NEXTEC

Next generation nano.engineered Thermoelectric Converters

Next Generation Nano-engineered Thermoelectric Converters - from concept to industrial validation

Coordinator:Professor Mamoun Muhammed
Royal Institute of Technology (KTH)
Stockholm, Sweden

EC-PO: Dr. Sophia Fantechi
PTA: Dr. Jiri Navartil

Funding Scheme

Theme 4 NMP

Activity II.1.2 Nanotechnologies and converging technologies.

NMP-2010-1.2-3

Thermoelectric energy converters based on nanotechnology-SM

NEXTEC

Next generation nano.engineered Thermoelectric Converters

SEVENTH FRAMEWORK PROGRAMME

Theme 4 NMP, Activity II.1.2 Nanotechnologies and converging technologies.

NMP-2010-1.2-3 Thermoelectric energy converters based on nanotechnology-SM

Project starting period	June 1st, 2011
Project Period	3 years
Total Budget	6.4 M EURO
EC-Contribution	3.9 M EURO

11 Partners :

- 5 Countries
- 6 Industrial companies
- 3 SME + Large companies
- 1 Technical University
- 2 National Labs
- 2 Research Centers

Partners:

Kungliga Tekniska Hoegskolan (KTH)	Sweden,
National Center For Scientific Research "DEMOKRITOS"	Greece
Cidete Ingenieros SL	Spain
NPL Management LTD	UK
Centro Tecnico De Seat SA	Spain
Electrolux AB	Sweden
Agencia Estatal Consejo Superior De Investigaciones Cientificas (CSIC)	Spain
Acondicionamiento Tarrasense Associacion (LEITAT)	Spain
Fraunhofer-Gesellschaft Zur Foerderung Der Angewandten Forschung EV	Germany
Siemens AG	Germany
Babrow Consultants LTD (exit Date April 2012)	UK
PANCO- Physikalische Technik Anlagenentwicklung & Consulting GmbH	Germany

The consortium

Sweden

Royal Institute of Technology (KTH)

Isafjordsgatan 22,164 40, Stockholm, Sweden

Contact person:
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Phone: +46 8790 8158
Website: www.kth.se

New Partner: PANCO GmbH

Objectives

- Use Nanotechnology to improve ZT of promising TE materials in bulk form.
- Processing materials into module/devices to be tested by industry.
- Material concept- Module/device concept - Application

1. Power Generation

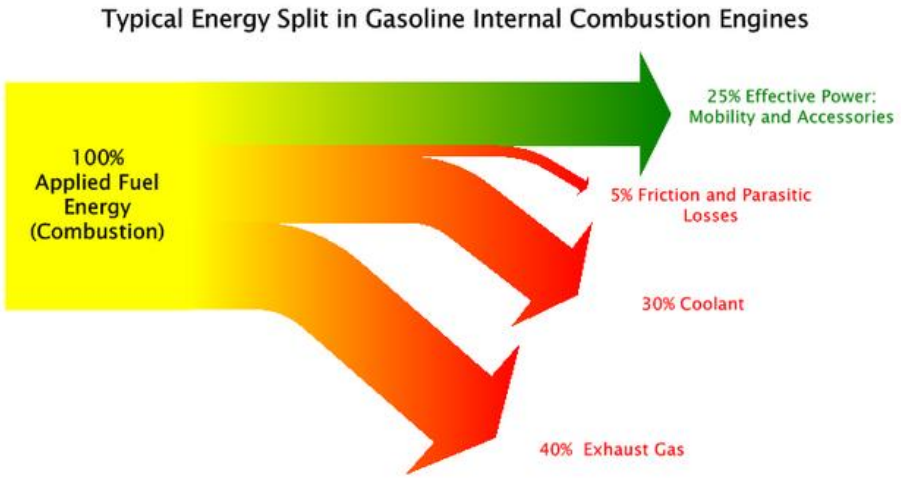
- Module utilizing skutterudite materials (for energy generation),
  - NS TE materials with even higher TE performance (ZT>1.5-3),
  - NS skutterudites and their nanocomposites display a maximum ZT in the temperature range 200–600 ° C
  - Generation of electricity from waste heat. 0.5 W/cm2

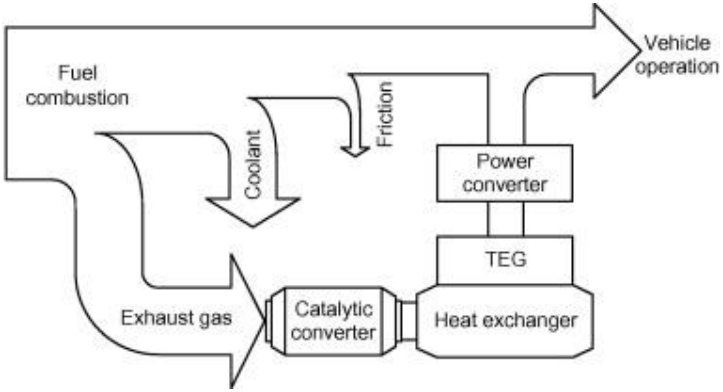
- Potential applications for waste heat recovery mainly from car exhaust pipes and industrial materials processing.

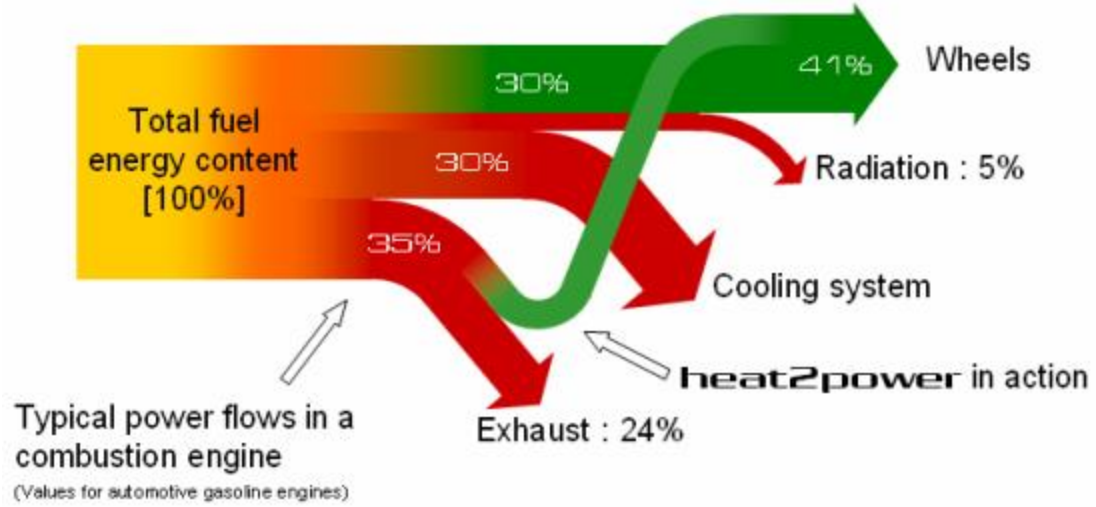
Energy Harvesting….

Thermoelectric Generators

(Power Generation)

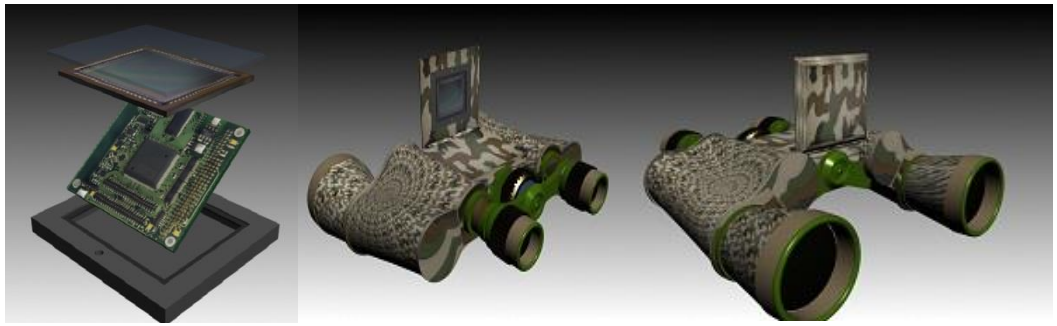

Typical Energy Split in Gasoline Internal Combustion Engines
100% Applied Fuel Energy (Combustion)
25% Effective Power: Mobility and Accessories
5% Friction and Parasitic Losses
30% Coolant
40% Exhaust Gas


Fuel combustion
Vehicle operation
Coolant
Friction
Power converter
TEG
Exhaust gas
Catalytic converter
Heat exchanger


Total fuel energy content [100%]
30%
41%
Wheels
30%
Radiation : 5%
35%
Cooling system
heat2power in action
Exhaust : 24%
Typical power flows in a combustion engine
(Values for automotive gasoline engines)

2. Cooling

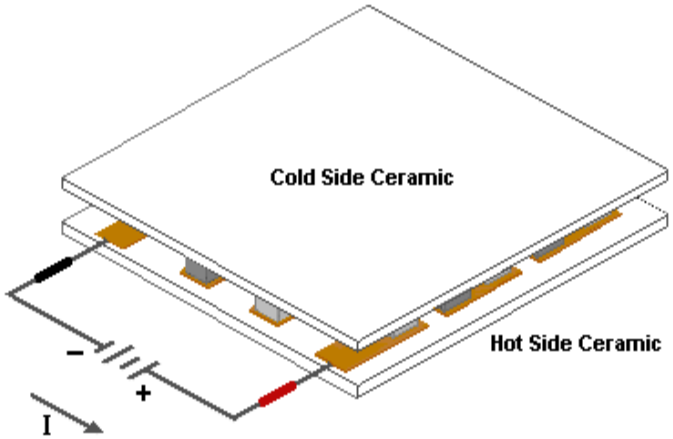
- Modules utilizing bulk NS bismuth telluride
  - Improvements in material properties .
  - Conventional TE module/device technology can be directly used for NS bulk bismuth telluride.
- Potential Applications in cooling of electronics, optics, refrigerators .



Thermoelectric Generation

Heat ⇄ **Electrical energy**

Seebeck Effect — Peltier effect cooler / heater



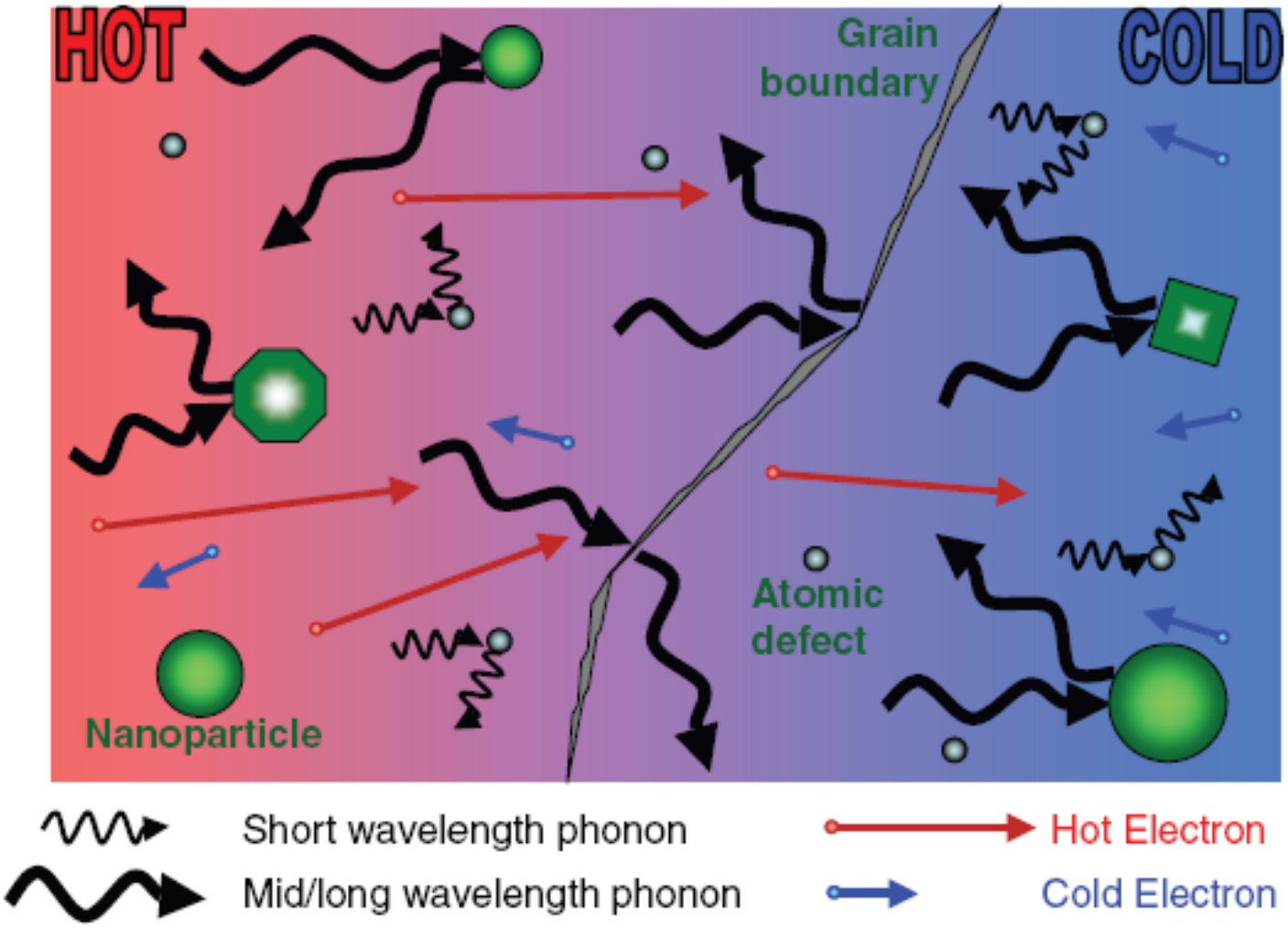
Materials with high electrical but low thermal conductivity needed!

Improved performance via nanostructuring:

- Favourable carrier scattering mechanism
- Much lower thermal conductivity

$$ZT = \frac{S^2\sigma}{\kappa}T$$

S Seebeck Coefficient,
σ electrical conductivity
κ thermal conductivity


HOT
COLD
Grain boundary
Atomic defect
Nanoparticle
Short wavelength phonon
Mid/long wavelength phonon
Hot Electron
Cold Electron

Strategy

$$ZT = \frac{S^2\sigma}{\kappa}T$$

Improved by;
Carrier Concentration Engineering

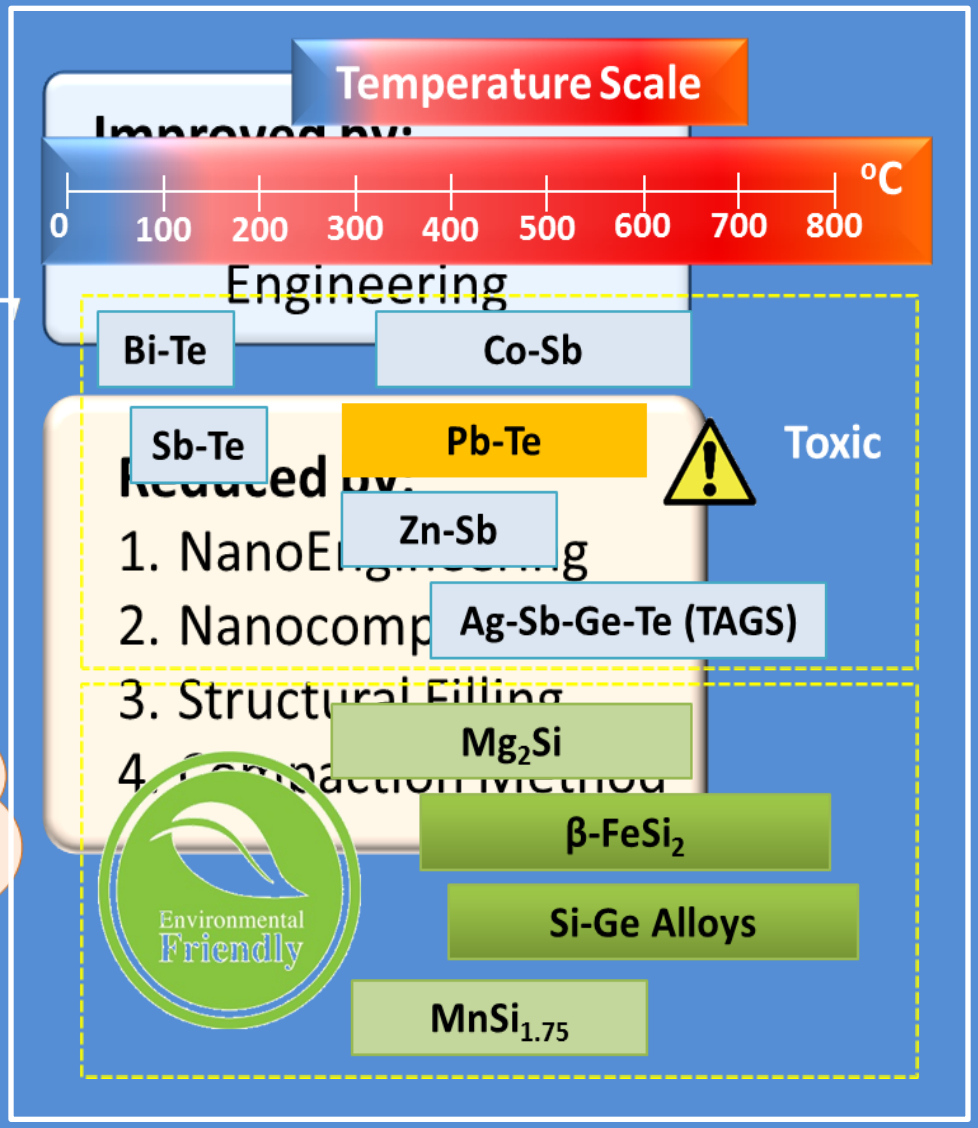
Reduced by;
1. NanoEngineering
2. Nanocomposites
3. Structural Filling
4. Compaction Method

Phonon Engineering ($\kappa = \kappa_e + \kappa_L$)

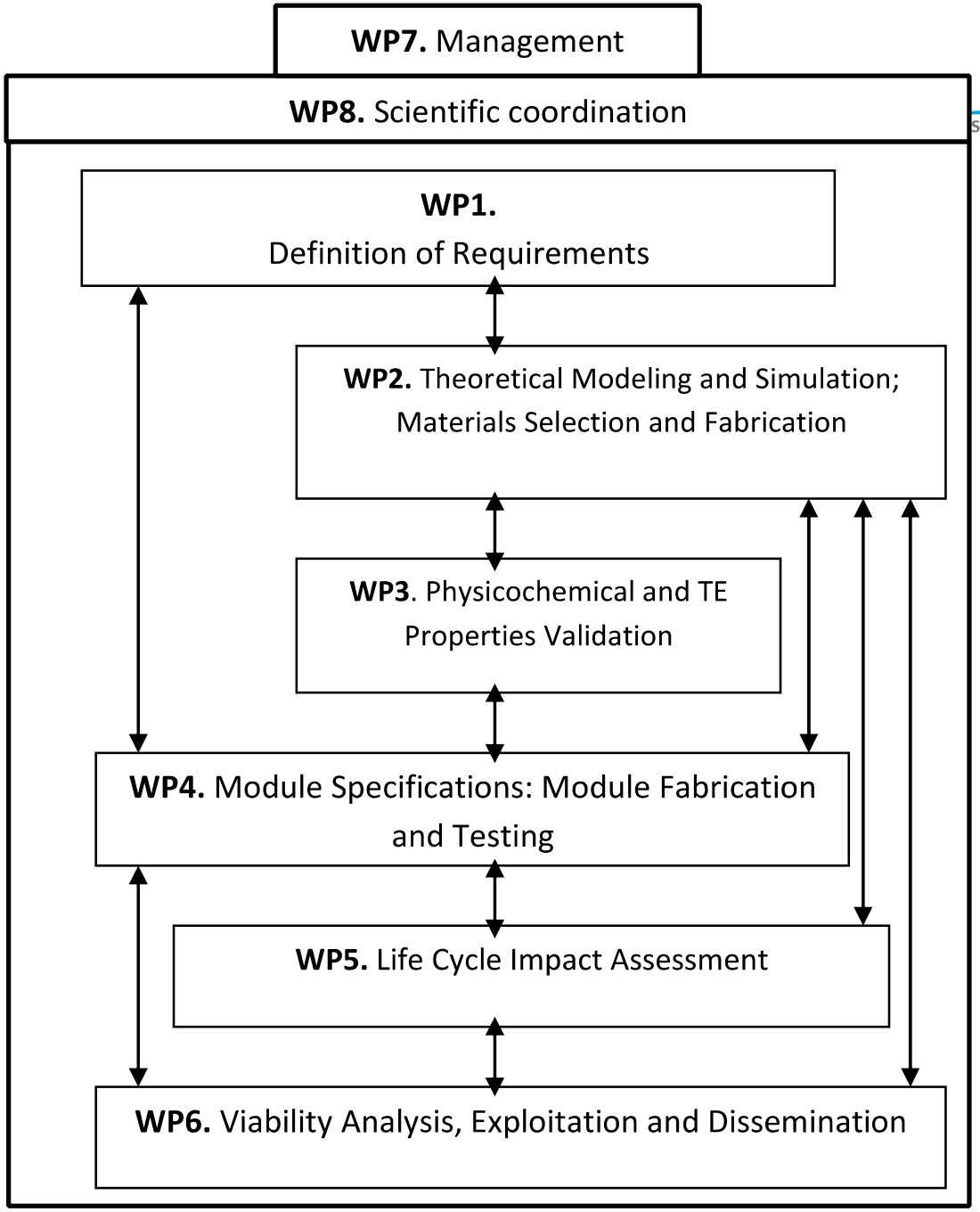
- Moderate to High Efficiency
- Industrial Scaling Challenges
- Less Earth Abundance
- Toxicity Issues

Phonon Engineering ($\kappa = \kappa_e + \kappa_L$)

- High Earth Abundance
- Easily Scalable for industry
- Moderate to High Efficiency
- NO Toxicity Issues
- Feasible Materials Recycling



Project Synopsis



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Workpackages

SEVENTH FRAMEWORK PROGRAMME

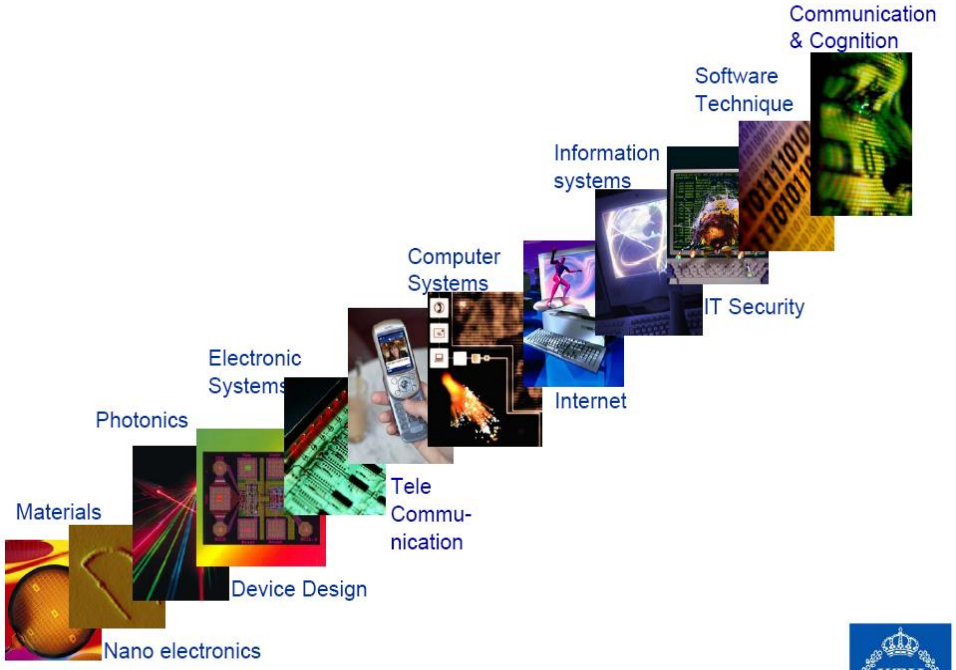
Project Number [1]	263167	Project Acronym [2]	NEXTEC

LIST OF WORK PACKAGES (WP)

WP Number [53]	WP Title	Type of activity [54]	Lead beneficiary number [55]	Person-months [56]	Start month [57]	End month [58]	LEAD
WP 1	Definition of System Requirements	RTD	10	32.50	1	12	SIEMENS
WP 2	Theoretical Modeling and Simulation; Materials Selection and Fabrication	RTD	1	139.00	1	36	KTH
WP 3	Physicochemical and Thermoelectric Properties Validation	RTD	7	135.00	1	36	CSIC
WP 4	Module Specifications: Module Fabrication and Testing	RTD	5	123.00	1	36	STC
WP 5	Life Cycle Impact Assessment	RTD	8	48.00	18	36	LEITAT
WP 6	Viability Analysis: Dissemination and Exploitation Activities	OTHER	1	27.00	1	36	NCSRD
WP 7	Management	MGT	1	12.00	1	36	KTH
WP 8	Scientific coordination	RTD	1	27.50	1	36	KTH
			Total	544.00			

The Partners

- KTH is the largest and oldest technical university in Sweden.
- Functional Materials Division has the expertise on a wide variety of nanomaterials synthesis ranging from bio-medicine, energy related materials, structural materials,etc.
- Coordinated several EC and Swedish funded thermoelectric projects for the past 12 years:



Main Research Areas

Nano-Medicine:
Nano materials for Biomedical Applications

Visualization - MRI
Bio-sensors, Drug delivery

Nano – Energy:
Nanostructured materials for Energy

Thermoelectrics
Heat Transfer:
- *Porous Nano Surfaces*
- *Nanofluids*

Fuel Cells
QD-Solar cells

Nano-Environment:
Functional Nanocomposites for Environment

Water – Soil – Air Clean up
- Nano-composites
- Nano-fibres
- Nano-particles
- Nano-catalysis

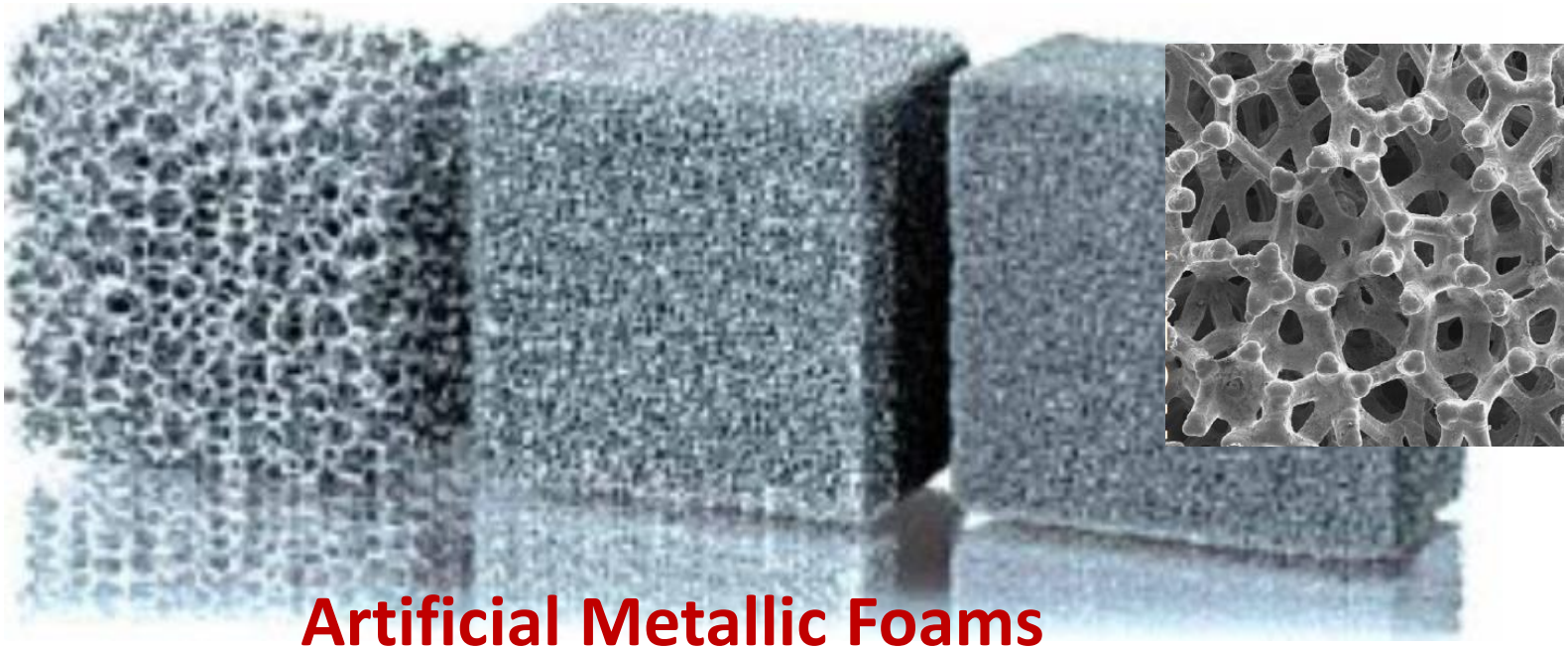
The Partners

Contact Person: **Prof. Dmitris Niarchos**

- National Centre for Scientific Research “Demokritos” is the biggest and most acclaimed research center in Greece, employing over 1,000 researchers, engineers, technicians and administrative personnel.

- Institute for Material Science is one of the 8 institutes within NCSR D
- D. Niarchos, has been in charge of the magnetism and superconductivity group of the IMS since 1985
- The group has a long experience in preparation and characterization of materials both in bulk and thin/thick films form.

The Partners



Artificial Metallic Foams

The Partners

Contact Person: Dr. German Noriega

- Over 25 years of experience in thermoelectrics
- Offers solutions from scratch to finish products for cooling, heating and power generation applications.
- Dr. German Noriega has over 100 publications and several key patents in the field of thermoelectrics and energy related technologies.
- The group has a long experience in preparation and characterization of materials both in bulk and thin/thick films form.

The Partners

Contact Person: **Dr Alexandre Cuenat**

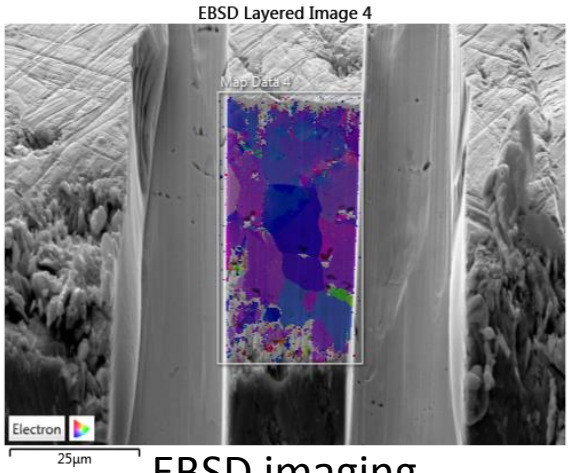
- The National Physical Laboratory (NPL) is a world leading metrology institute involved in all aspect of measurement, qualification and standards development

- NPL has in-depth experience in the measurement and characterization of all the physical properties of materials

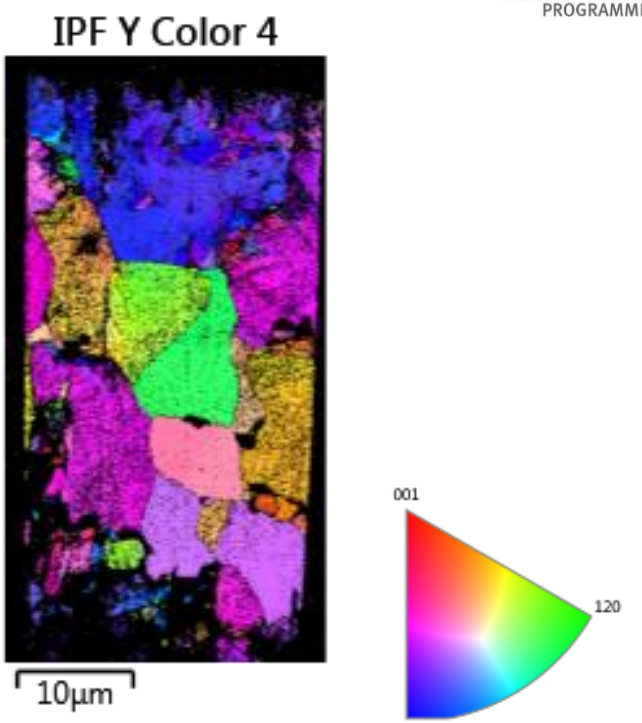
- The NPL Nanomaterials team has expertise on scanning thermal microscopy and 3 omega techniques for transport properties evaluation.

- Dr. Cuenat is the technical and workpackage leader in several EC funded projects.

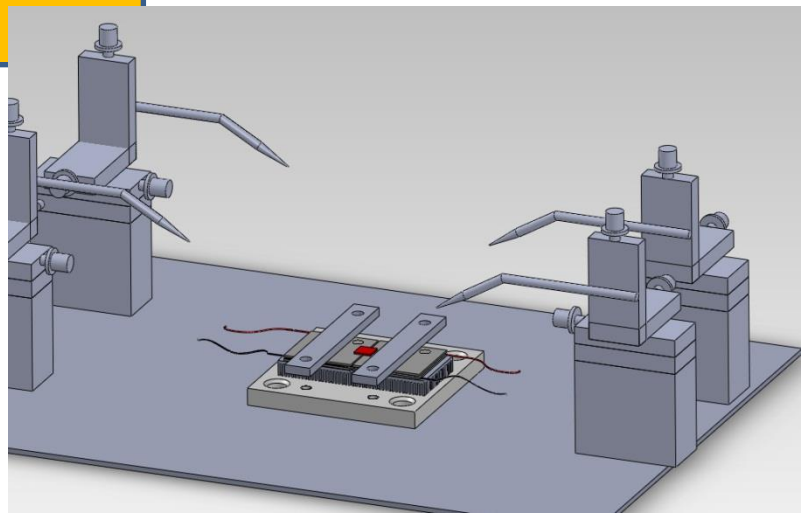
The Partners



EBSD imaging



NPL National Physical Laboratory



Air-bridge measurement technique

The Partners

Contact Person: **Dr Stefan Ilijevic**

- SEAT is the leading automotive brand in Spain for the past 60 years
- The SEAT Technical Center focuses on R & D and is the only centre of its kind in Spain
- SEAT has one of the most advanced R & D and Design-centers world-wide contributing to development of numerous vehicles for the Group-members VW and AUDI.

The Partners

Contact Person: **Dr Richard Furberg**

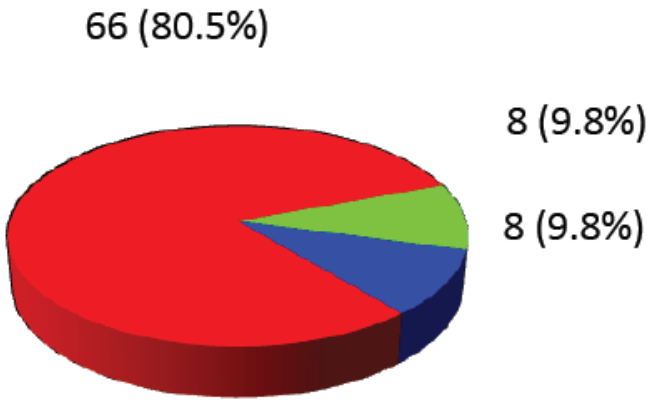
- Electrolux is a global leader in household appliances and appliances for professional use, selling more than 40 million products to customers in more than 150 markets every year.
- Electrolux products include refrigerators, dishwashers, washing machines, vacuum cleaners and cookers.
- 2008, Electrolux had sales of SEK 105 billion and 55,000 employees.
- It has over 90 years of experience in leading innovations and design.

The Partners

Contact Person: **Prof. Marisol Martin Gonzales**

CSIC
Consejo Superior de Investigaciones Científicas

82 people:
- 33 Permanent (CSIC)
- 49 Non permanent



Scientific personnel:
- 20 Permanent researchers
- 3 RyC
- 15 Post Docs
- 28 Students

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The Partners

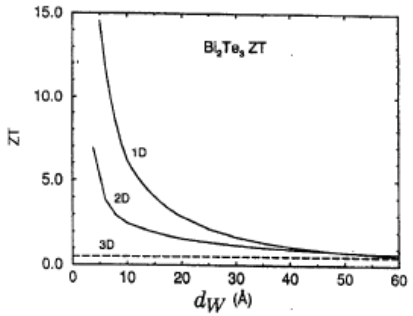
SEVENTH FRAMEWORK PROGRAMME

Contact Person: **Prof. Marisol Martin Gonzales**

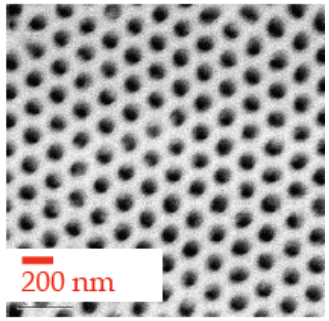
Thermoelectric figure of Merit:

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

Low-dimensionality theory for TE:

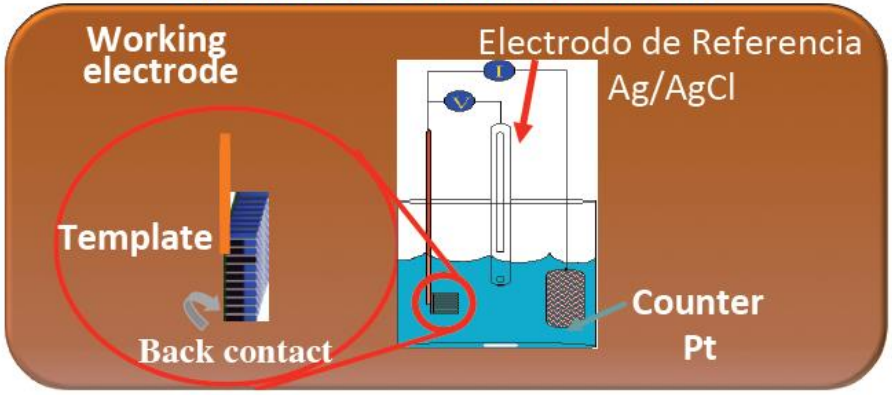


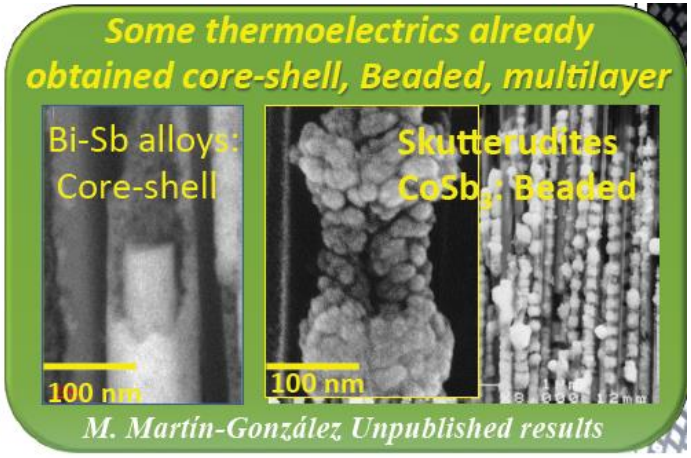
From L.D. Hicks et al. PRB 1993



40 nm porous alumina matrix

Experimental: Electrochemical cell





The Partners

Contact Person: **Dr. Laurent Aubouy**

LEITAT is a private non-profit entity,(Industrial association) with legal status and own assets, incorporated in 1906.

LEITAT develops R&D activities in the areas of materials sciences, environment, renewable energies and smart systems with deep knowledge and experience in technological transfers to several industrial sectors.

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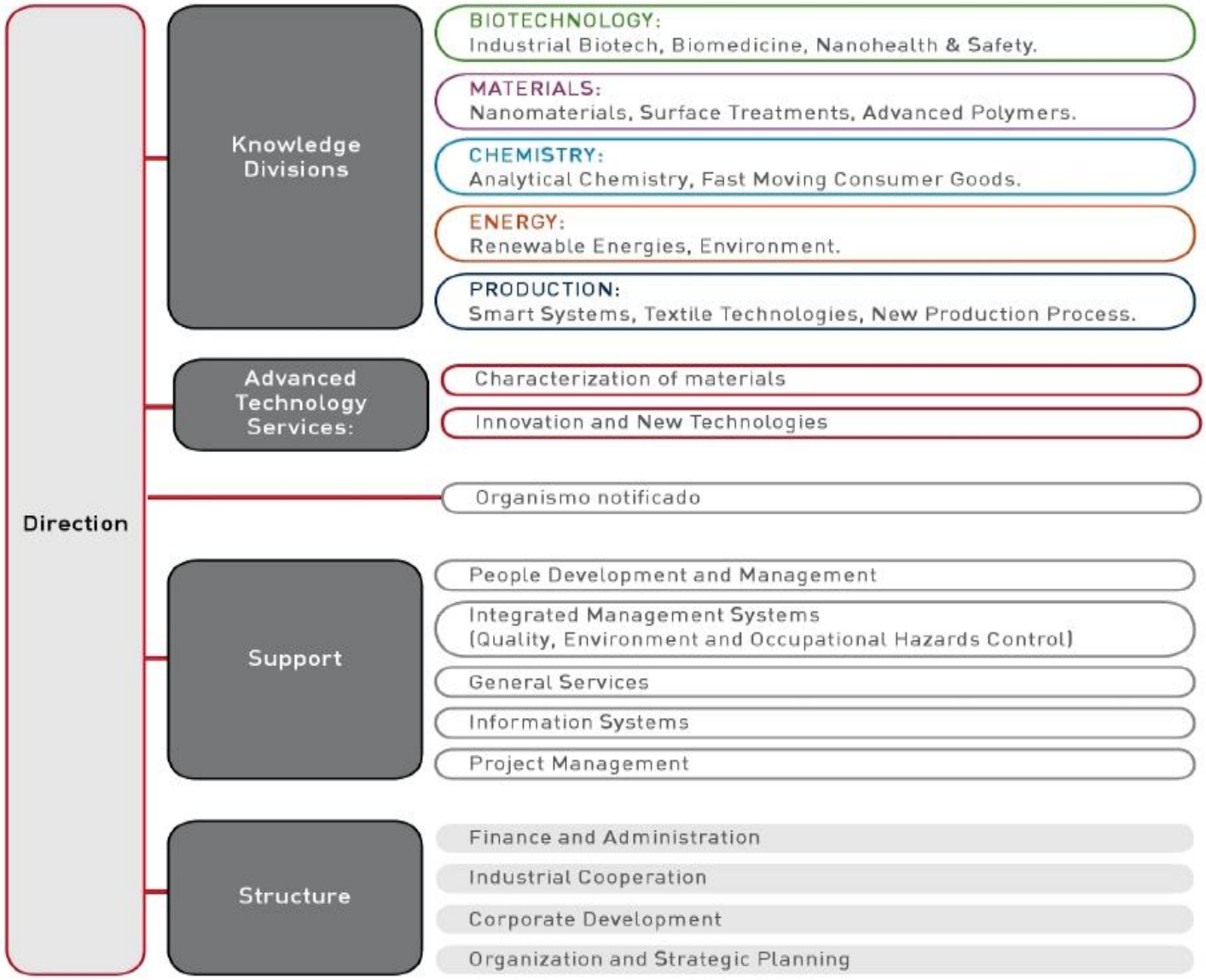
The Partners

SEVENTH FRAMEWORK PROGRAMME

Contact Person: **Dr. Laurent Aubouy**

LEITAT Technological Center
managing your technologies
member of TECNIO

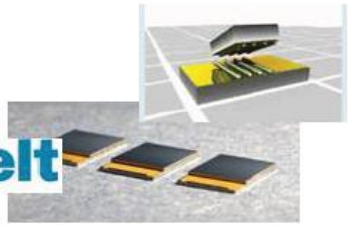


The Partners

Contact Person: **Dr. Martin Jaegle**

Fraunhofer IPM

R&D for micropelt



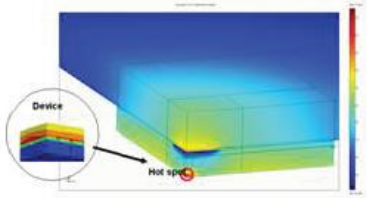
Nanoscale materials
Nanocomposites

Bulk Materials
Modules
>200 °C; ZT>1

Thermoelectric metrology

Customer-specific applications

Simulations/ calculations



The Partners

Contact Person: **Dr. Philip Howell**

SIEMENS

Industry

- Industry Automation
- Drive Technologies
- Customer Service
- Metals Technologies

Energy

- Fossil Power Generation
- Wind Power
- Solar & Hydro
- Oil & Gas
- Energy Service
- Power Transmission

Healthcare

- Imaging and Therapy Systems
- Clinical Products
- Diagnostics
- Customer Solutions
- Audiology Solutions

Infrastructure & Cities

- Rail Systems
- Mobility & Logistics
- Low & Medium Voltage
- Smart Grid
- Building Technologies
- (Osram – will be floated)

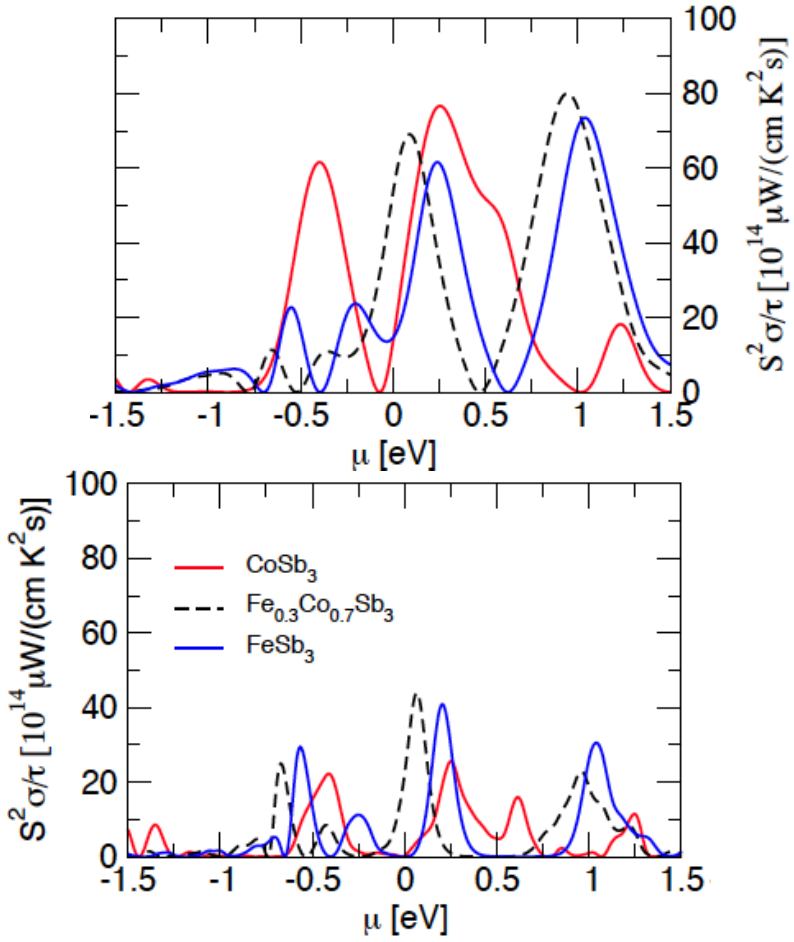
Overview

Workpackage 1: Definition of system requirements

- Shortlisted application scenarios identified
- Key operating conditions and minimum ZT requirements identified
  - Temperature range: Hotside: 200 – 600 ^{o}C
    Coldside: 60 – 80 ^{o}C
  - Module power density: 0.5 W cm^{-2}
  - Minimum ZT: > 0.8

Overview

Workpackage 2: Theoretical Modeling and Simulation; Materials Selection and Fabrication



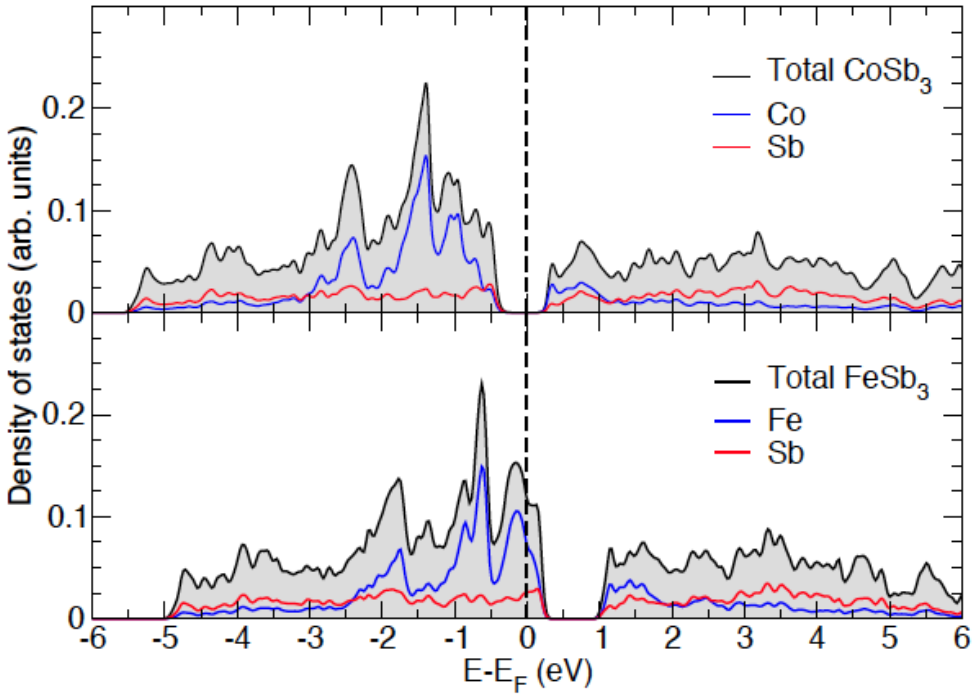


Figure 1. Calculated density of states for $CoSb_3$ and $FeSb_3$. The total density of states is shown in black (shaded region) and the Co (Fe) projected density of states is shown in blue. The projected density of states on Sb is shown in red.

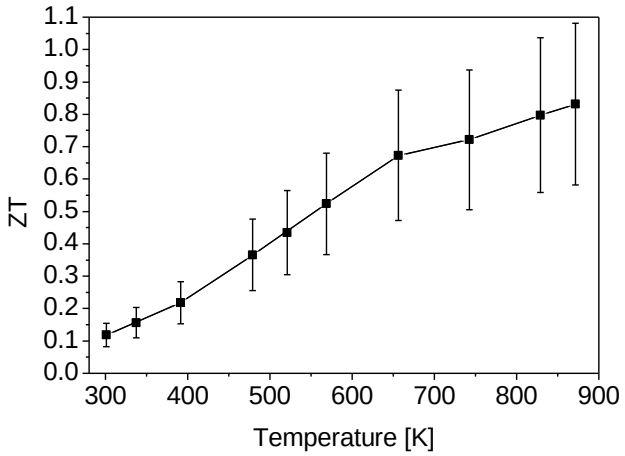
❖ Optimal power factor for x = 0.3

Overview

Workpackage 2: Theoretical Modeling and Simulation; Materials Selection and Fabrication

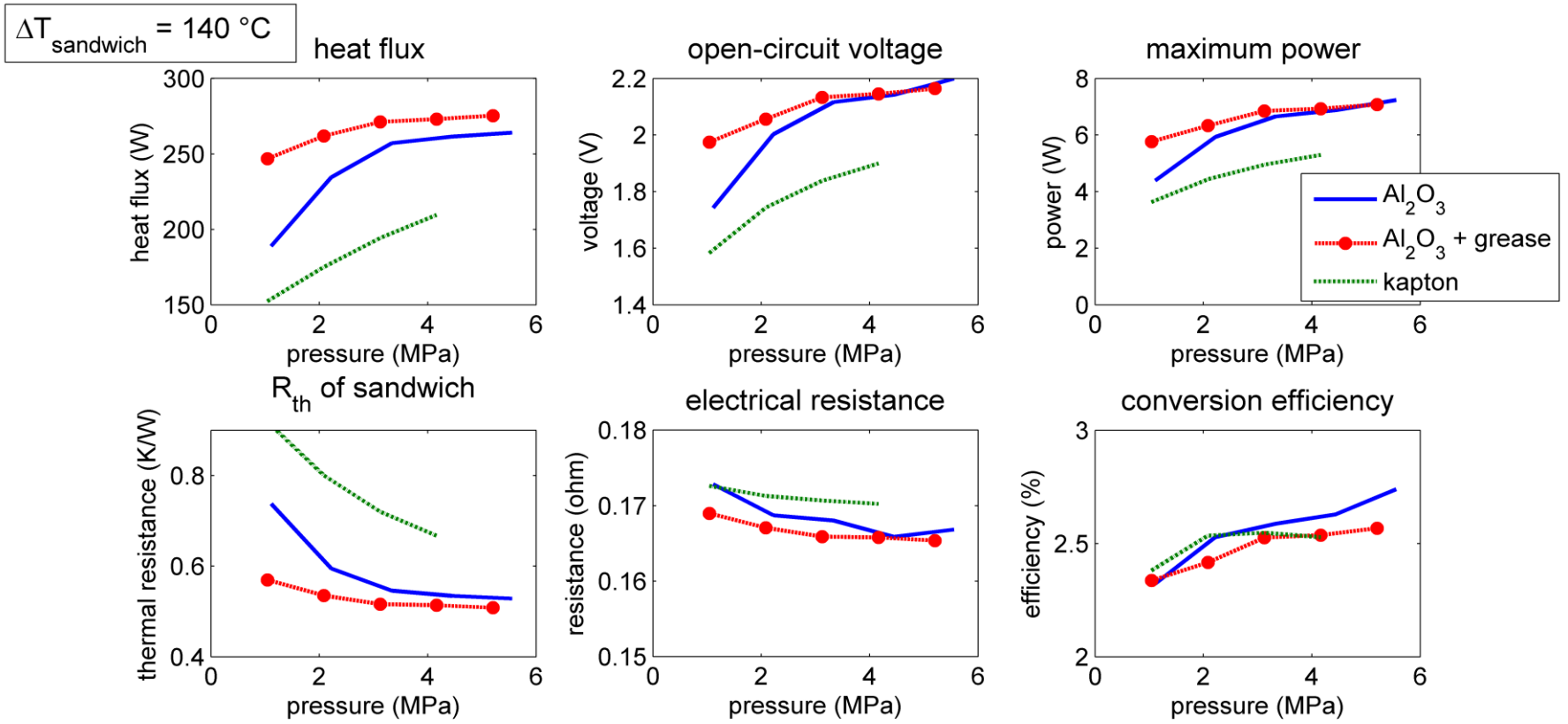
State of the art results for unfilled skutterudites

- n-type: $Fe_{0.1}Co_{0.9}Sb_3$ ***ZT*** of ca. 0.9 at 700 K
- n-type: $Ni_{0.3}Co_{0.7}Sb_3$ ***ZT*** of 0.47 at 740 K
- p-type: $Fe_xCo_{1-x}Sb_3$ $(x \geq 0.2)$ ***ZT*** of 0.35 at 700 K



Overview

Workpackage 4: Module specifications: module fabrication and testing



- Increasing pressure ➔ higher open-circuit voltage ➔ higher maximum power
- Increasing pressure ➔ lower thermal resistance ➔ higher heat flux ➔ limited increase in efficiency
- Kapton has highest thermal resistance ➔ lower heat flux ➔ lower electrical power
- Thermal grease ➔ same performance as for Al_2O_3 achieved with lower pressures

Overview

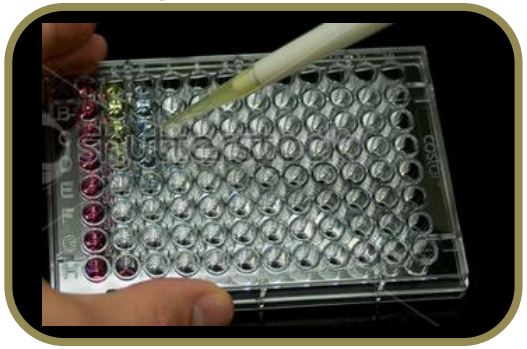
Workpackage 5: Life-cycle impact assessment

skutterudites

Dispersion in culture media

Exposure

Seeding of cells (A549)



24h

72h

Toxicological assays (Viability in A549 cells)

Concluding Remarks

- NEXTEC is in the third and last year
- Developed NS Skutterdite and BiTe with improved ZT
- Optimized conssolidation and procesing techniques for NS materials
- Constructed 2 modules for heat recovery
- Developed novel construction of modules (ring stuctucte) for heat recovery.
- Modules are being tested in rigs by industrial partners
- Three Patent-applications – over 40 papers and presentations