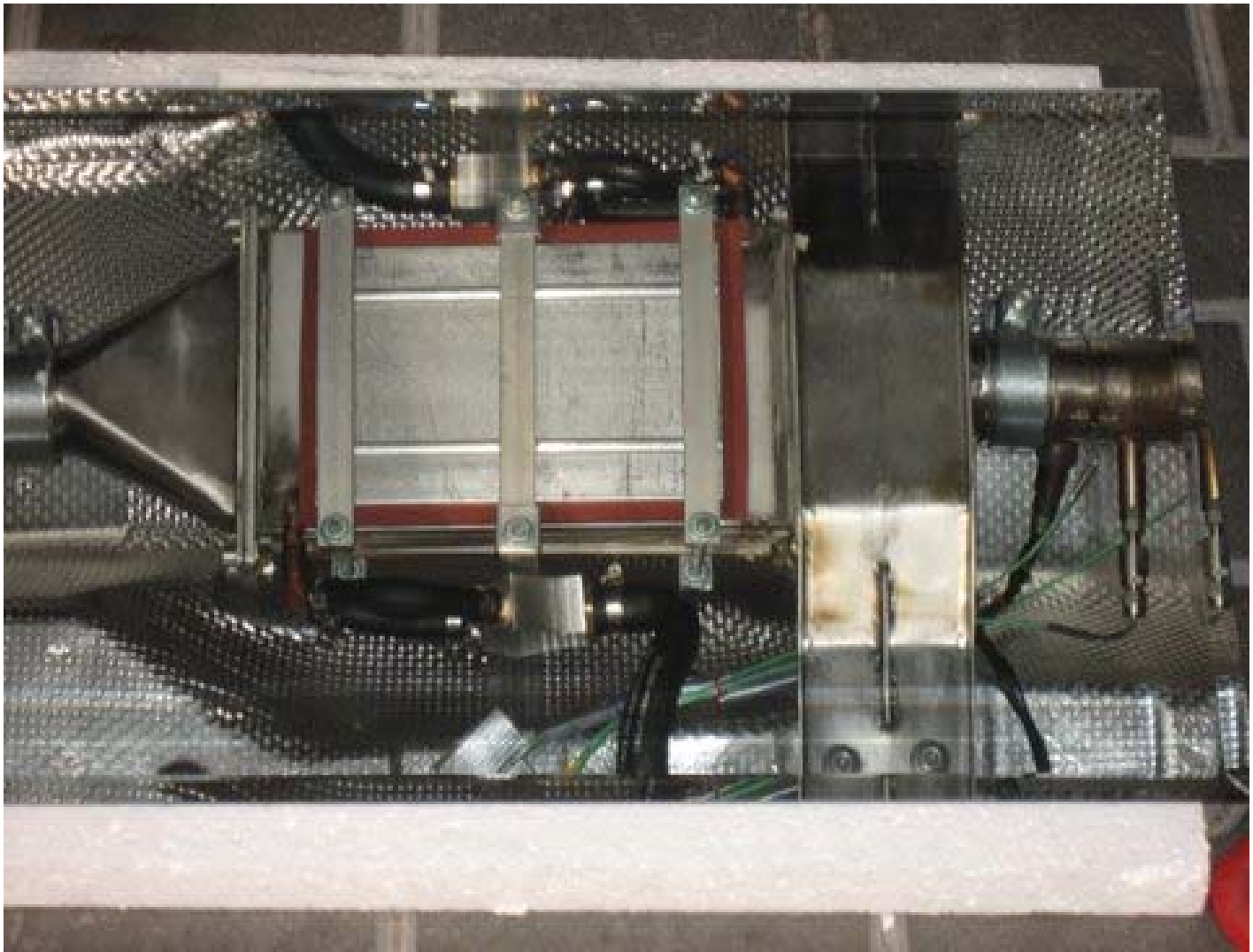
Conclusions

- **Huge amounts of waste heat, is discharged into the environment.**
- **Vast quantities of untapped natural heat is available most of which is below 100C.**
- **Thermoelectric generation is an environmentally friendly technology able to convert low and high temperature waste heat into electricity.**
- **Both high and low temperature recovery technology have been successfully demonstrated on a laboratory scale and in prototype commercial systems/vehicles**
- **Wide scale application of this technology can only be achieved by substantial improvements in material thermoelectric performance.**
- **Including thermoelectrics in EU research program calls has resulted in an upsurge of collaboration between European Universities and Industry and is already having an impact particularly in automobile exhaust heat recovery.**

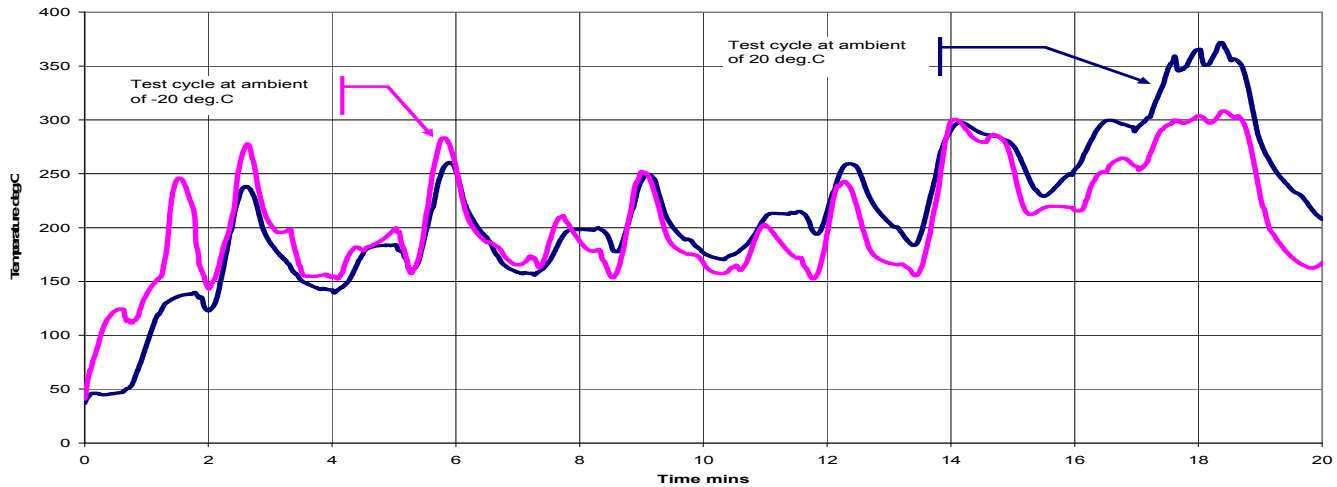
Potential thermoelectric recovery from a typical small steel plant

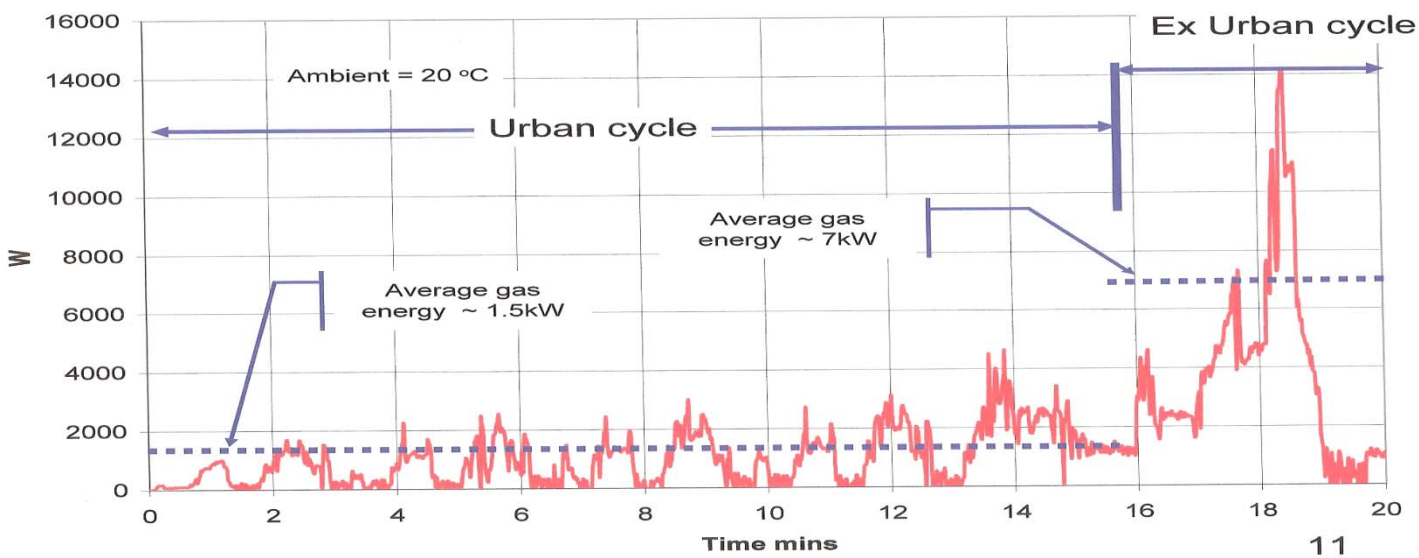


Underside showing typical strapped module assembly



Temperature profiles and exhaust heat energy from start-up time



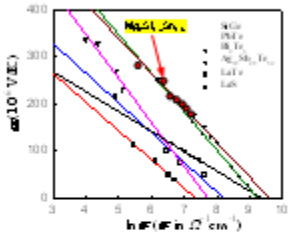


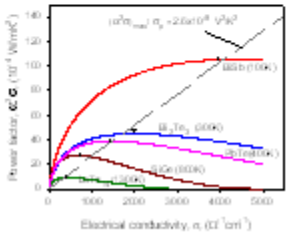
EU Funded thermomag project

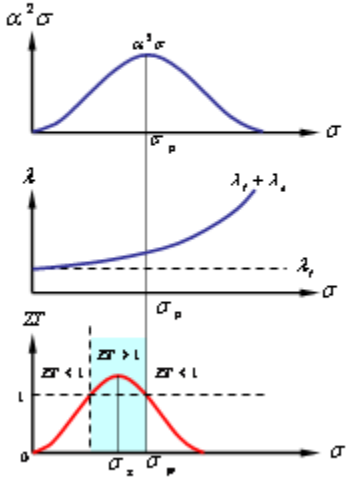
Proposal submitted to develop low density thermoelectric materials

- **ESA (NL)** – Dr. David Jarvis, Dr. Nick Lavery
- **AGH-Krakow** (PL) – Prof. Elzbieta Godlewska, Dr. Krzysztof Mars
- **Fraunhofer (DE)** – Dr. Harald Boettner, Dr. Jan Koenig, Dr. Martin Jägle
- **University of Cardiff (UK)** – Prof. Michael Rowe, Dr. Gao Min
- **University of Nancy (FR)** – Prof. Hubert Scherrer
- **CERAM Research (UK)** – Dr. Nick Adkins
- **Ioffe Institute St. Petersburg (RU)** – Prof. M. Fedorov
- **Aristotle University of Thessaloniki (EL**) – Prof. Konstantinos Paraskevopoulos
- **Termo-Gen AB (SE)** – Dr. Lennart Holmgren
- **CR-FIAT (IT)** – Dr. Mauro Brignone
- **Volvo Technology Corporation (SE)** – Dr. Michael Balthasar, Dr. Jonas Edvardsson, Dr. Staffan Lundgren
- **Rolls Royce (UK)** – Dr. Wayne Voice (tbc)
- **EADS Innovation Works** – Dr. John Price (tbc)

α-lnσ plot as ZT indicator:







Ref: D.M Rowe and Gao Min, J. Mater. Sci. Lett, 14, (1995), 617-619

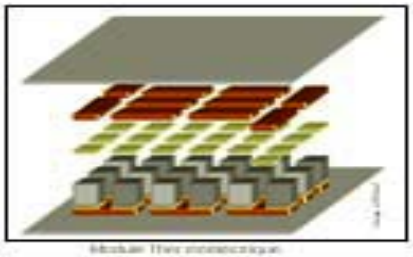
RENOTER (Projet FUI6)

« *R*écupération d'*ÉN*ergie à l'échappement d'un m*O*teur par Th*ER*moélectricité »

Objectifs

- Convertir l'énergie thermique du moteur en électricité grâce à l'effet Seebeck.
- Etudier les matériaux thermoélectriques les plus adaptés (performance, coût, nocivité...).
- Concevoir et tester un démonstrateur sur moteur dXi11 d'une puissance électrique de 1 à 3kW.

Renault Trucks Optibat Lab

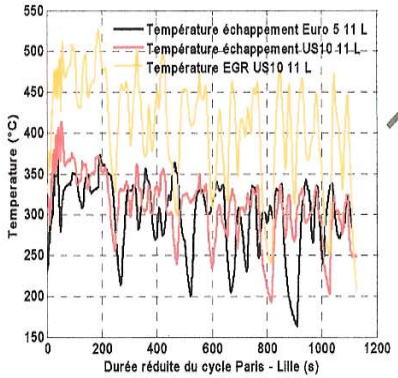


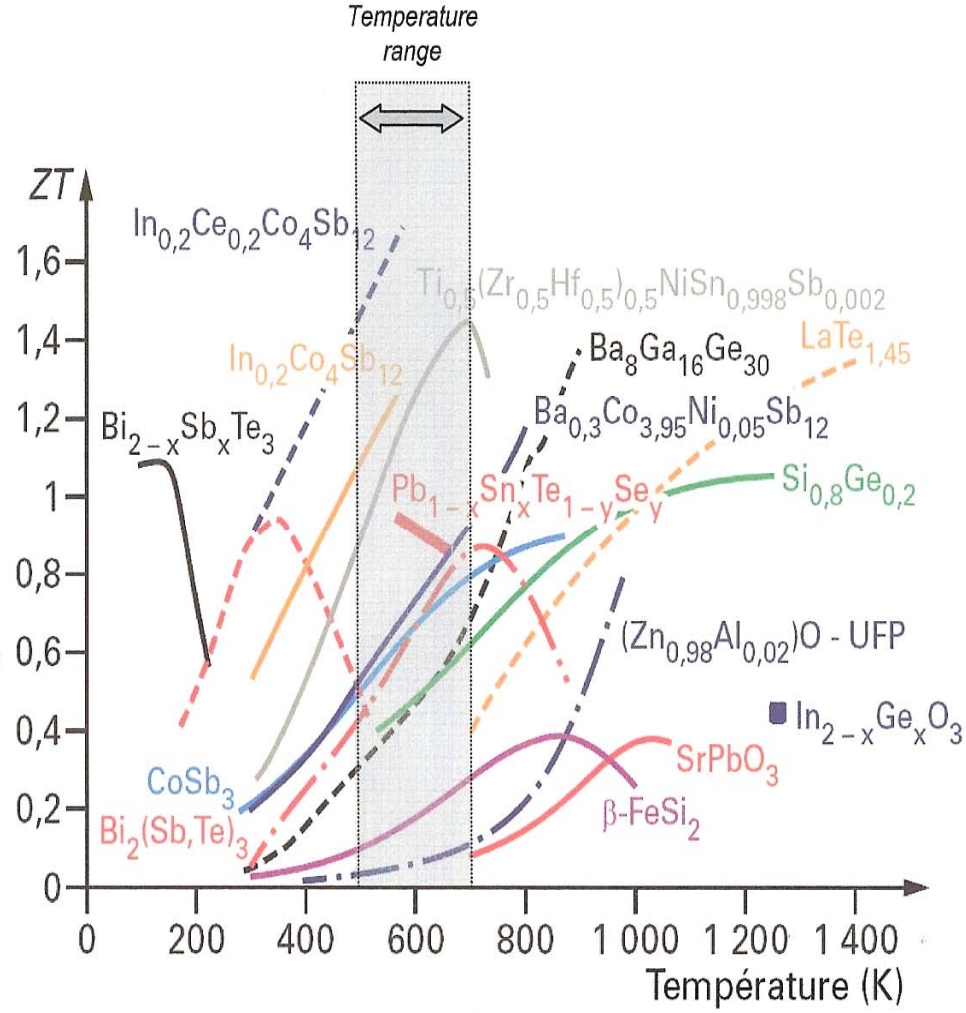
Module Thermoélectrique

Partenaires et durée

- Constructeurs, Laboratoires, Equipementiers
- Projet de 3 ans démarré en Octobre 2008

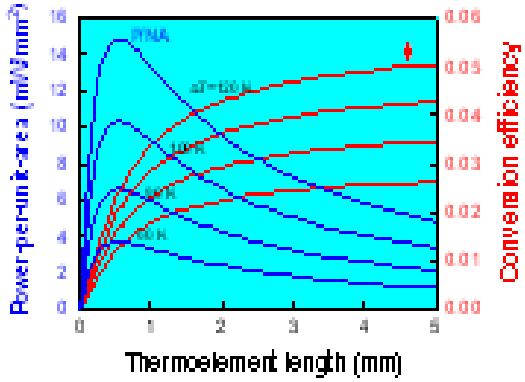



Température échappement Euro 5 11 L
Température échappement US10 11 L
Température EGR US10 11 L
Temperature (°C)
Durée réduite du cycle Paris - Lille (s)

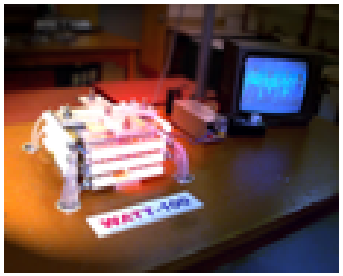

Temperature range
ZT
Température (K)
$In_{0,2}Ce_{0,2}Co_4Sb_{12}$
$Ti_{0,5}(Zr_{0,5}Hf_{0,5})_{0,5}NiSn_{0,998}Sb_{0,002}$
$In_{0,2}Co_4Sb_{12}$
$Ba_8Ga_{16}Ge_{30}$
$LaTe_{1,45}$
$Bi_{2-x}Sb_xTe_3$
$Ba_{0,3}Co_{3,95}Ni_{0,05}Sb_{12}$
$Pb_{1-x}Sn_xTe_{1-y}Se_y$
$Si_{0,8}Ge_{0,2}$
$(Zn_{0,98}Al_{0,02})O$ - UFP
$In_{2-x}Ge_xO_3$
$SrPbO_3$
$CoSb_3$
β-$FeSi_2$
$Bi_2(Sb,Te)_3$

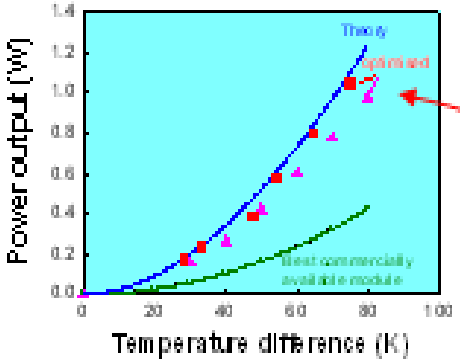
Design steps leading to the WATT-100 generator

TE Module Design Theory for Waste Heat Recovery



Thermoelement length optimisation enables:
1) large power output, or
2) high conversion efficiency



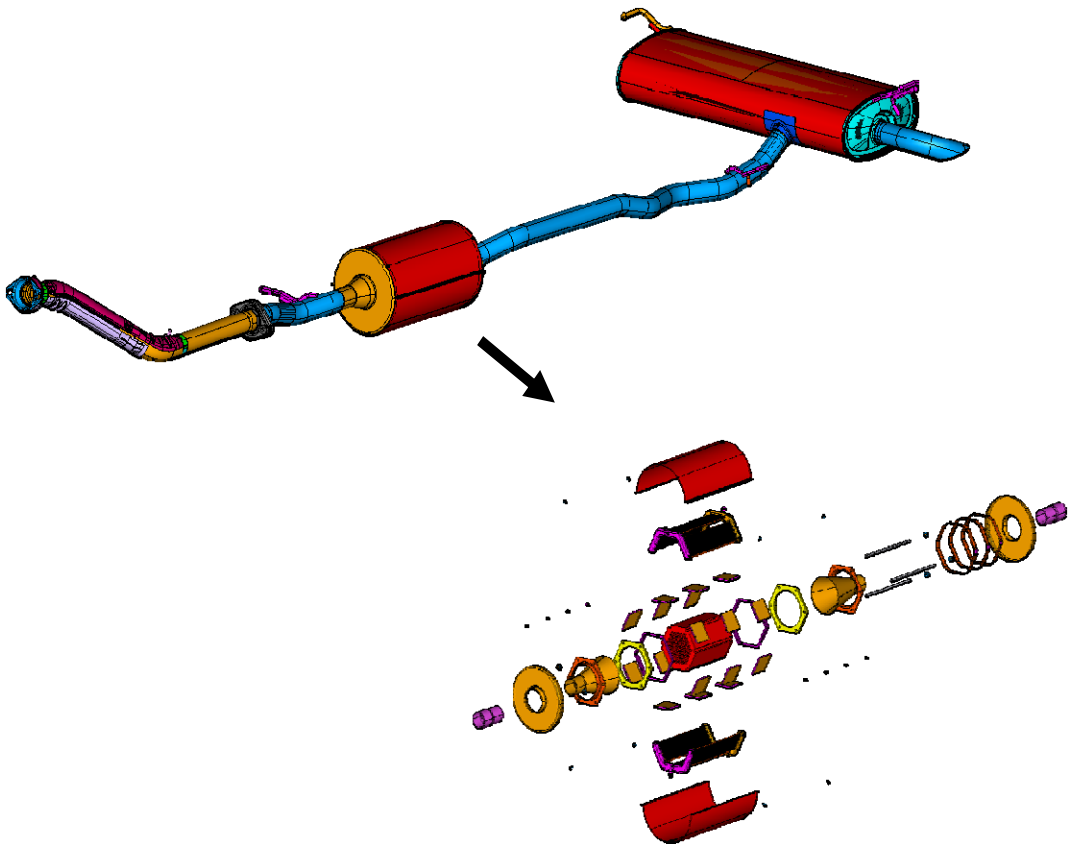


Power output per unit area is more than doubled

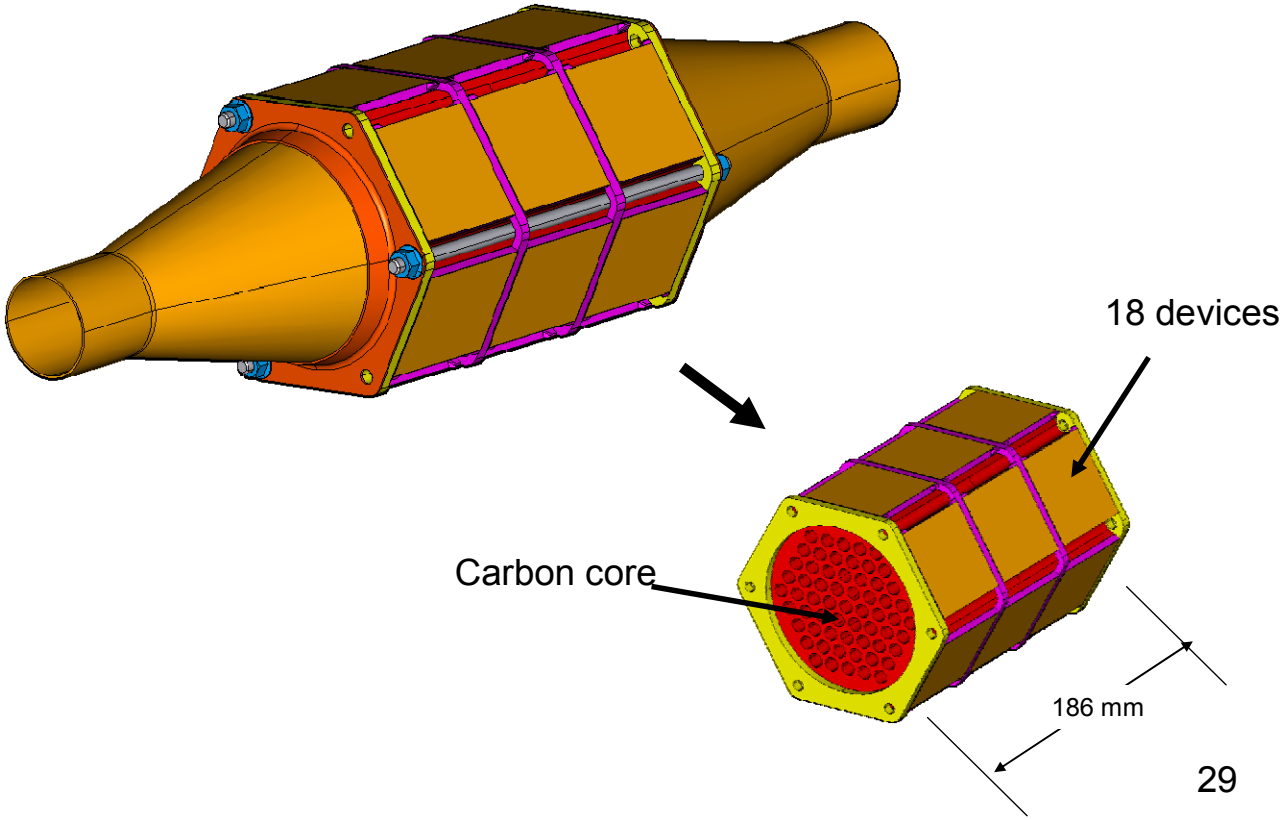
Hot Water (85°C) TEG
P = 80W, η = 3.0 %
Cardiff University, 1999

Ref: Gao Min, CRC Handbook of Thermoelectrics, 1995 & 2005.

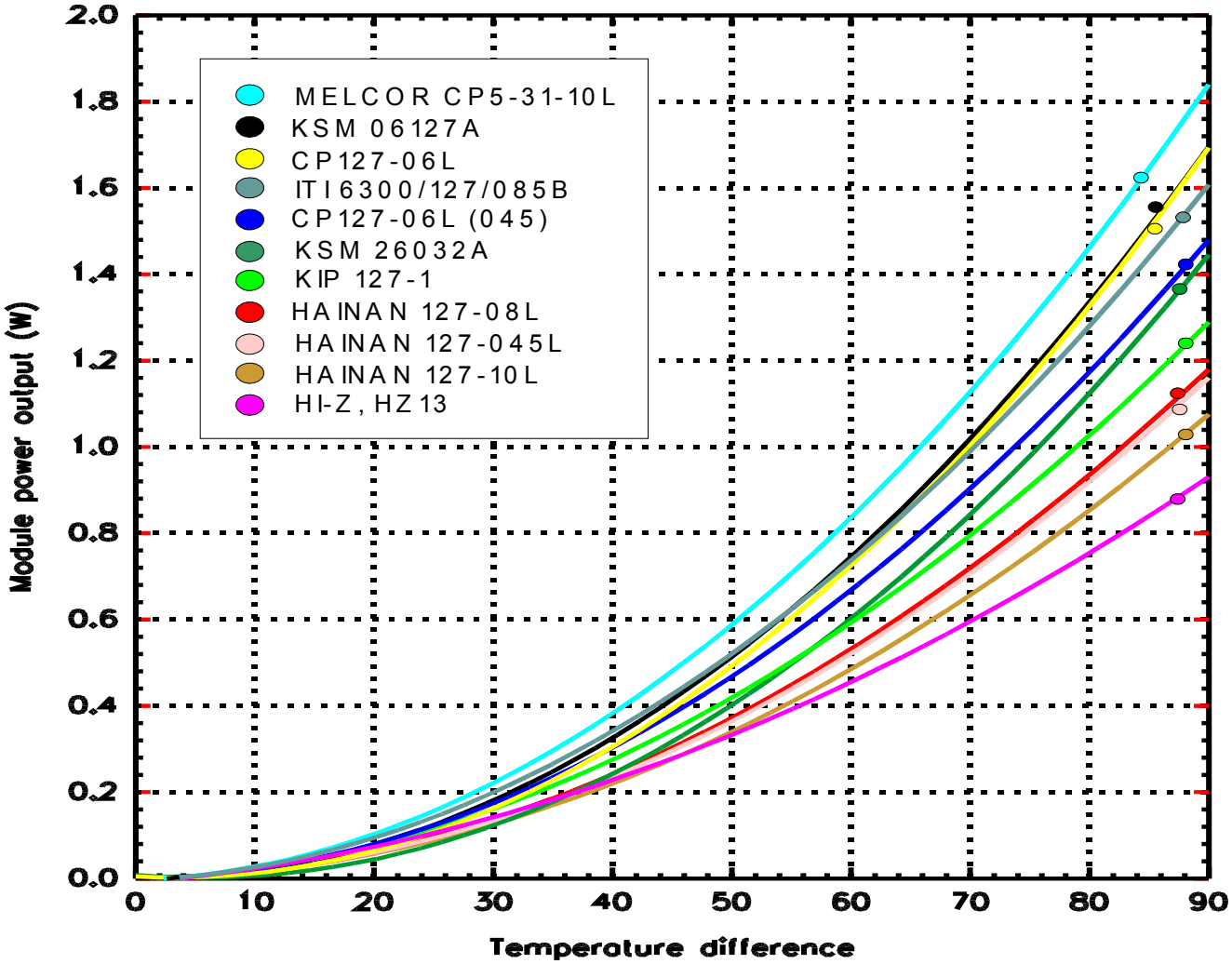
Module installed in current exhaust system



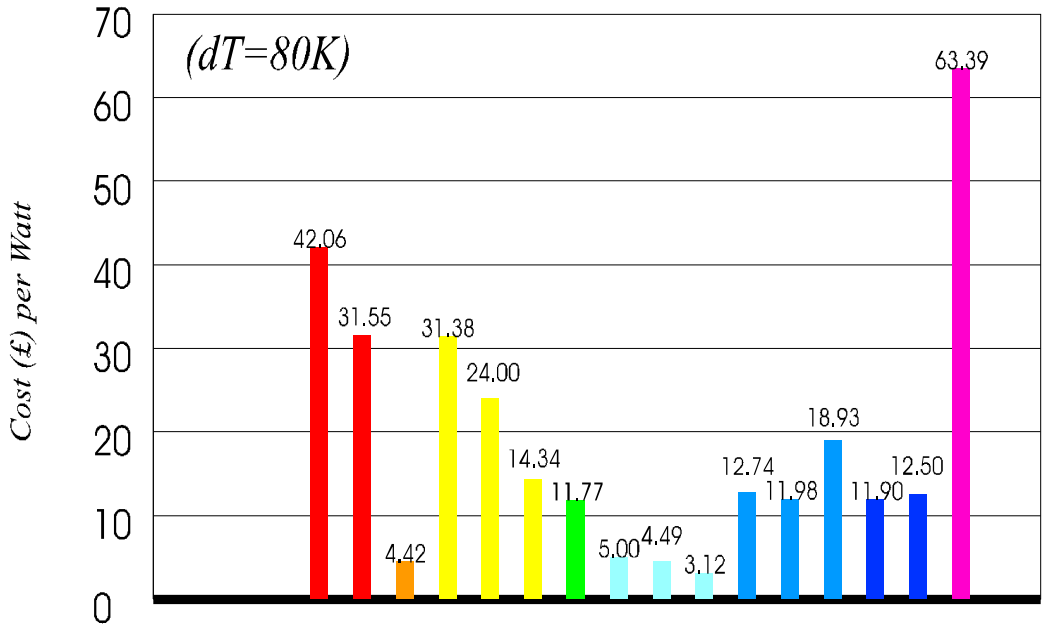
Heat exchanger design



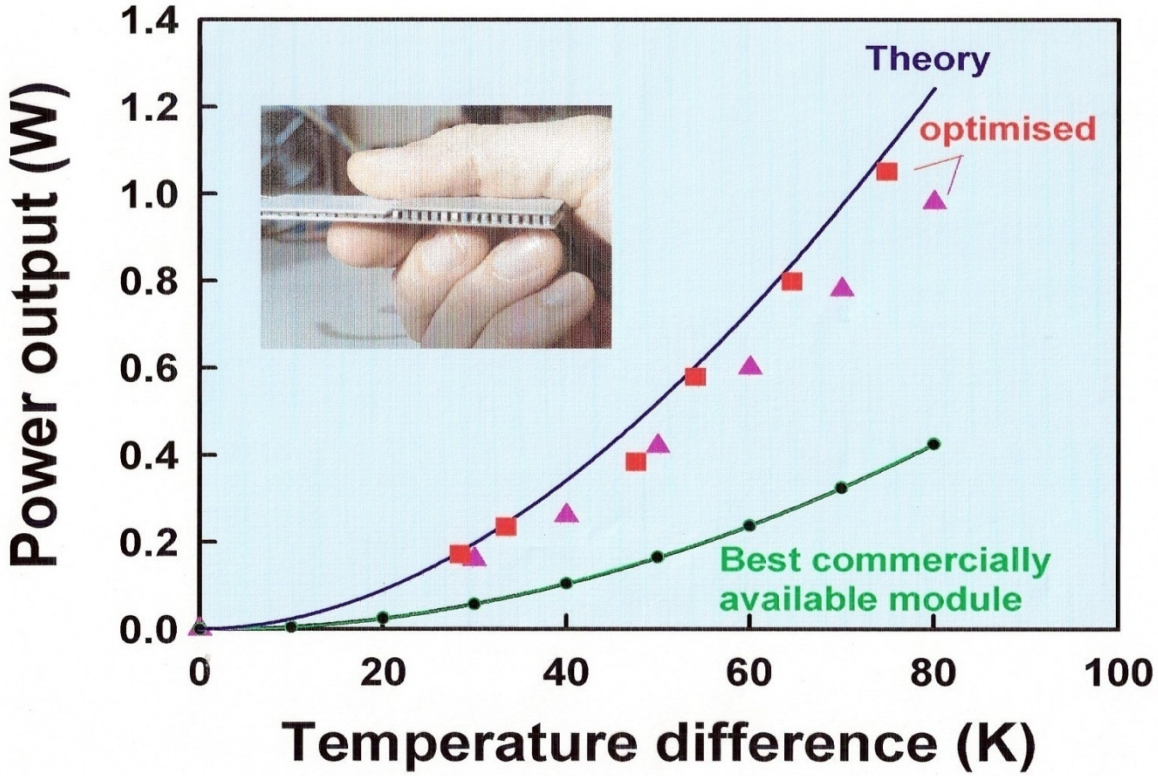
Power output for range of available modules for low temperature heat recovery.



Cost per watt for a range of modules operating over 80K temperature difference



High Power Density Module



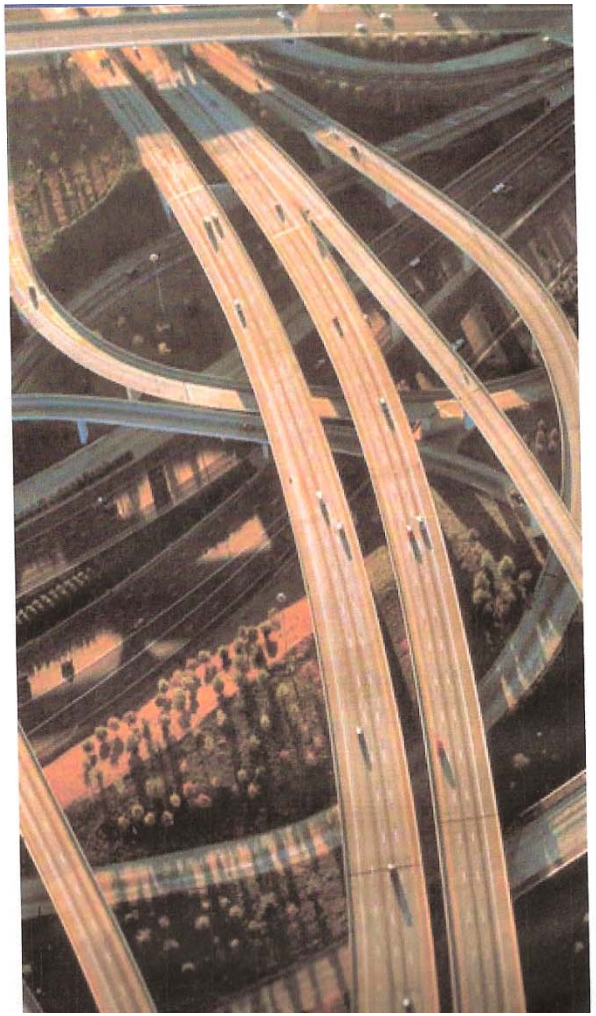
Industrial waste heat recovery,ArcelorMittal, Aviles, Spain.

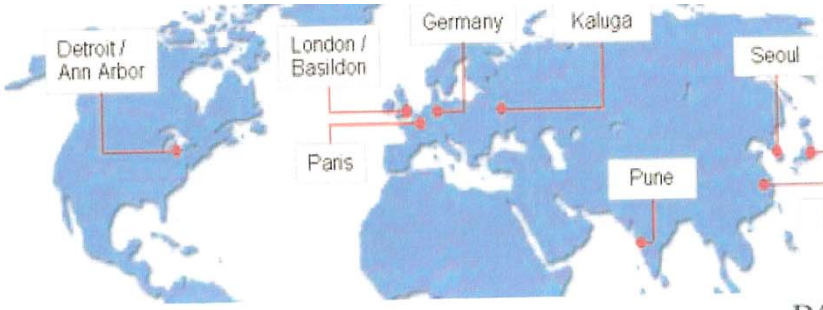
- Steel making cooling water
- Continuous supply
- 4000 cubic metres an hour
- Constant temperature of around 90C
- Available cooling water
- Convenient geometry.

Building a Joint UK-France RTG

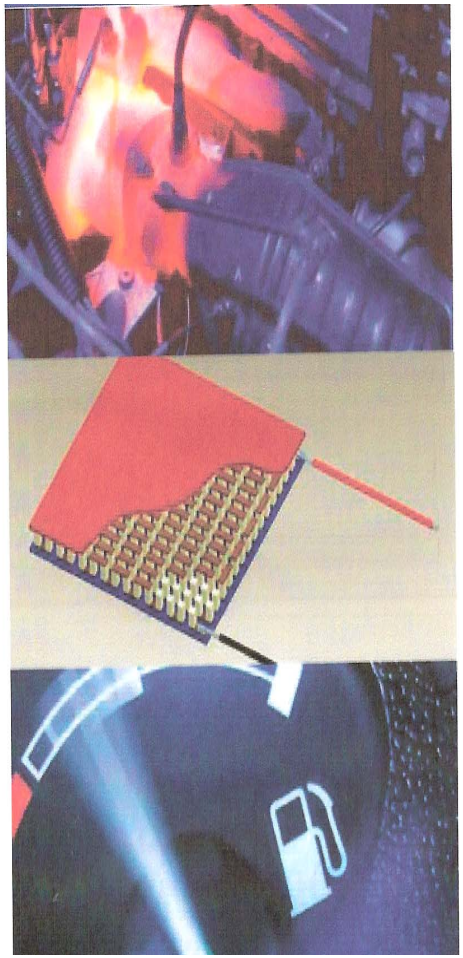
- Thermoelecric Applications Wokrshop
- San Diego California 29 Sept-2 October

IAV Ingenieurgesellschaft Auto und Verkehr





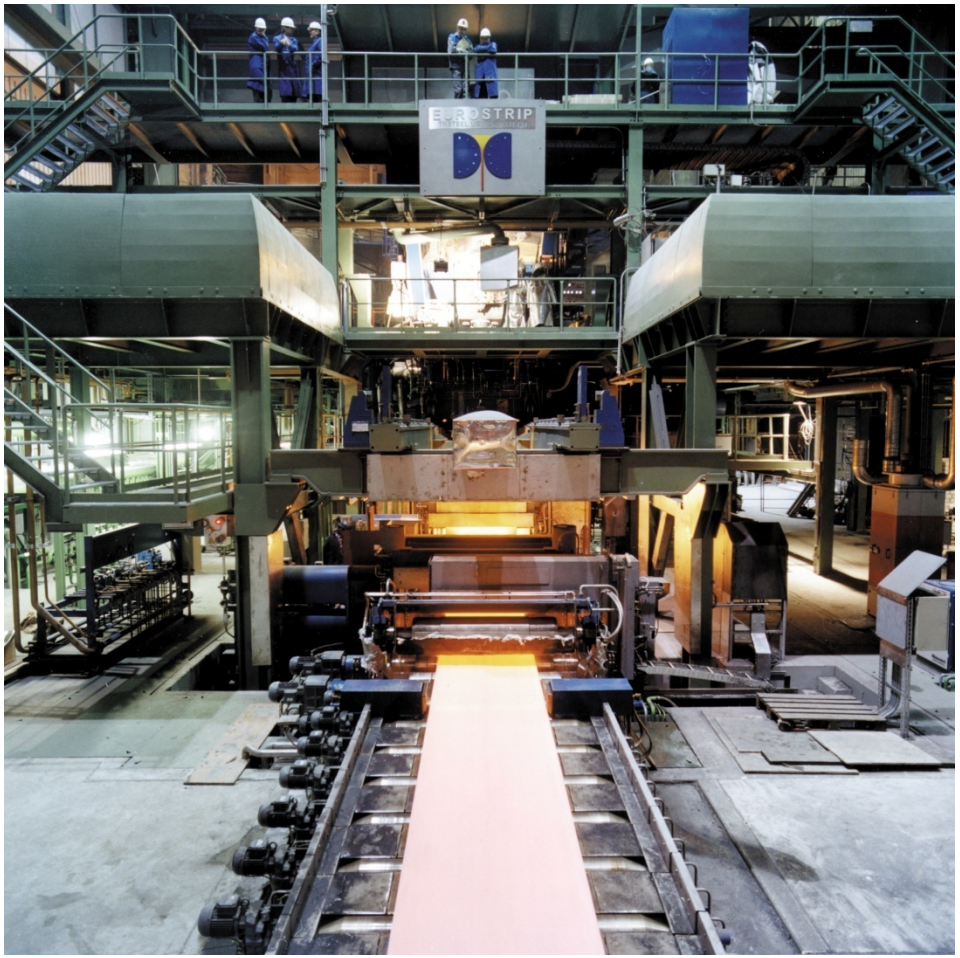
- Globally operating development partner to the automotive industry
- More than 4000 members of staff
- 25 years of experience in automotive engineering
- Expertise for the entire vehicle:
  - **Powertrain development**
  - **Electric/electronics development**
  - **Vehicle development**

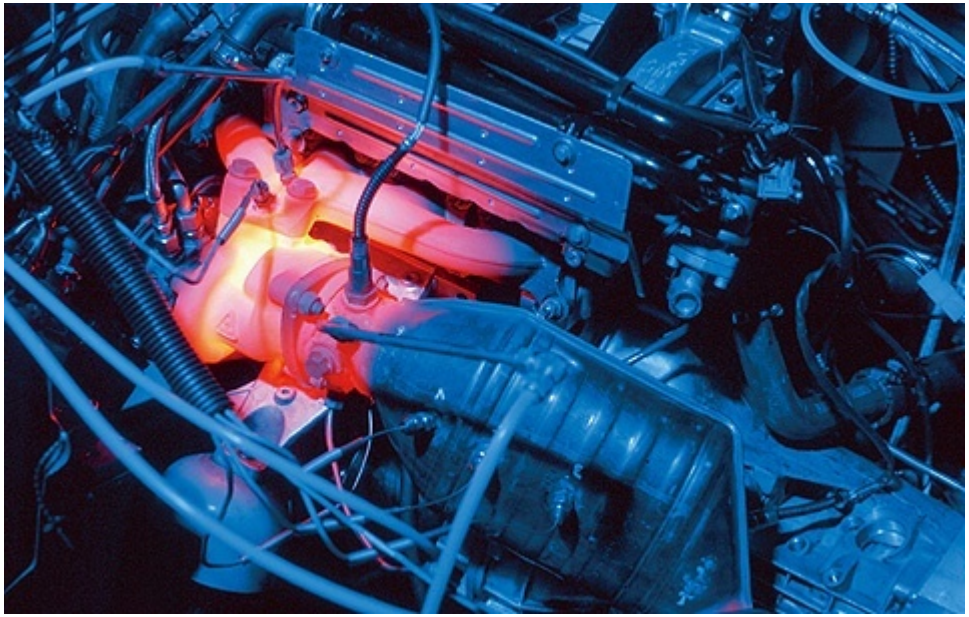


- Convert heat directly into electric energy or generate cold or heat
- No moving parts, no liquids
- Solid, robust, maintenance-free, long-living, noiseless, emission-free
- Flexible in geometry, scalable
- Low system complexity
- Reduce fuel consumption/ CO_2 and exhaust gas emissions
- Increase energy efficiency and ensure sustainable mobility


Thermoelectric
in motion

Water cooled four strand billet casting furnace


EUROSTRIP



Current activities in thermolecrc geerting applcations

Rowe

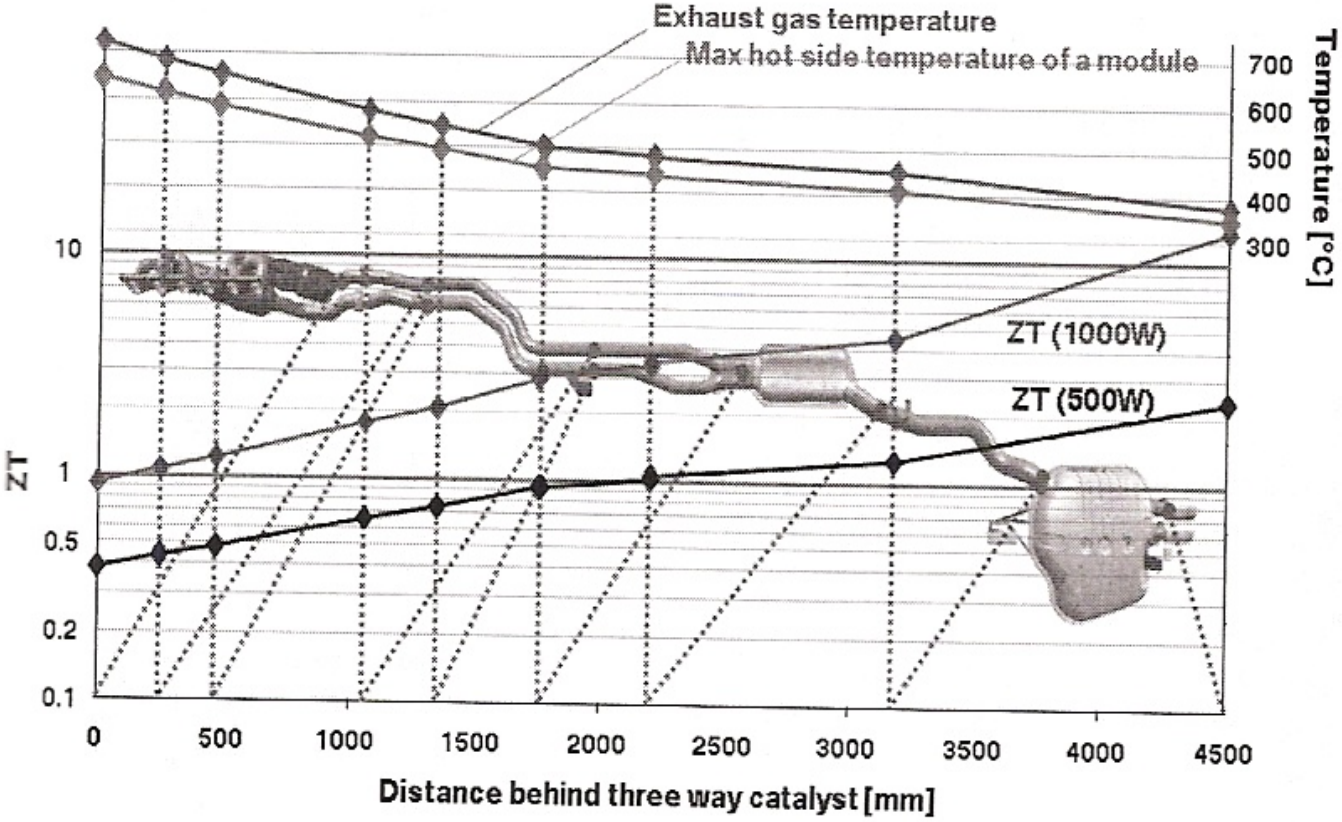
European Research Funding

- **Budget for period 2007-2011**

- The amended FP7 proposals from the European Commission, following the budget agreement between the European Council and European Parliament amount to a total of EUR 50,521 million, partitioned among the specific programmes as follows:

- Cooperation EUR 32,413 million
- Ideas EUR 7,510 million
- People EUR 4,750 million
- Capacities EUR 4,097 million
- JRC (non-nuclear) EUR 1,751 million
- Euratom (to 2011) EUR 2,751 million

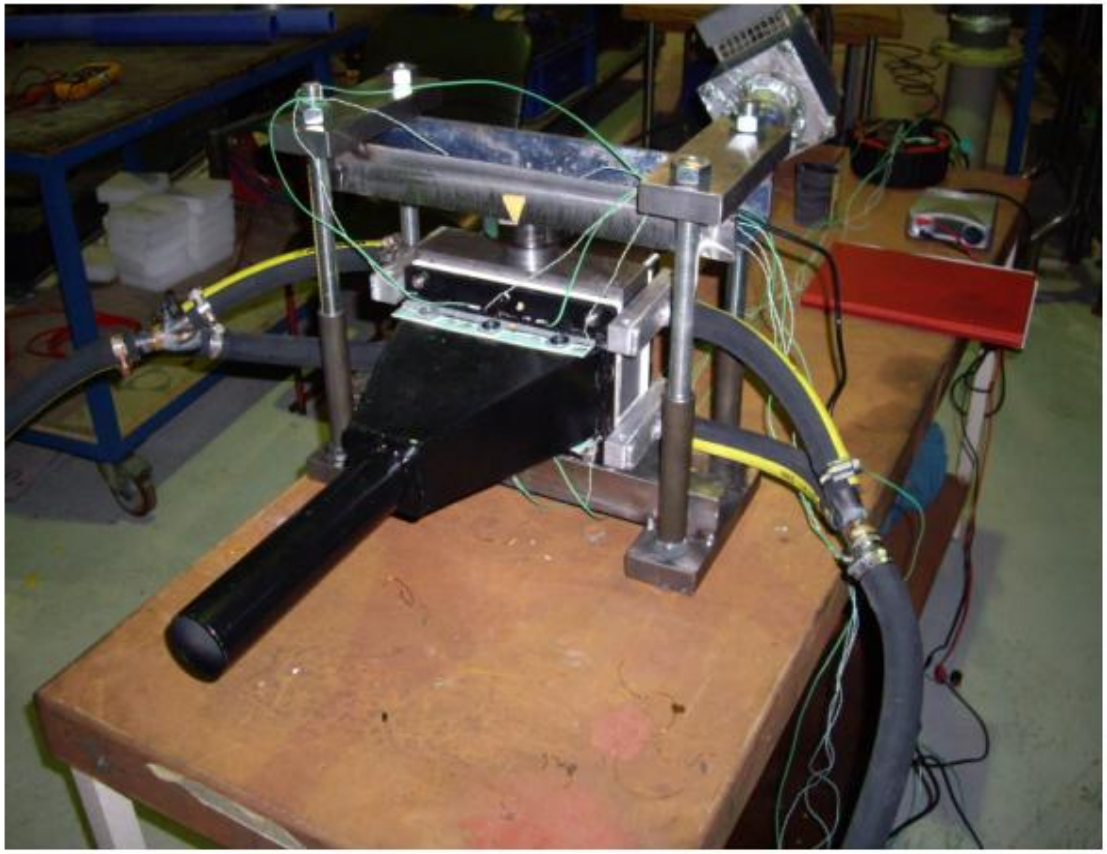
Material performance required to generate 500W and1000w



Bench testing simulated exhaust recovery system

Calsonic Kansei

Bench test set up



First demonstration in Europe of a TG recovering waste exhaust heat