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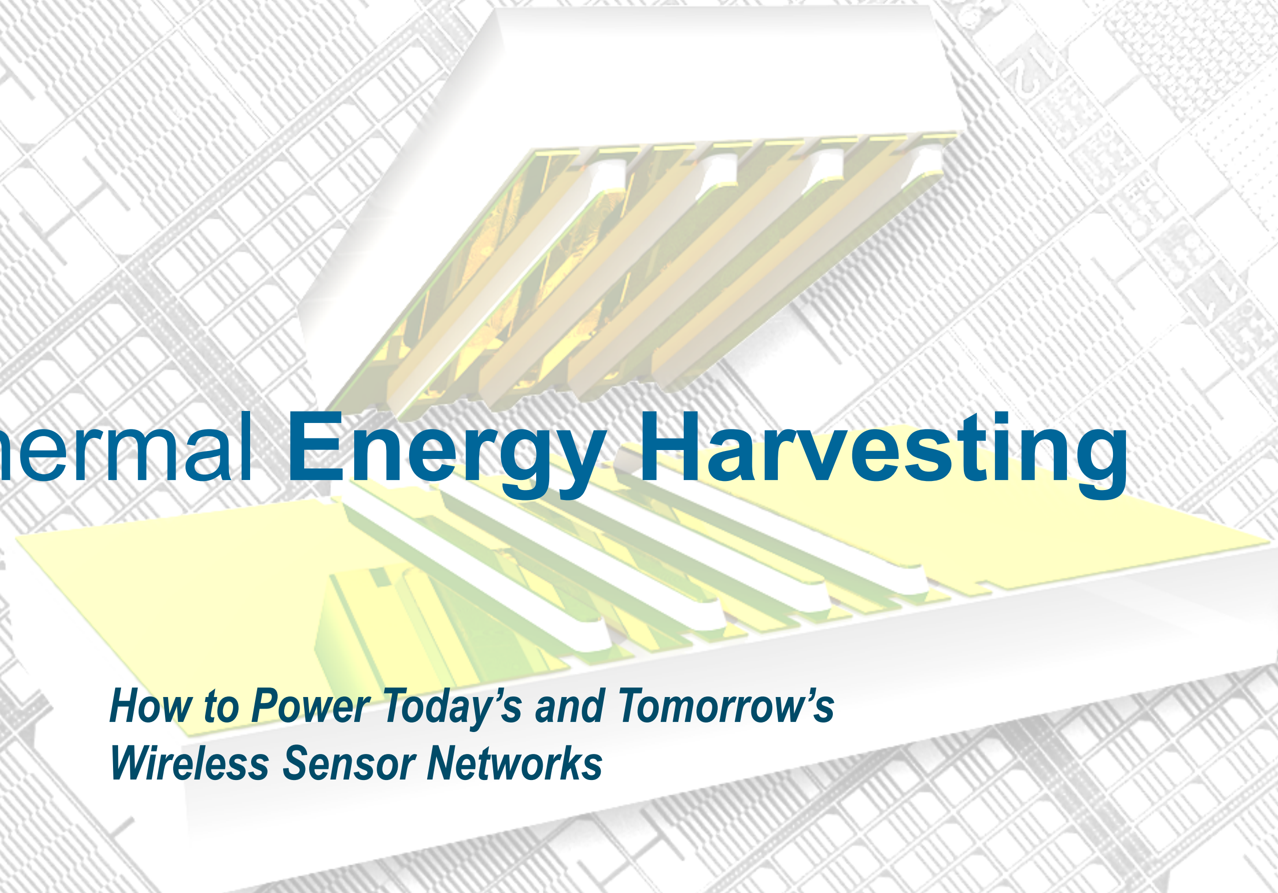

Thermal **Energy Harvesting**

How to Power Today's and Tomorrow's Wireless Sensor Networks

by

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Freiburg, Germany

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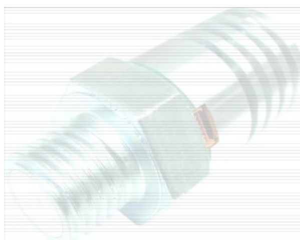
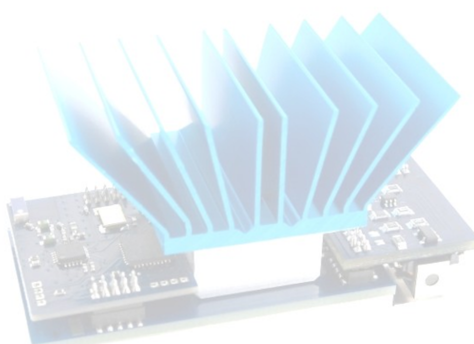
Outline





Introduction

Motivations

- Energy Harvesting System View
- Micropelt Introduction
- Sourcing Free Primary Energy
- Thermoharvesting Basics
- From Technologies to Applications
- Conclusions & Discussion

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Take a little bit...

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Motivation
More Intelligent, Sustainable Technology & Operations

- Past
  - Design and dimensioning based on experience, trial & error
  - Operation = based on experience, trial & error
  - Maintenance = reactive
- Present
  - Design and dimensioning based on knowledge, statistics, FEM…
  - Operation = based on statistics, inevitable sensor feedback, and experience
  - Maintenance = preventive
- Future
  - Design and dimensioning based on knowledge, detail statistics, FEM, simulations…
  - Operation = based on process modeling + massive sensor feedback
  - Maintenance = condition based

Information is key!

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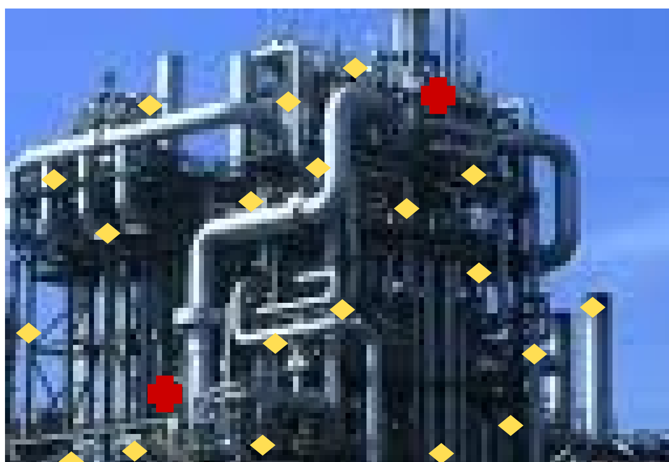
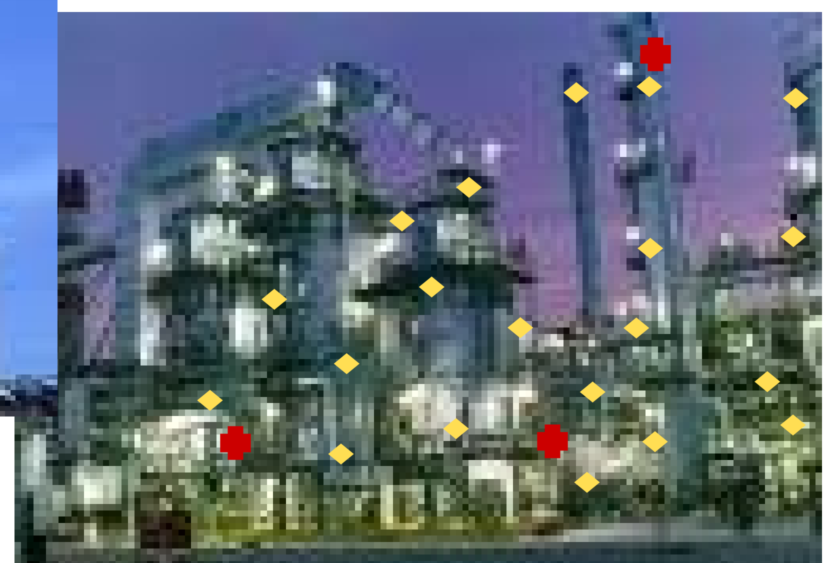
The Utility of Energy Harvesting

- 50% to 75% of each maintenance $ is spent in vain
  - Condition based operation and maintenance is a new paradigm to fix this
- Much better insight through extensive sensing
  - Improve productivity, reliability and control,
  - Reduce cost, risk and resource utilization.
- The last big time savings potential at the bottom line?

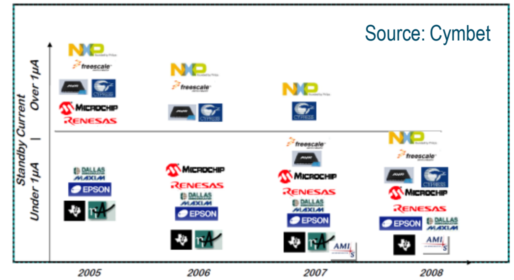




The Enabling Wireless Platform

IEEE 802.15.4

- Hardware standard for ultra-low power (ULP) short range wireless networks
- Defining layers 1 and 2 of OSI model
- International unlicensed frequency bands



FEATURES

- Data rates of **250 kbps**, 40 kbps, and 20 kbps.
- Two addressing modes; 16-bit short and 64-bit IEEE addressing.
- Support for critical latency devices, such as joysticks.
- CSMA-CA channel access.
- Automatic network establishment by the coordinator.
- Fully handshaked protocol for transfer reliability.
- Power management to ensure low power consumption.
- 16 channels in the **2.4GHz ISM** band, 10 channels in the **915MHz** I and one channel in the **868MHz** band.

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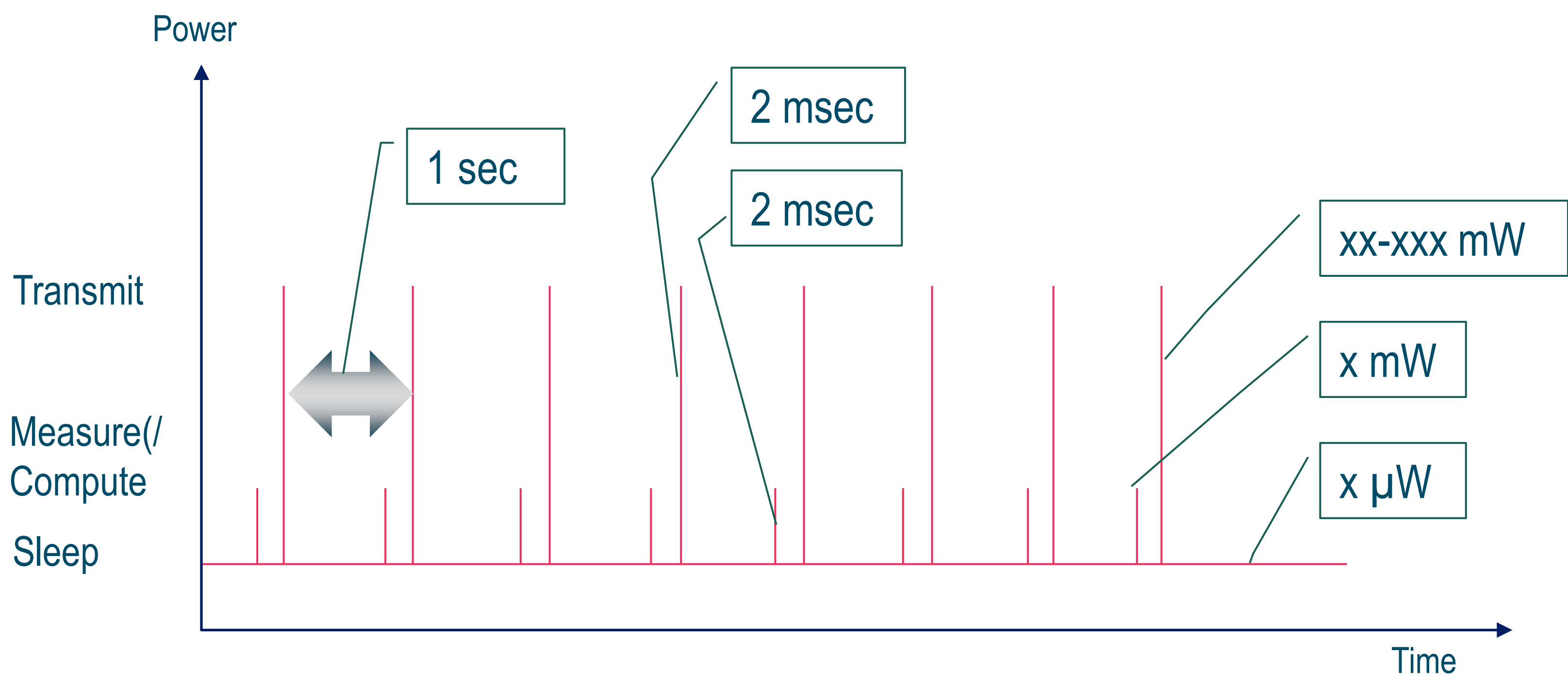
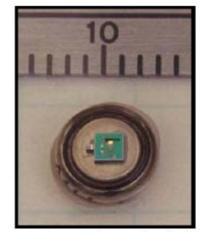
Ultra-Low Power Paradigm: **Duty Cycle**

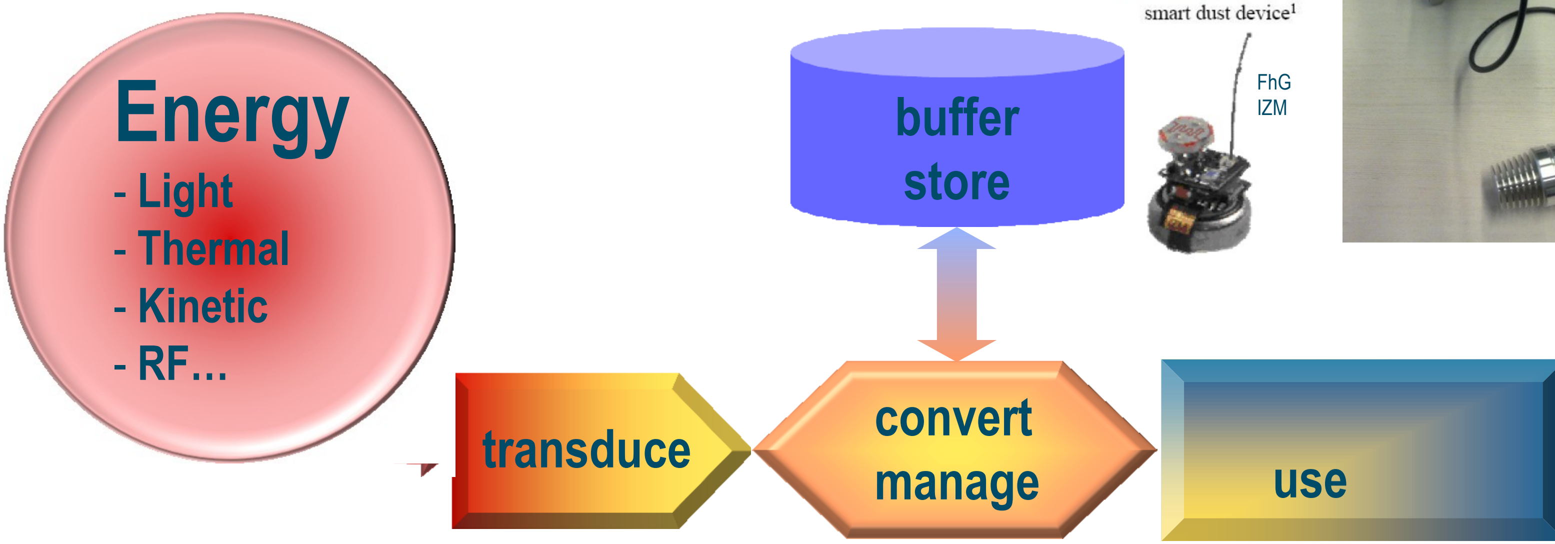
- Definition
  - Active time(s) divided by total cycle time $\frac{T_a}{T_c}$ [%]
  - e.g. 4 milliseconds active time per second = 0.4% duty cycle



The Concept

- Take a small portion of an otherwise lost flow of ‚primary' energy, and convert it into a small flow of USEFUL electrical energy.
- Economically:
  - Zero CoO - the energy is free, maintenance is not required


smart dust device[1]



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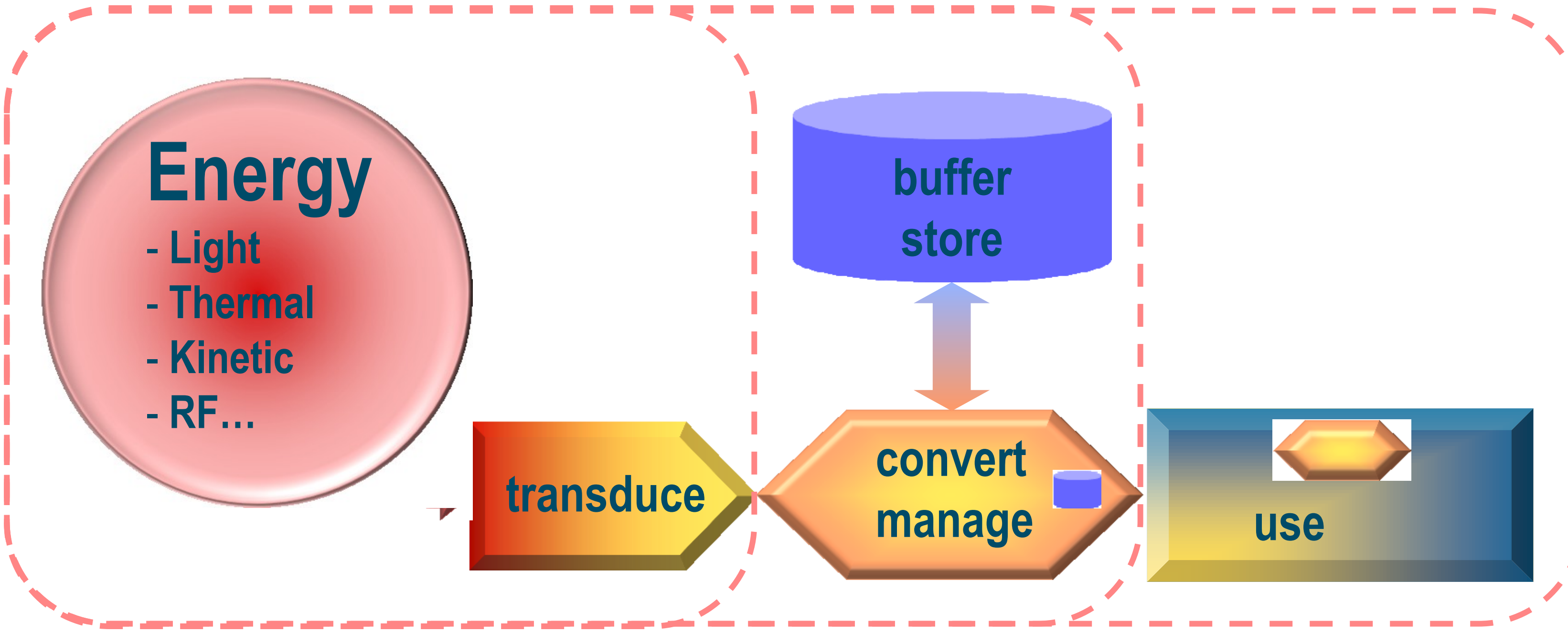
Options of Implementation

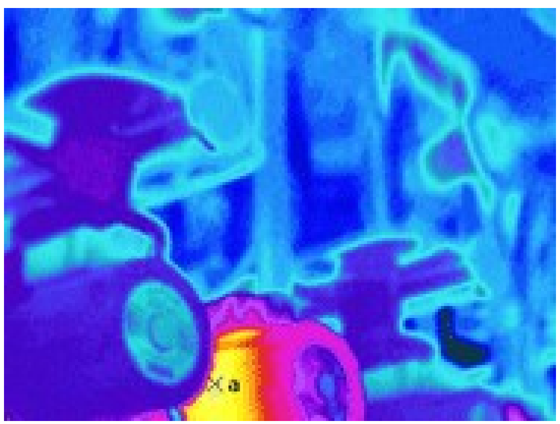
- Harvester integrated instrument
- Buffered Harvester
  - Supplies duty pulses
- Trickle charging Harvester
  - Recharges / supplements instrument's energy buffer
- Primary harvester
  - Instrument does it all



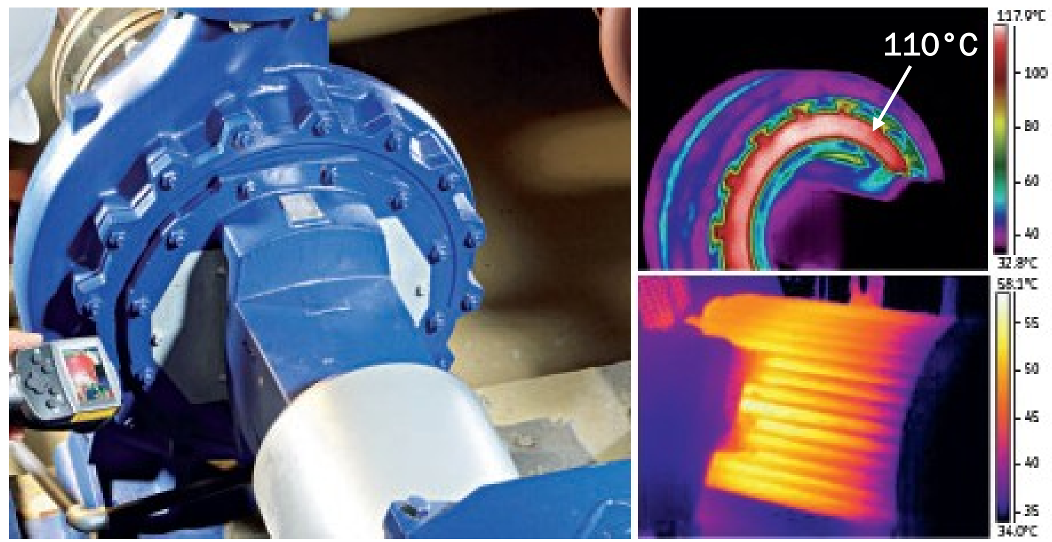
Thermoharvesting

- Just a moment...

Water pump with bearing failure*3



Bearing during normal operation *4



Quellen/Source:
*3 www.vonderlieck.de - Von der Lieck GmbH, Germany
*4 SKF Info Magazine April 2006, Germany

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Micropelt Focus Markets

Addressing opportunities in existing and emerging markets

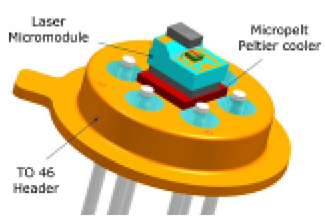
Fast ΔT Sensing

- Explosion detection & control
- Detection of temperature differences & changes
- Calorimetry

Life Science Bio-Chemical

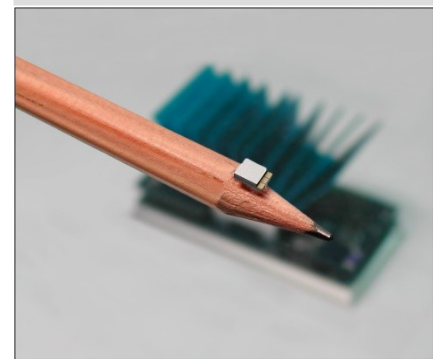
- Faster cycling for PCR and bio-chemical µl processes
- Thermal control for Lab-on-Chip and instant diagnostic applications

Laser Cooling



- Smaller package sizes,
- Lower power
- Easier assembly,
- Reduced cost of ownership

Power Generation



- Energy from waste heat
- Maintenance free low power devices
- Wireless sensing & sensor networks

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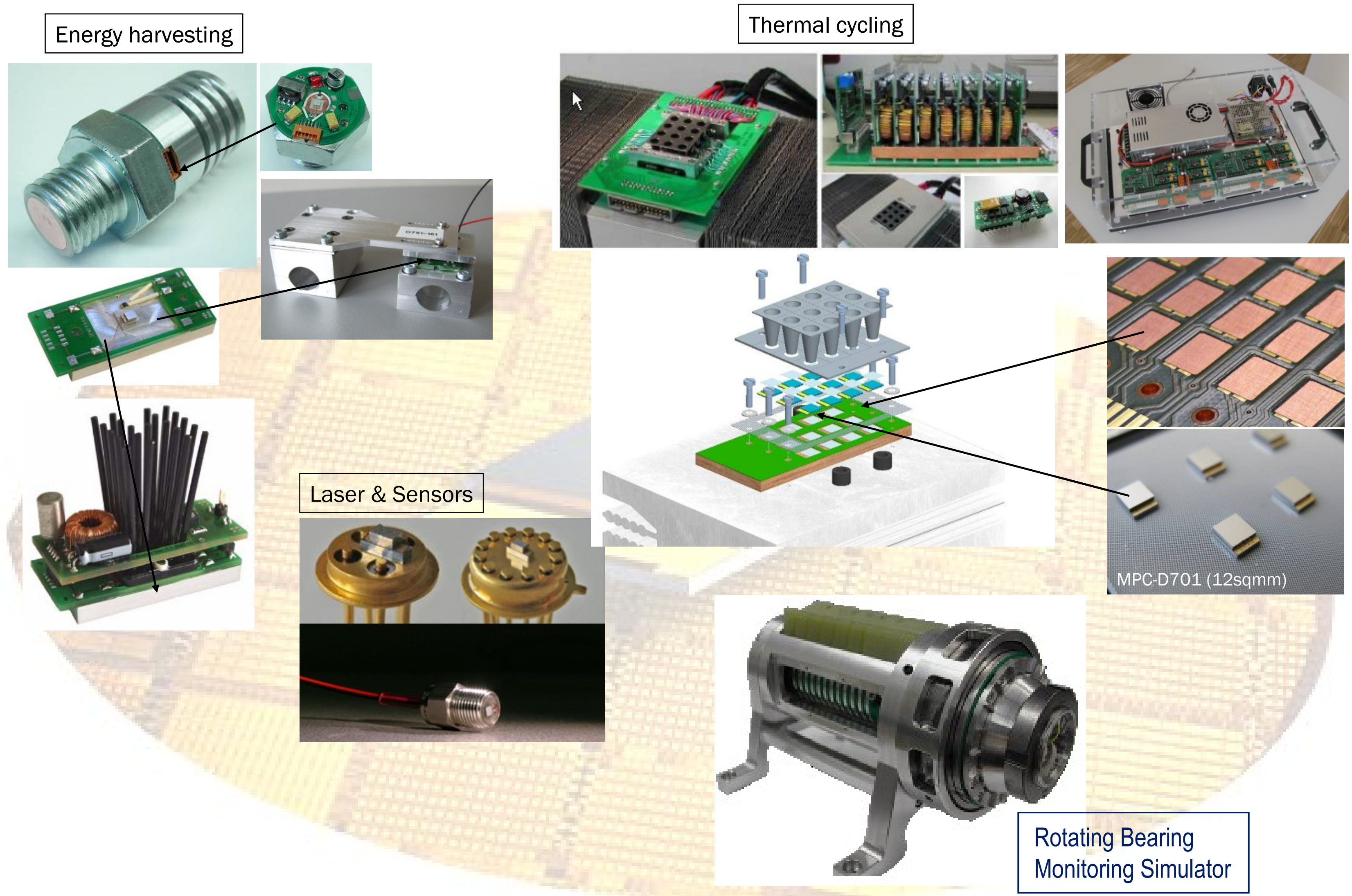
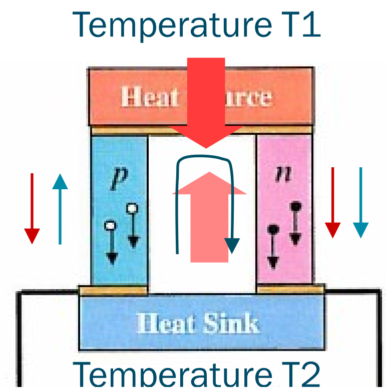
Chip Manufacturer with Prototyping & Engineering in all Target Markets

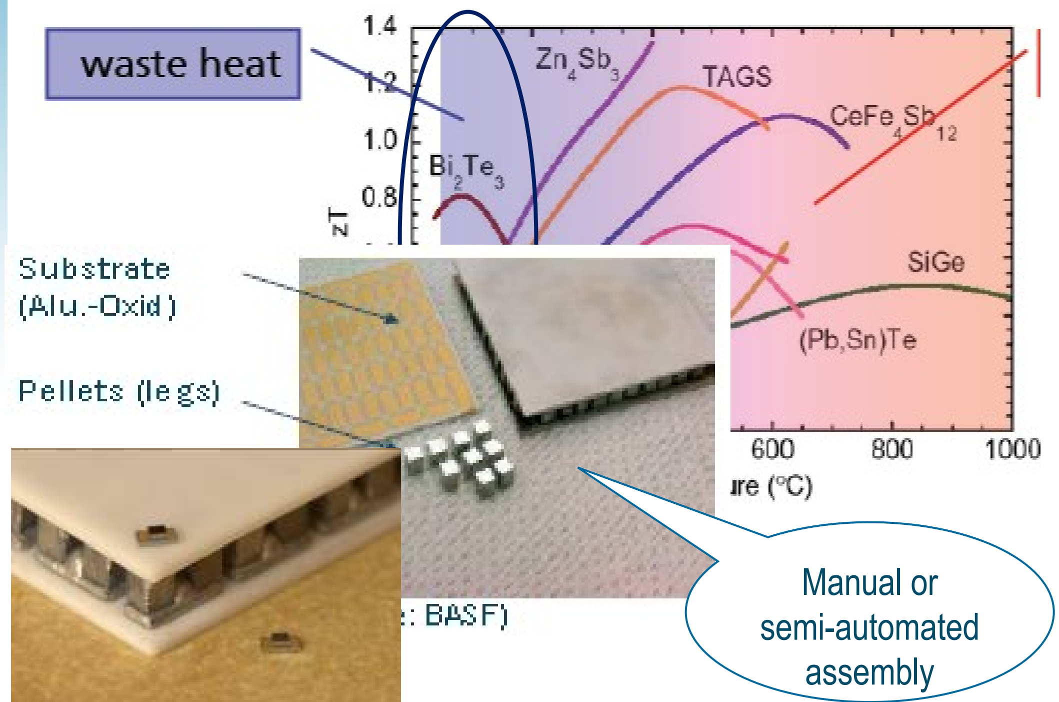


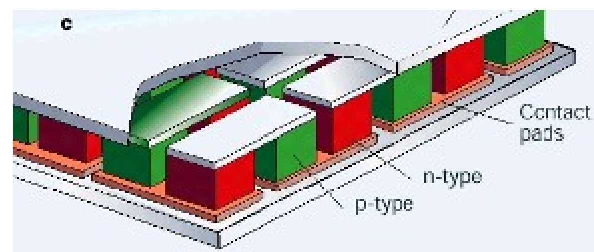
Thermoelectric Basics

The and
basic building block
= **Thermocouple**



Material system: Bismut-Telluride (Bi_2Te_3) with best properties between 25 C and 150 C





TE Element = multiple thermocouples:
Thermally in parallel,
electrically in series

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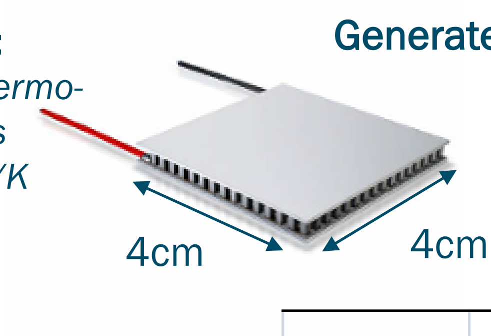
Thin Film vs. 'Bulk' Thermogenerators

Legacy:
128 thermo-couples
50 mV/K

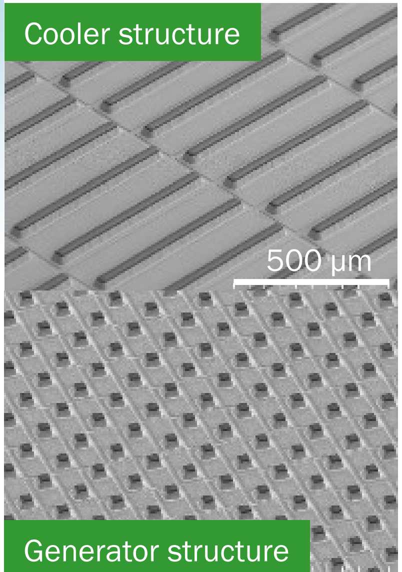


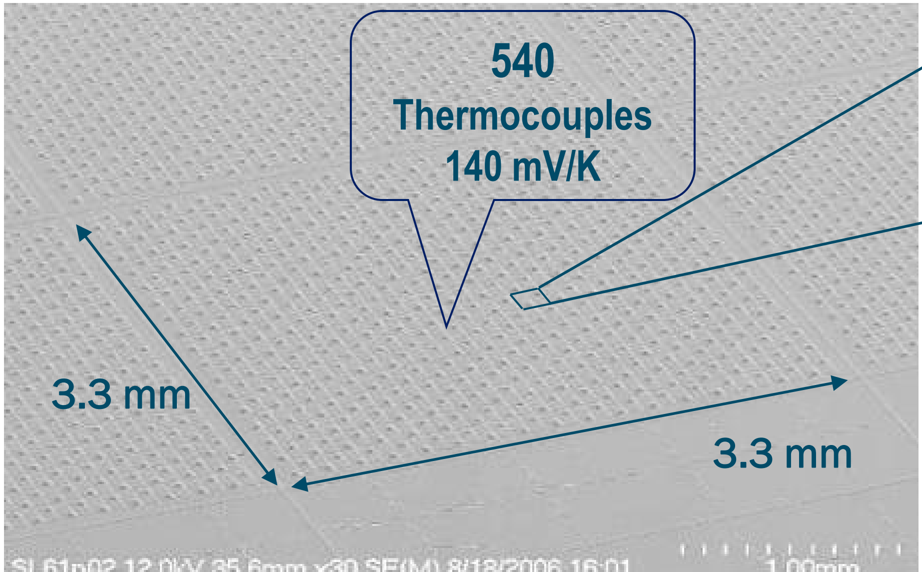
Generated voltage directly proportional to number of thermocouples

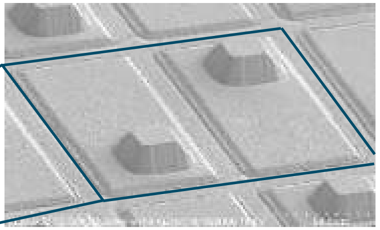
$$U\ (V) = N_{leg} * (dT * \alpha)$$
Seebeck's Law

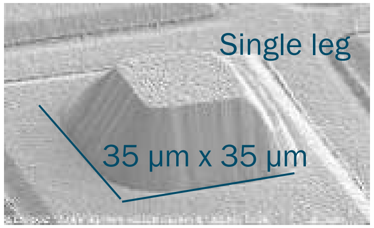
U: Output voltage U in Volt open circuit
N: Number of leg pairs
α: Seebeck coefficient Volt per Kelvin
dT: Applied temperature difference

	Typical Legacy Device			MPG D751	
Device Area	16	cm²		0,11	cm²
Voltage / leg pair	0,0004	V/K		0,00026	V/K
Leg pairs / cm²	128	8 per cm²		540	4958 per cm²
Voltage / Gradient	0,05	V/K		0,14	V/K
Voltage / Area	0,003	V/Kcm²		1,3	V/Kcm²





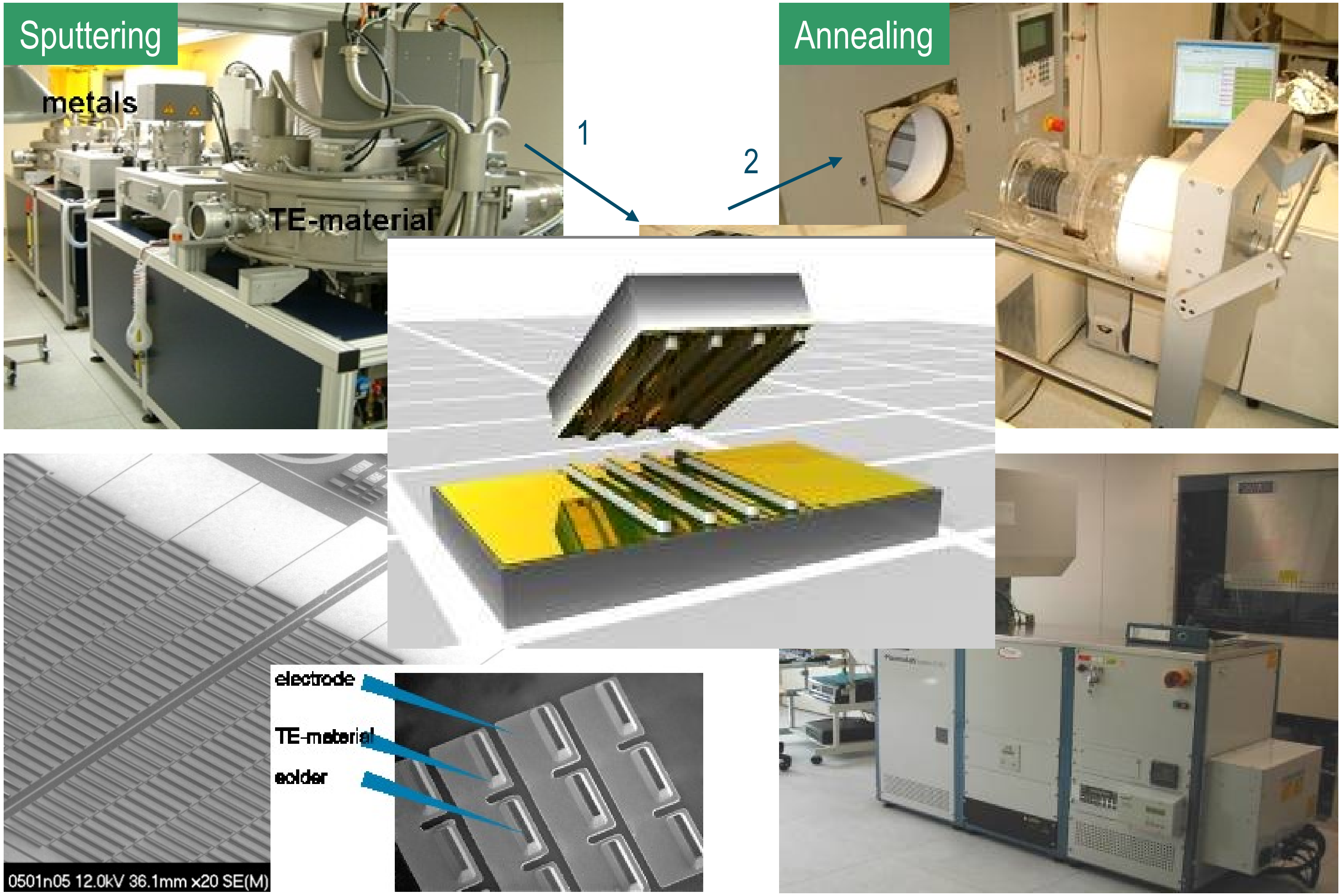




Thin Film Volume Production

Micropelt pilot production line (Frontend)

- Low material usage per Watt generated, scalable mass production



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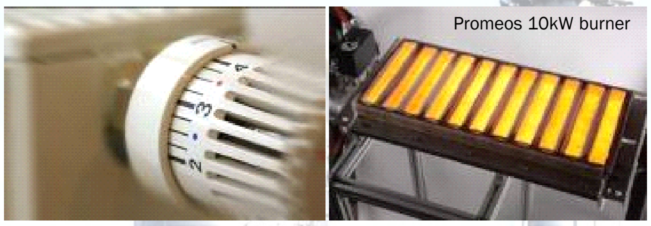
Applications in Process and Condition Monitoring, Building Automation…

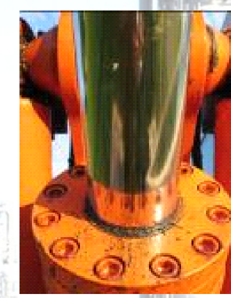
Heating / HVAC / off-grid combustion control



Bearing condition monitoring

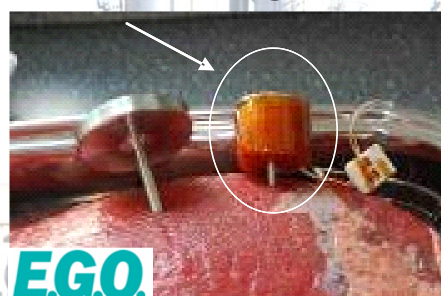
Pressure valves & steam traps monitoring

Hydraulics monitoring



Process control / sensing

Wireless cooking sensor



Temp.-transmission every 2nd. sec.

Machine & structural health

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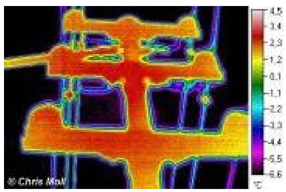
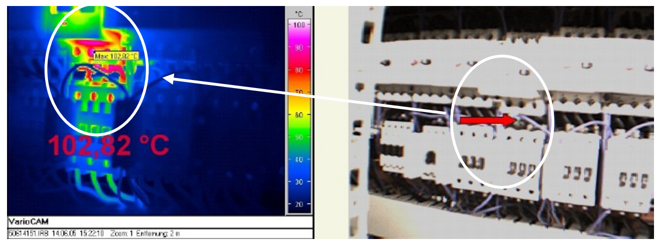
Ubiquitous ‘*Free Primary Energy*’ Sourcing

‘Every technical process produces waste heat’

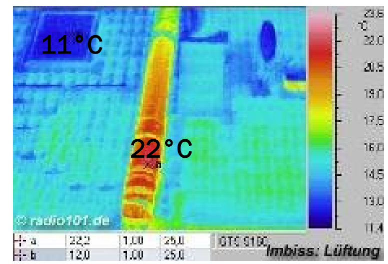
Electrical tower*1



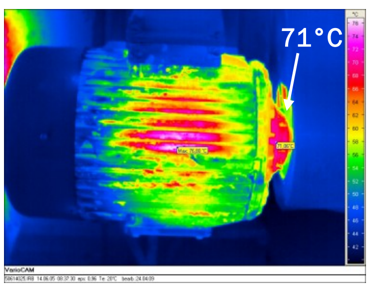
Switchboard*2



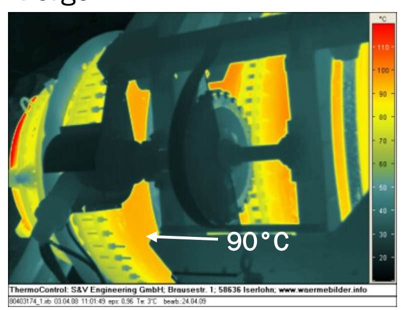
Vent pipe on roof*1



Electric motor*2



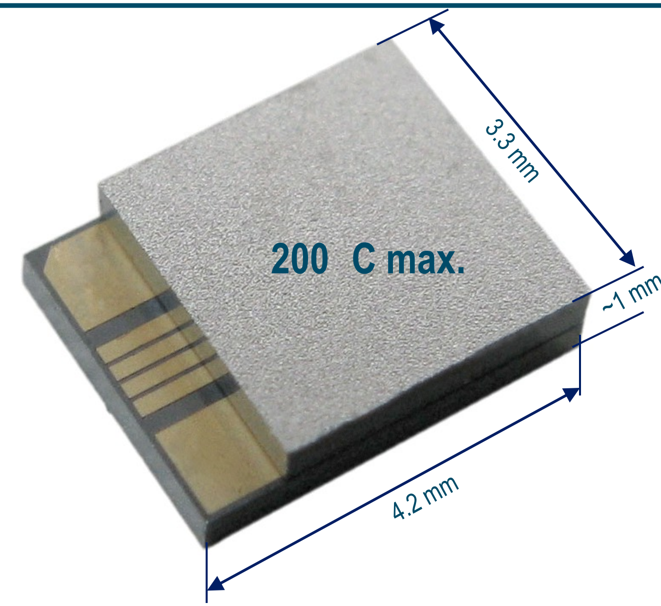
Forge*2

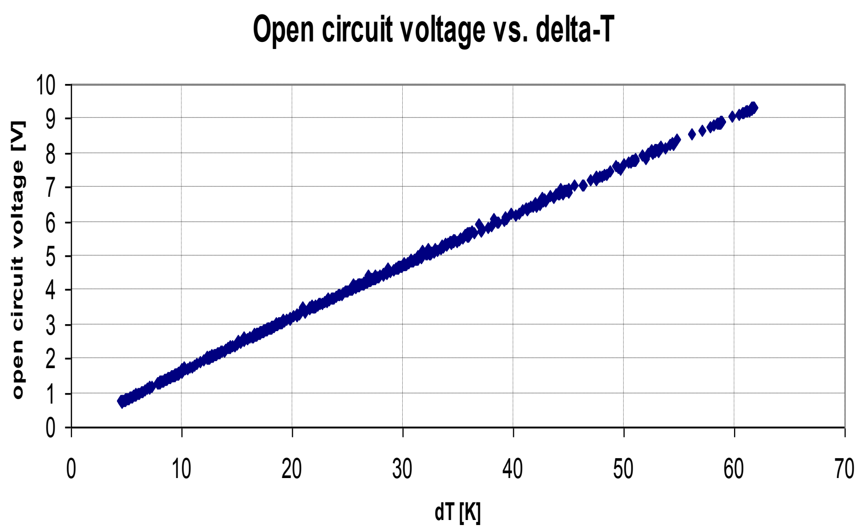


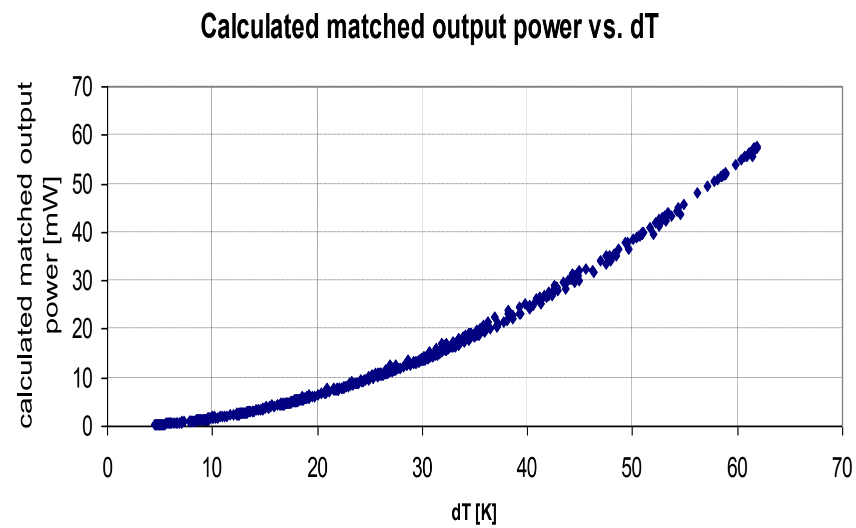
Quellen/Source:
*1 www.radio101.de
*2 www.waermebilder.info S&V Engineering, Germany

Thermogenerator Characteristics
MPG-D751

- Electrical:
  - Thermo-Voltage: u_{TEG} = 0.14 V/K
  - Electrical Resistance: R_{TEG} ~ 350 Ω
- Thermal:
  - Thermal Resistance: R_{th} = 12,5 K/W
- Output







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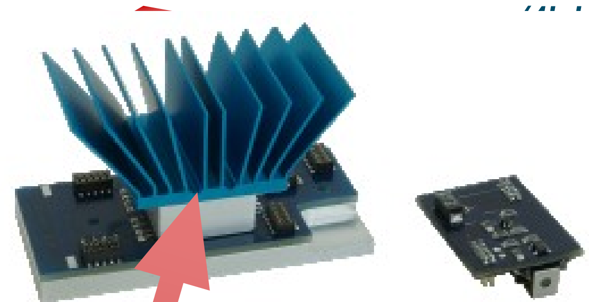
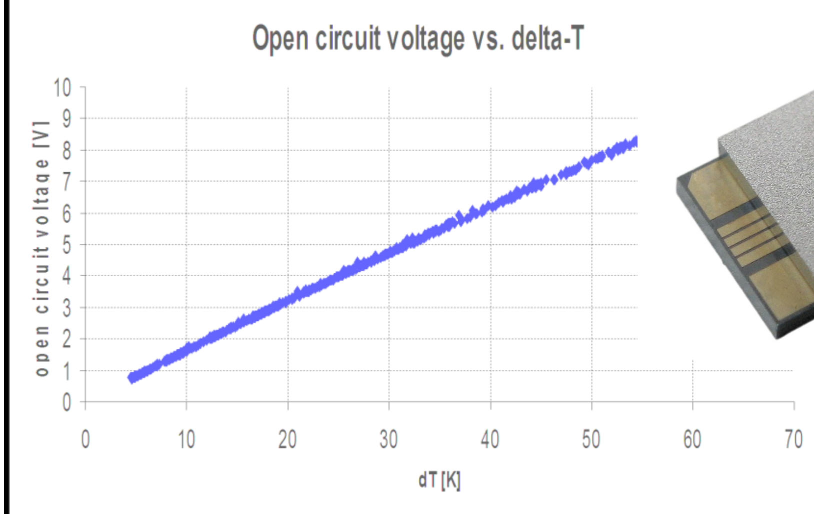
Approach Practical Implementation
e.g. modular wireless thermoharvesting evaluation system

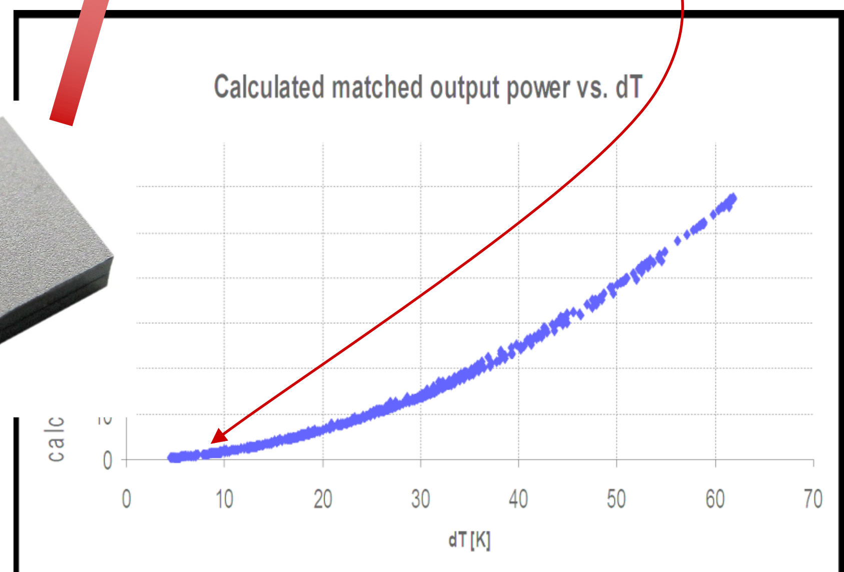
- TE-Power ONE
  Gross Harvesting
  power source
- TE-Power PLUS
  Net harvesting
  1.6 V - 4.2 V DC
  Adjustable voltage &
  capacitor extension
- TE-Power NODE
  Harvesting Wireless Sensor Node &
  Power Budget Explorer

- 4 Channels - I²C interface
- *1Tx/sec @ 3 Knet*
- *0,2% Duty Cycle*

- *5.600 mAh p.a. net*
  ...'s, 7K dT across TEG
  ...oost eff.)



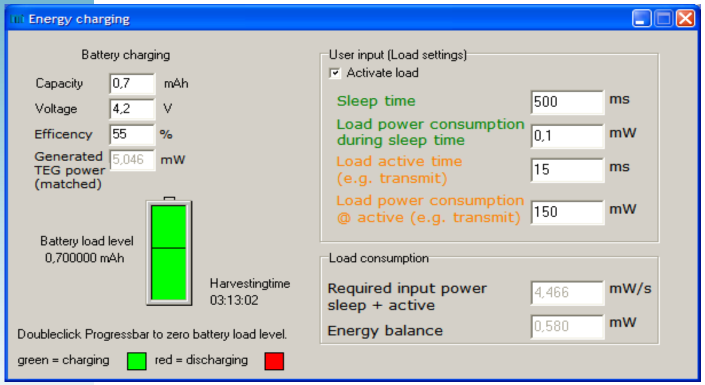


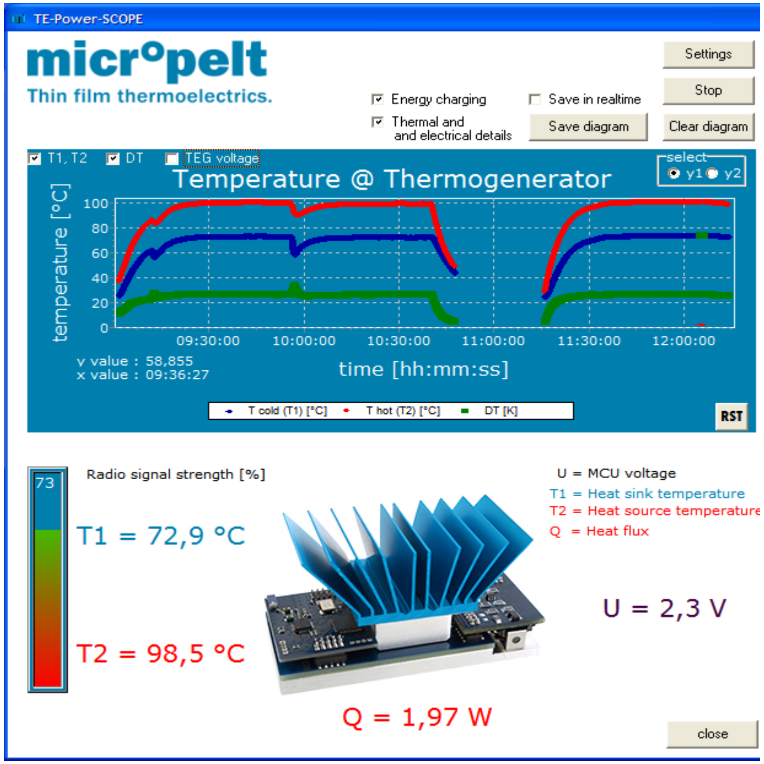


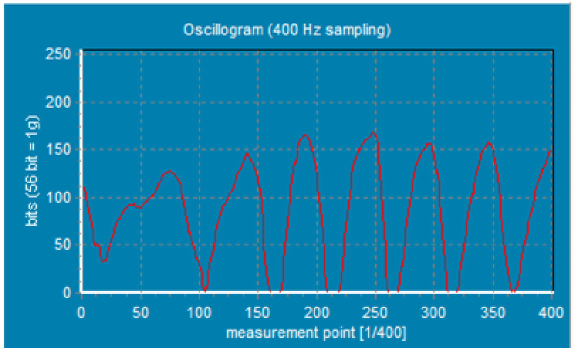
Approaching Real Life Applications

Practical Exploration & Energy Budgeting Software

- Flexible, long term histogram for site studies
- Real-time harvesting conditions and electrical output
- Parameterized energy storage and device power budget analysis
- NEW: Low frequency vibration sensing & analysis

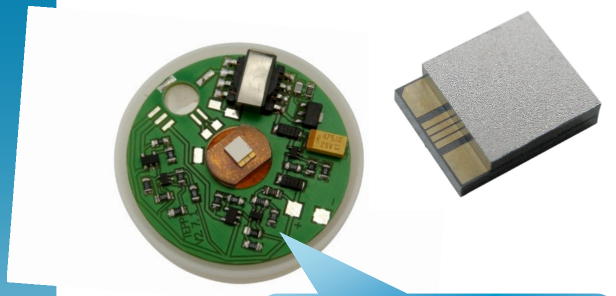




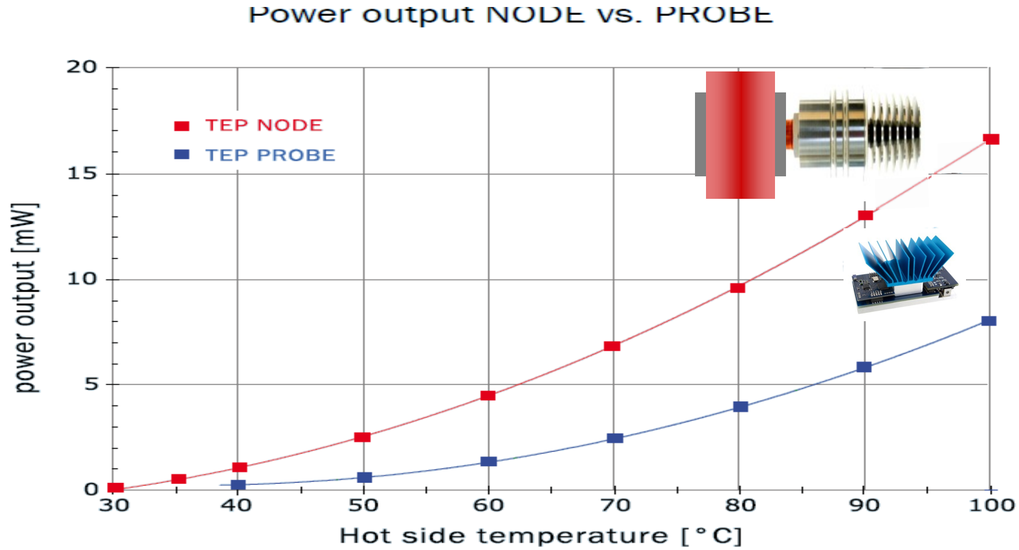


TE-Power PROBE – Micropelt's First Commercial Thermoharvester
Power & Flexibility

Buy at Mouser.com

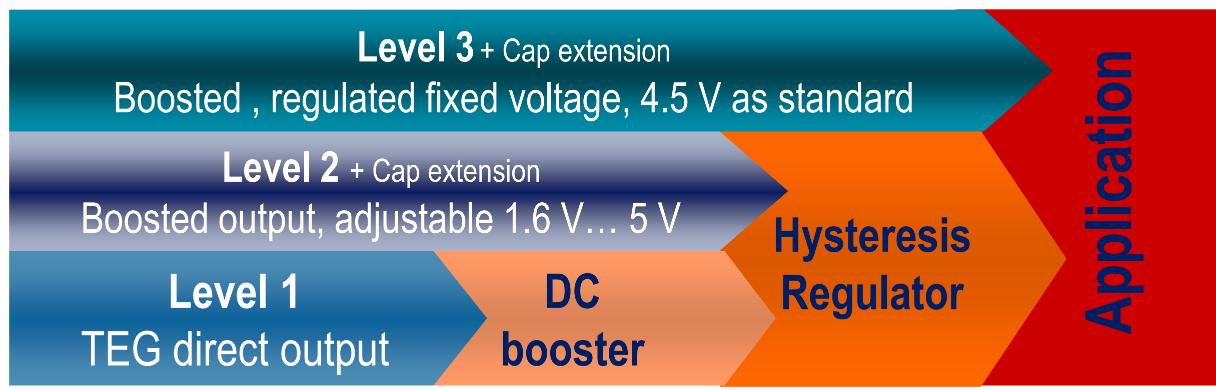


DC Converter or
Power Conditioning



/t (thread)
dry attach

/f
fluid attach



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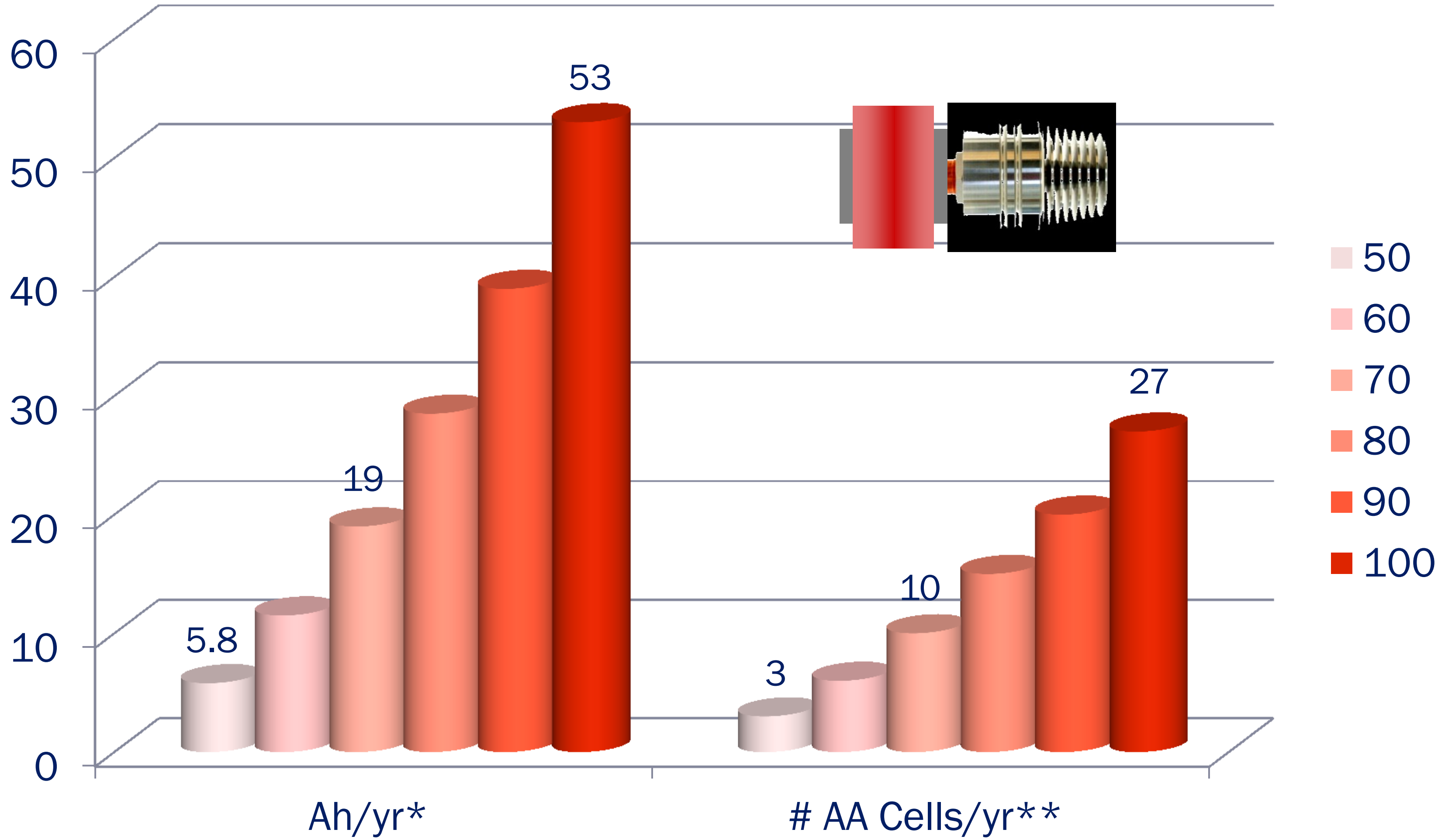
TE-Power PROBE @ 24/7 Constant Harvesting

Net Amp Hours & Battery Equivalents

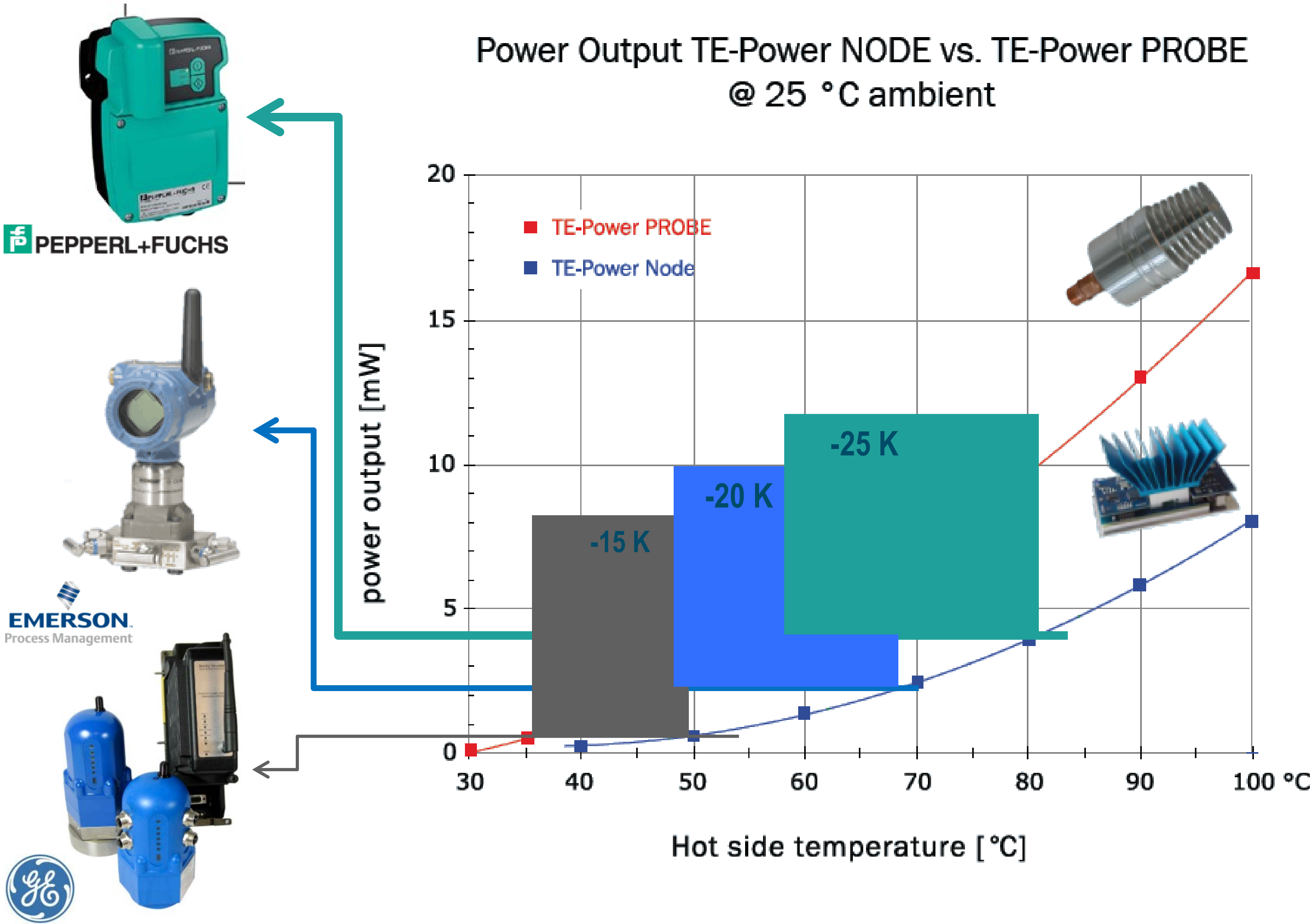


* System voltage: 3 Volt
** Cell capacity: 2,000 mAh

TE-Power NODE vs PROBE

Application scenarios @ different tasks & duty cycles

Available at Mouser.com



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Award-Winning Integrated Transmitter

- ABB Technology Demontrator
  - *Self-powered Wireless*HART temperature transmitter
  - Fully integrated thermogenerators
  - Powered by Micropelt TEG & boost technology

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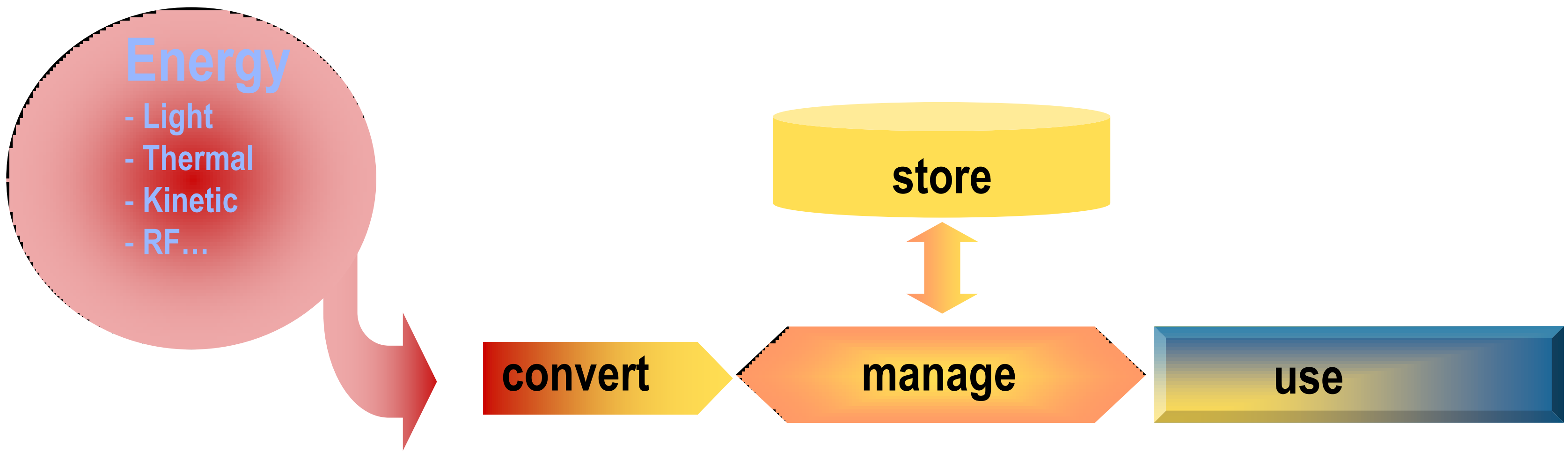
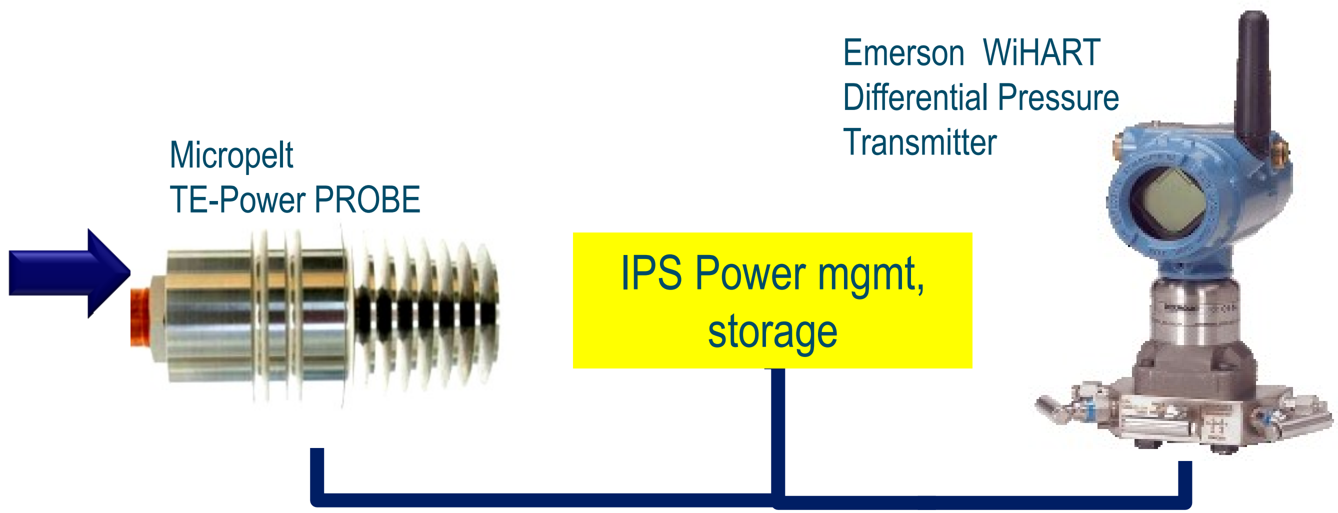
Proof of Concept

Shell Field Trial (Den Helder, The Netherlands)



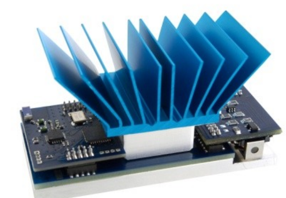


Utilizing Energy Harvesting To Power The Pressure Measurement

- Installation location identified with thermal camera
- Trial purpose:
  - Proof of concept
  - Integrate technologies
  - Identify field requirements
  - Project for university student's thesis

Summary

- Harvesting 1 mW takes less than 20K deltaT
  - Equal to approx. 3,000 mAh
- Most wireless sensors will NEVER be deployed if battery-based
  - Energy harvesting is a key enabler for ‚unlimited sensing‘
- Target applications in most technical environments
  - No real time control
- Thermoharvesting is easy to explore and quantify
  - Off the shelf solutions available
- Power can be maximized
  - Standard harvesting devices
    - Emerging interface standards (ISA & NAMUR)
  - Custom designs for specific applications



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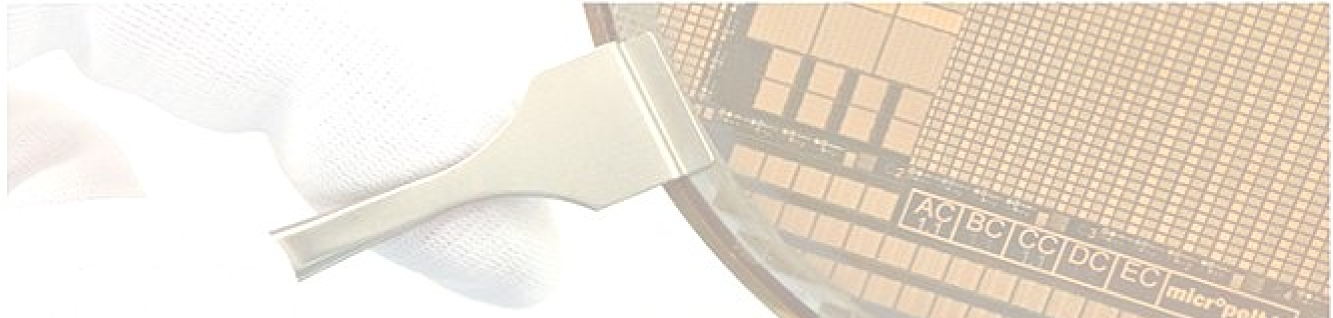

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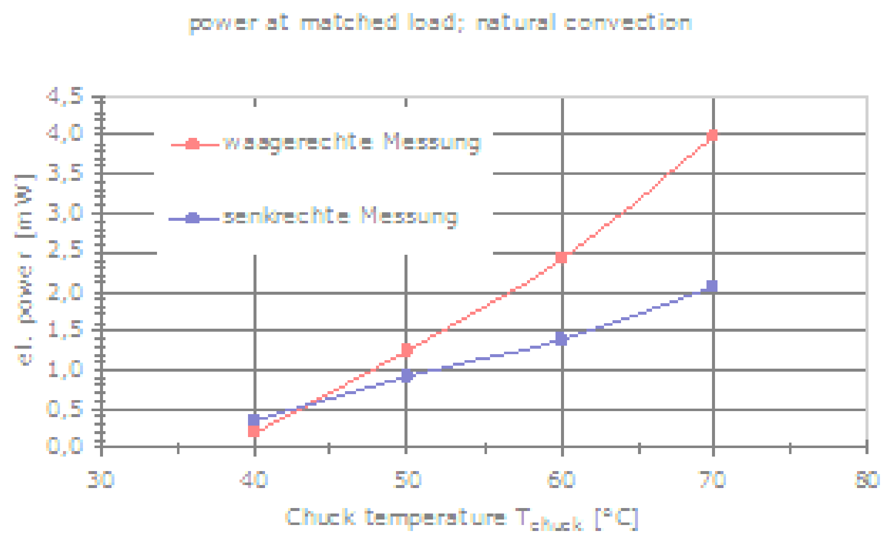

Your questions, please!

Contact:
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VP Business Development
burkhard.habbe@micropelt.com