

# The role of **Micro**-**Energies**

(why studying micro energies can push the autonomous sensor market and the future of computing at once)

Luca Gammaitoni

Dipartimento di Fisica, Università di Perugia

**NiPS** Laboratory  
Noise in Physical Systems



[www.nipslab.org](http://www.nipslab.org)

**Energy Harvesting 2013**

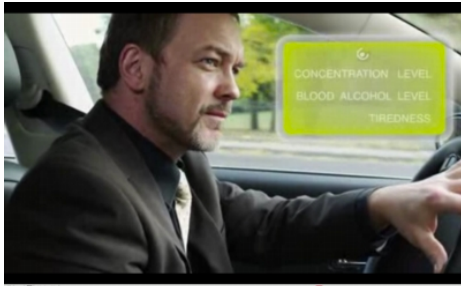
25 March 2013 Hamilton House, Mabledon Place, London, WC1H 9BD

This talk is about a journey...  
...a journey toward a promised land

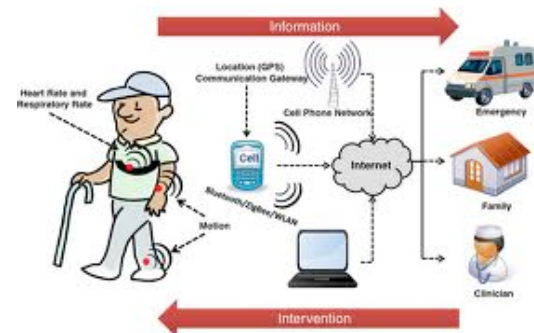
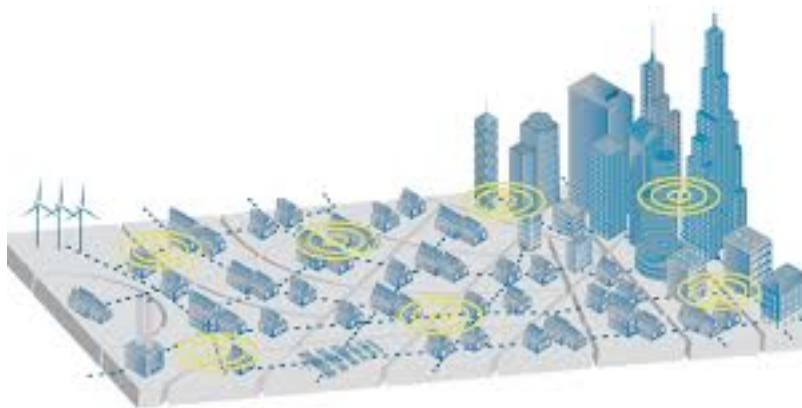


The land of portable electronics

# The promised land

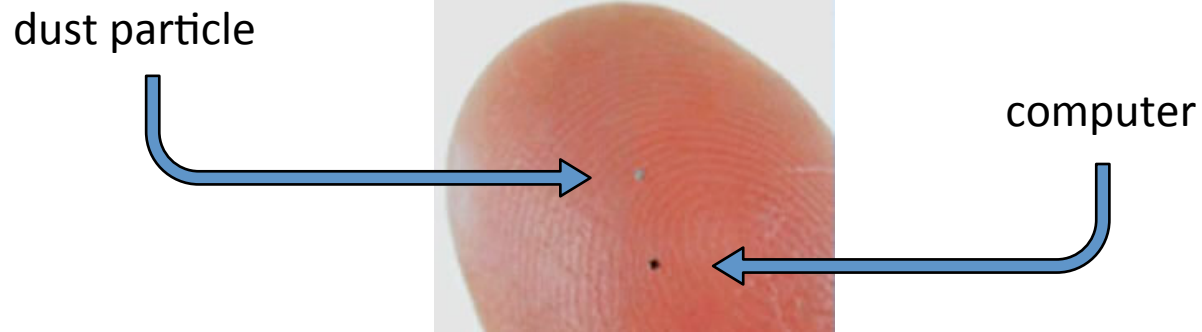


This is the land of wireless micro-sensors that continuously and ubiquitously measure, process and transmit data to improve our living.



This is the long-time announced revolution where the cities become smart and the human and animal health is monitored and controlled.

# The promised land



The land where computers are as small as dust particles



and more powerful than the human brain

# The promised land

## Why are we not there yet?

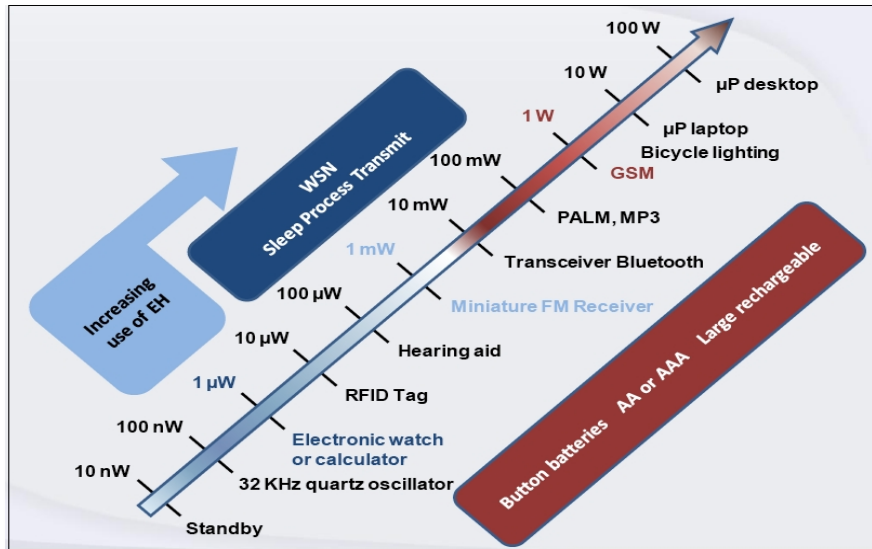
# The promised land

But, as in any promised land.... There is a desert to cross



In our case the desert is the distance between the energy required and the energy available to power the portable electronics

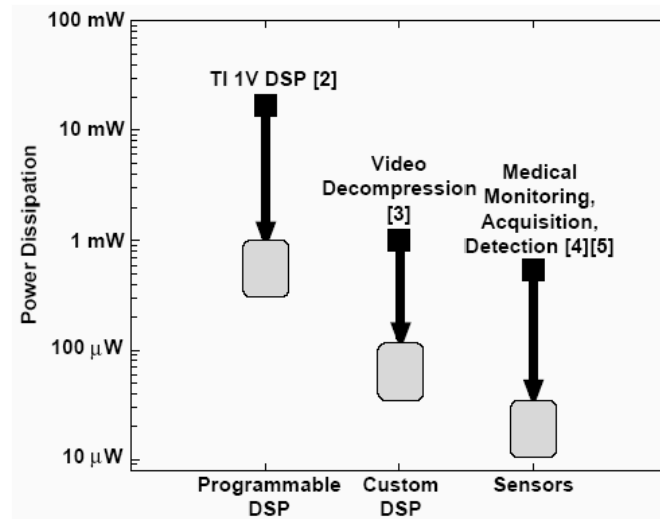
Energy required to  
operate the portable  
devices



Energy available from  
portable sources

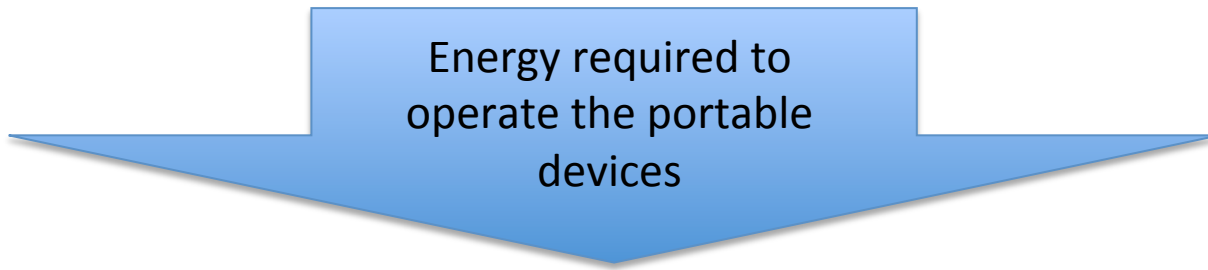
Energy required to  
operate the portable  
devices

### Power Trends for Digital Signal Processing



Energy available from  
portable sources

In recent years we have made progresses but.... There is still some room for improvement

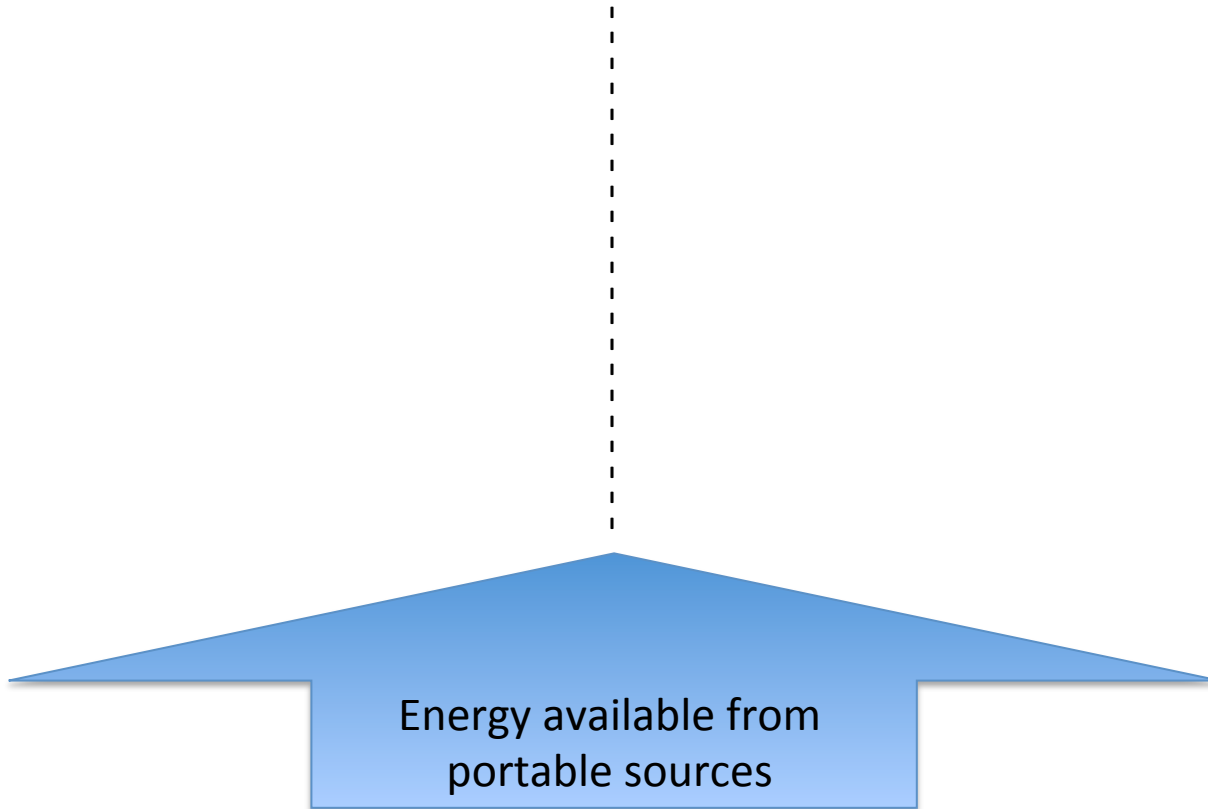


We need to bridge the gap by acting on both arrows



## Questions:

- What is the best technology for energy harvesting ?
- How can we improve efficiency in energy transformation ?
- How do the system scale when we go to micro and nano scale ?
- ...



Few things that I know...

# Energy harvesting

- 1) Significant progresses in recent years in photo-voltaic, thermoelectric and kinetic.
- 2) In kinetic EH introduction of non-linear oscillators allowed for improved efficiency for broad band vibration harvesting

PRL **102**, 080601 (2009)

PHYSICAL REVIEW LETTERS

week ending  
27 FEBRUARY 2009

## Nonlinear Energy Harvesting

F. Cottone,<sup>\*</sup> H. Vocca, and L. Gammaitoni<sup>†</sup>

*NiPS Laboratory, Dipartimento di Fisica, Università di Perugia, and Istituto Nazionale di Fisica Nucleare,  
Sezione di Perugia, I-06100 Perugia, Italy*

(Received 18 September 2008; published 23 February 2009)

Plus some patents:

- IT RM 2007A00079, Generatore piezoelettrico bistabile - 15/2/2007.
- PCT/IT2008/000081 - "Bistable piezoelectric generator." 2008.
- WO/2008/099437 - "Bistable piezoelectric generator." 2008.
- US2010207491 (A1) "Bistable piezoelectric generator." 2008



Video available at: [www.wisepower.it](http://www.wisepower.it)

# Vibration database: RealVibrations

It is very important that we can characterize the spectral features of the vibration we want to harvest...

## Vibration sources digital library

This Task is devoted to the realization of database containing digital time series and spectral representations of experimentally acquired vibration signals.



**NiPS** Laboratory  
Noise in Physical Systems



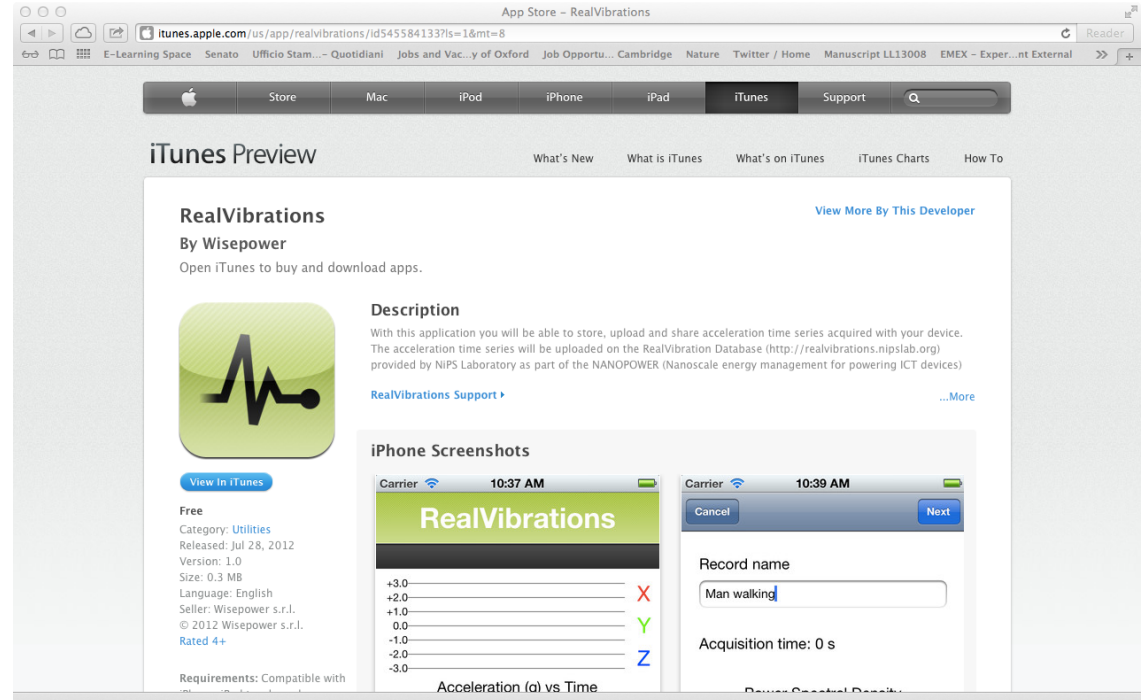
[www.nipslab.org](http://www.nipslab.org)

## Signal presentation:

- Description
- Power spectrum
- Statistical data
- Time series download (authorized users)

[realvibrations.nipslab.org](http://realvibrations.nipslab.org)

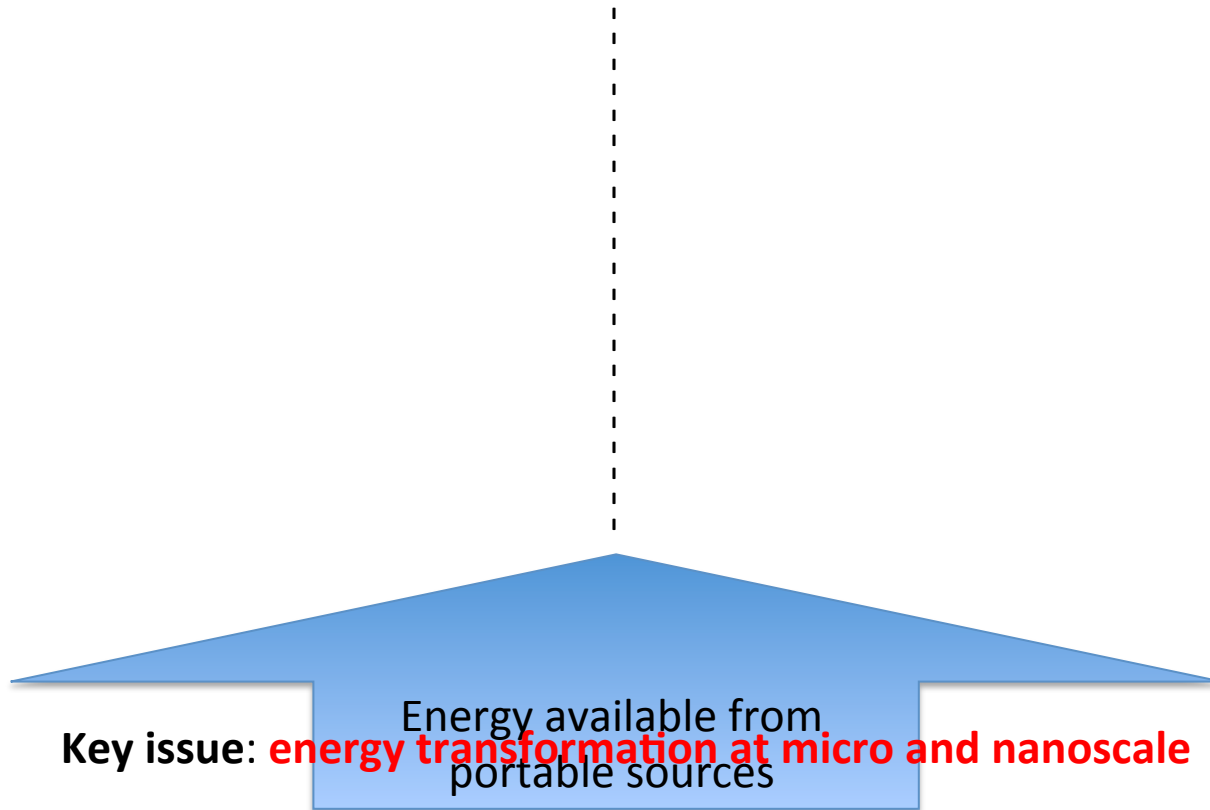
# New App for contributing to the database

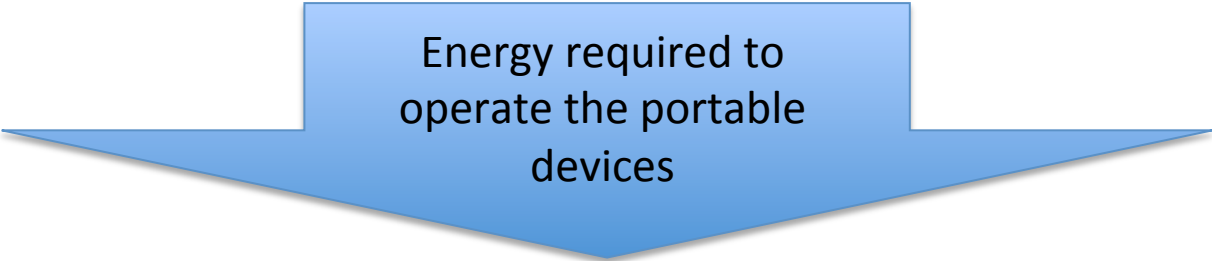


Available on the App Store: **RealVibrations**


## Questions:

- What is the best technology for energy harvesting ?
- How can we improve efficiency in energy transformation ?
- How do the system scale when we go to micro and nano scale ?
- ...





Energy required to  
operate the portable  
devices



Questions:

- How much can we decrease the energy consumption ?
- Is there any limit to the minimum energy required ?
- What is the future technology (beyond CMOS) ?
- ...

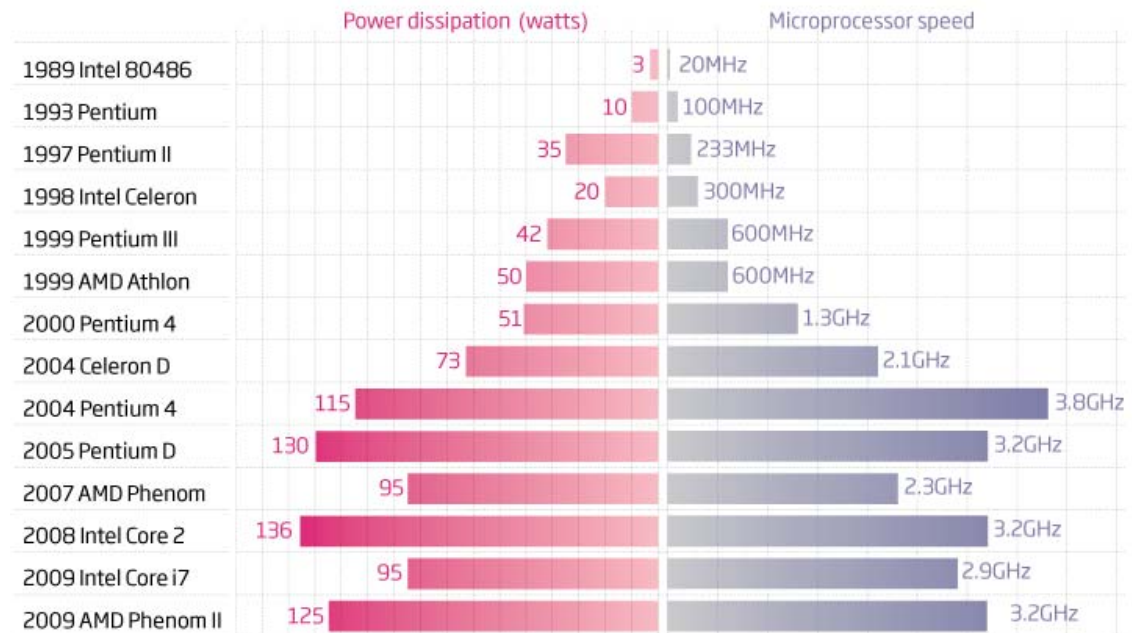
# The problem with ENERGY EFFICIENCY in present ICT

**Energy efficiency** in computing systems has become a major issue for the future of ICT

## Cooler running

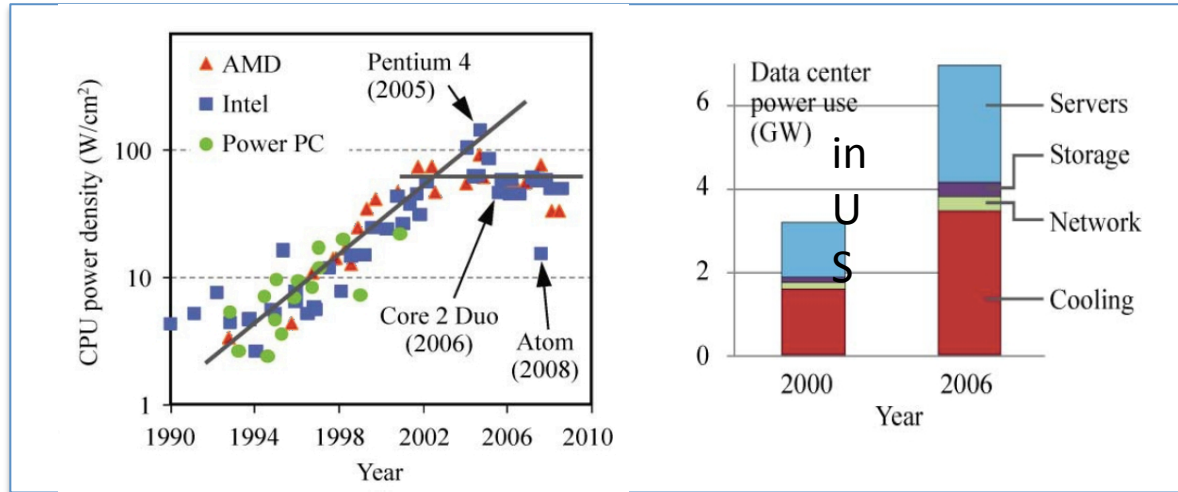
©NewScientist

In general the faster a microprocessor runs, the more heat it generates. In the past five years, the speed of chips has been limited by the need to keep them cool and so stop thermal noise from affecting performance

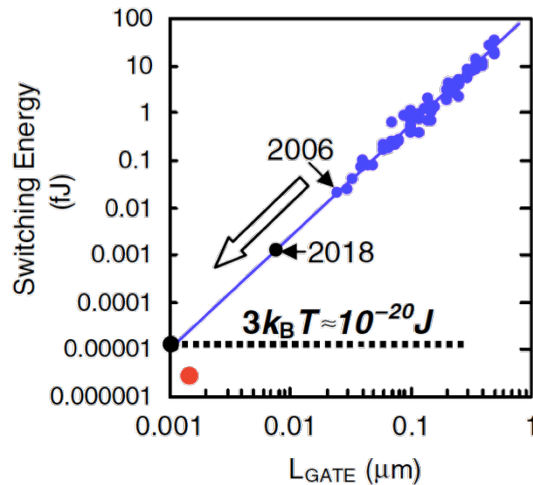


# ICT - Energy

**Energy efficiency** in computing systems has become a major issue for the future of ICT



E. Pop, *Energy Dissipation and Transport in Nanoscale Devices*, Nano Res (2010) 3: 147–169



Research directions and challenges in nanoelectronics  
R. K. Cavin<sup>1</sup>, V. V. Zhirnov, D. J. C. Herr<sup>1</sup>, Alba Avila and J. Hutchby, 2006

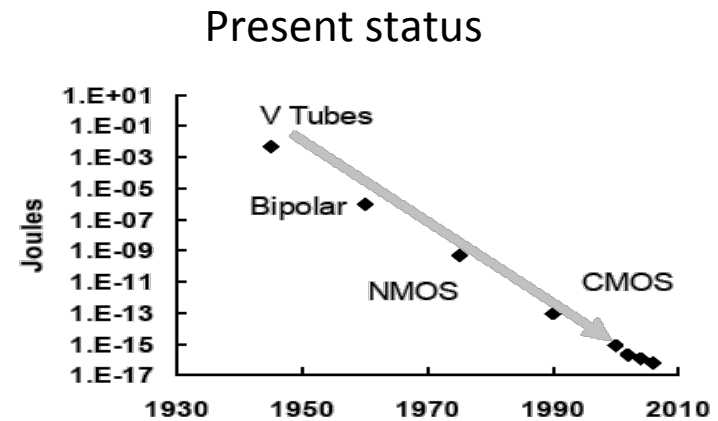


Figure 3: Energy per logic operation

Electronics Beyond Nano-scale CMOS, Shekhar Borkar

## Energy impact of ICT is under discussion

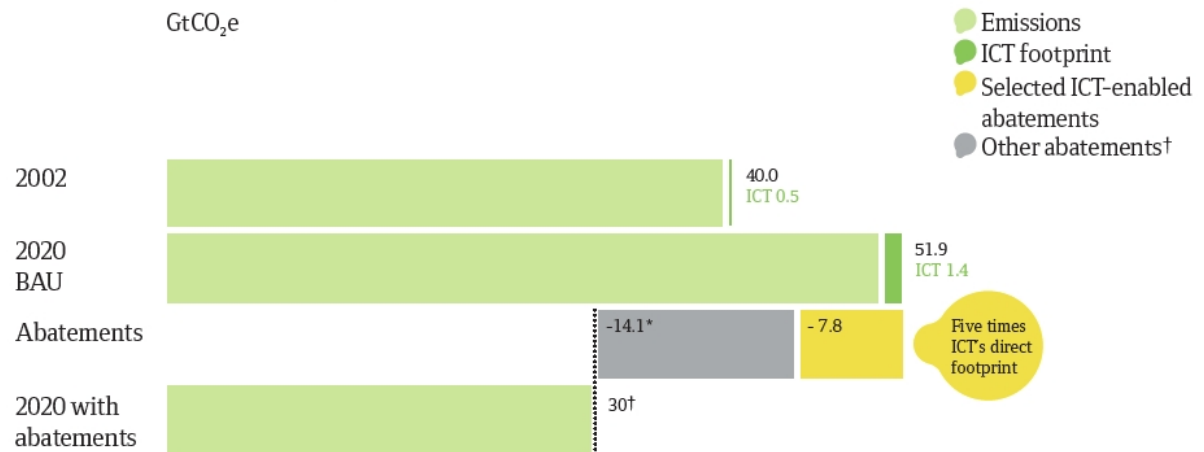
It will be **a clear future priority** world wide to decrease mankind's carbon footprint.

According to the SMART2020 study, the share of ICT on the world wide energy consumption today is in the range of 2-5%.

Hence, it becomes more and more important to consider and improve the energy efficiency of ICT.

On the **short term**, it will be an obvious and practical solution to exploit better the potential of technologies that already exist or are currently in the making. On the **long term**, new and disruptive ideas will be needed, and **we must start to search for those ideas already now**.

Fig. 1 ICT impact: The global footprint and the enabling effect



\* For example, avoided deforestation, wind power or biofuels.

† 21.9 GtCO<sub>2</sub>e abatements were identified in the McKinsey abatement cost curve and from estimates in this study. Source: Enkvist P, T. Naucler and J. Rosander (2007), 'A Cost Curve for Greenhouse Gas Reduction', The McKinsey Quarterly, Number 1.

Energy required to  
operate the portable

Key issue: **energy dissipation at micro and nanoscale**

devices

Questions:

- How much can we decrease the energy consumption ?
- Is there any limit to the minimum energy required ?
- What is the future technology (beyond CMOS) ?
- ...

**Key issue: energy transformation at micro and nanoscale**

**Key issue: energy dissipation at micro and nanoscale**

They both sits on a common scientific ground:

## **Micro and nano scale energy management**

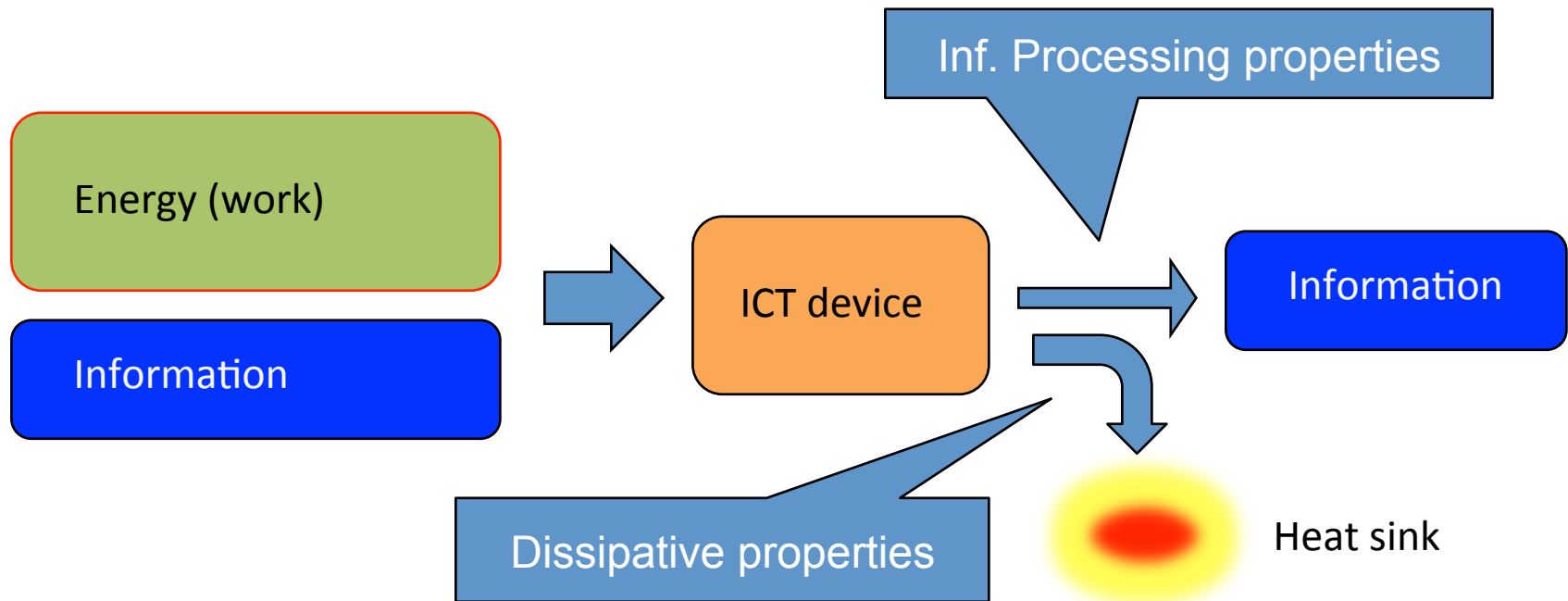
Questions like:

- How does electric energy get converted into heat at nanoscale
- How can we find an information transport solution that does not add to dissipation
- How can we harvest thermal vibrations to power nanoscale devices
- ...

Could be asked and answered within this framwork.

In order to better contestualize the issue let's focus on a scheme for ICT devices...

An **ICT device** is a machine that inputs **information** and **energy** (under the form of work), processes both and outputs information and energy (mostly under the form of heat).



**Energy efficiency** is usually defined as the percentage of energy input to a device that is consumed in useful work and not wasted as useless heat,

### Presently:

the main effort is aimed at **cooling down** the heat produced during computation with specific attention to the charge transport on one hand and on the other hand on reducing the voltage operating levels up to the point of not compromising the error rate due to voltage **fluctuations**.

### We propose:

to address the problem at a very fundamental level:

- what are the **basic mechanisms** behind the heat production?
- How can we **take advantage** of the **fluctuations** instead of avoiding them?
- How the physics of the heat and charge transport can be merged with the phonon engineering in order to advance the computing tasks?

It is not simply an incremental progress toward the reduction of heat production in room temperature conductors or new technology *beyond CMOS*.

It is a **new, visionary approach** that challenges the **very basic foundation** of thermodynamics. We propose to understand the **dissipative mechanisms at nanoscale** with the aim at setting the bases for a new thermodynamics of ICT devices.

# ON A BROADER PERSPECTIVE

The well-known laws of heat and work transformation that lie at the base of the classical thermodynamics are going to **need a rethinking**. The very basic mechanism behind energy dissipation requires a new definition when non-equilibrium processes involving only few degrees of freedom are considered.

Industrial Revolution  
XVIII-XIX

Heat-Work  
relations

ICT Revolution  
XX-XXI

Fluctuation-Dissipation  
relations

Information is physical !!!

## CHALLENGE:

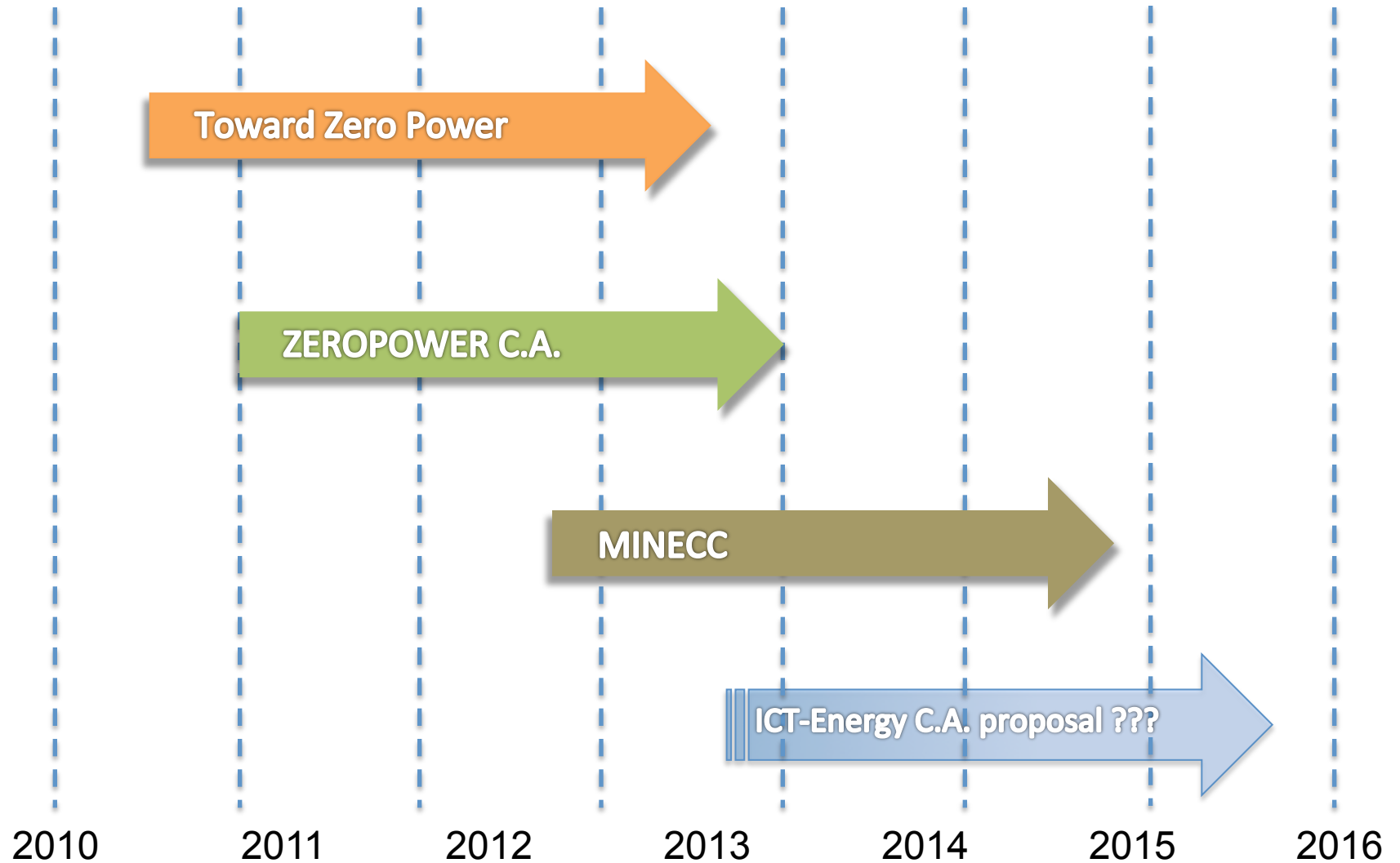
the description of **energy transformation processes at the nanoscale** aimed at unveiling new mechanisms for powering next generations of ICT devices.

This is part of an ongoing effort at European level

- Jan 2008, Brussels. Expert Consultation on "Molecular-scale Information Systems"
- July 2009, **Call FP7-ICT-2009-5 - ICT 2009.8.6 Towards Zero-Power ICT**
- Feb 2010, Brussels. Consultation workshop on "Disruptive Solutions for Energy Efficient ICT"
- Aug.1<sup>st</sup> 2010 three project started (SiNAPS, GREEN SILICON, NANOPOWER)
- Jan 1<sup>st</sup> 2011 **ZEROPOWER** C.A. started
- 26 July 2011 **FP7 CALL 8, ICT 9.8 FET Proactive: Minimising Energy Consumption of Computing to the Limit (MINECC)**
- 12 Oct 2011 FET Proactive Information Day (MINECC) – Brussels
- 12 June 2012 MINECC Project coordination meeting – Brussels
- 1 Sept 2012 Starting of the 7 MINEC funded projects (Landauer, ...)

**ZEROPOWER**

# Timeline

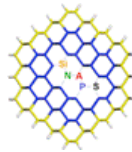


# Networking activity

## ZEROPOWER

ZEROPOWER is aimed at creating a **coordination activity among consortia** involved in “Toward Zero-Power ICT” research projects (FET proactive call FP7-ICT-2009-5, Objective 8.6) **and communities of scientists** interested in **energy harvesting and low power, energy efficient ICT**.

### NANOPOWER



NiPS Laboratory, Università degli Studi di Perugia, Italy  
Julius-Maximilians Universität Würzburg, Würzburg, Germany  
Valtion Teknillinen Tutkimuskeskus, VTT, Espoo, Finland  
Catalan Institute of Nanotechnology, Bellaterra (Barcelona), Spain  
Université de Genève, Genève, Switzerland  
Università degli Studi di Camerino, Camerino, Italy

Tyndall National Institute, University College Cork, Ireland  
Institut für Photonische Technologien E.V., Jena, Germany  
École Polytechnique Fédérale de Lausanne, Switzerland  
Imperial College of Science, Technology and Medicine, London, U.K.  
Aquamarijn Research B.V., Zutphen, The Netherlands

### GREEN Silicon

School of Engineering, University of Glasgow, U.K.  
L-NESS, Politecnico di Milano, Como, Italy  
Institute for Semiconductor and Solid State Physics, Universität Linz, Austria  
Electron Microscopy, ETH Zürich, Switzerland

16  
Groups

# Educational activities

2010



2011

Summer School "Energy Harvesting at micro and nanoscale"  
Workshop "Energy management at micro and nanoscale"  
Perugia (IT), Aug. 1-6, 2011



2012 Summer School - 23-27 July 2012, Erice (Sicily)



2013

**Summer School "Energy management at micro and nanoscales"**  
Perugia (IT), July 8-10, 2013  
[www.nipslab.org/summerschool](http://www.nipslab.org/summerschool)

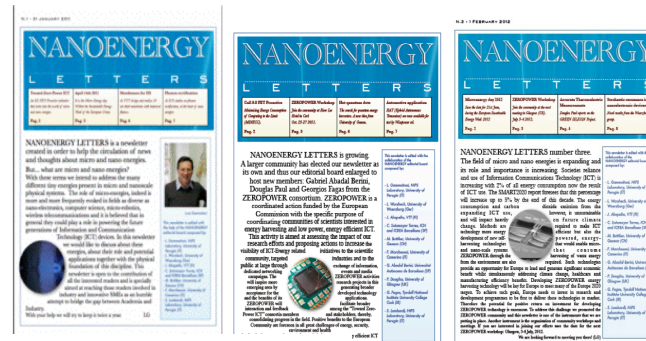
A new devoted web site has been realized and opened at

[www.nanoenergyletters.eu](http://www.nanoenergyletters.eu).

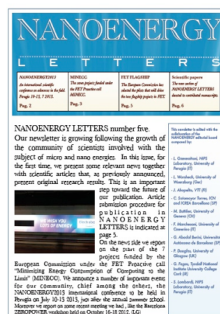
In the last two issues we have started a special session devoted to the publication of original scientific papers. Instruction for submission procedure is available at:

<http://www.nanoenergyletters.eu/submission>

The screenshot shows the Nanoenergy Letters website. At the top is a blue header with the title "NANOENERGY LETTERS" in large white letters. Below the header is a navigation bar with links for "Home", "Issues", and "Submission". The main content area is divided into two columns. The left column contains a "NANOENERGY Letters" section with a "Stay informed on our latest news!" message, an "E-mail" subscription form, a "Subscribe" button, and a link to "Previous issues". The right column features a "Welcome" message, a small thumbnail image of a newsletter cover, and a paragraph explaining the newsletter's purpose: to help the circulation of news and thoughts about micro and nano energies. It mentions that the newsletter addresses various tiny energies present in micro and nanoscale physical systems, such as nano-electronics, computer science, micro-robotics, and wireless telecommunications. It also states that the newsletter is open to the contribution of all interested readers and is specially aimed at reaching those readers involved in industry and innovative SMEs. At the bottom, it acknowledges financial support from the Future and Emerging Technologies (FET) programme within the ICT theme of the Seventh Framework Programme for Research of the European Commission.



issue N. 4 (Jul. 2012)



issue N.5 (Jan. 2013)

The last issue has been distributed to more than 800 subscribers

# ZEROPOWER Research Agenda

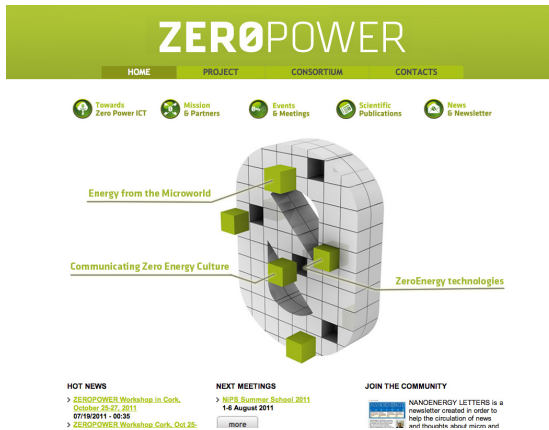
A research agenda for “ICT-Energy” roadmapping, including strategic objectives, identification of research drivers and measures for assessment.

A first draft of the ZEROPOWER Research Agenda has been made publicly available via deliverable D3.1

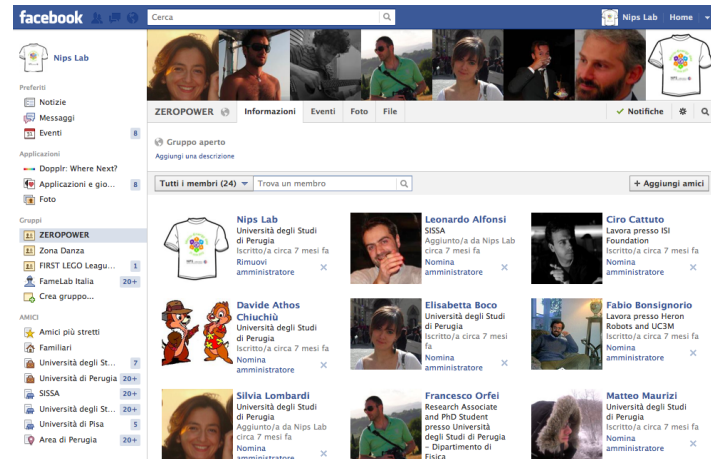
ZEROPOWER Strategic Research Agenda	EC FP7 Project No. 270005
ZEROPOWER Strategic Research Agenda	
Executive Summary	
<p>Societal reliance and use of Information Communications Technology (ICT) is increasing with 2% of all energy consumption now the result of ICT use. FP7/ICT has highlighted ICT as a key engine of growth, with the use of ICT to improve energy efficiency by managing energy demand and use. The energy consumption and carbon dioxide emissions from the expanding ICT use, however, is unsustainable and will impact heavily on future climate change.</p> <p>Methods are required to make ICT technology more energy efficient but also the development of new self-powered, energy-harvesting technologies that would enable micro- and nano-scale systems that consume ZEROPOWER through the harvesting of waste energy from the environment are also required. Such technologies provide an opportunity for Europe to lead and generate significant economic benefits whilst simultaneously addressing climate change, healthcare and manufacturing efficiency benefits. Developing ZEROPOWER energy harvesting technology will be key for Europe to meet many of the Europe 2020 targets.</p> <p>ZEROPOWER autonomous sensors for temperature and pollution monitoring are key for SMART networking to reduce energy consumption in domestic and industrial environments. ZEROPOWER autonomous sensors for healthcare applications have the potential to change the expensive reactive healthcare market to a cheaper and more effective point-of-care diagnostic system. Such healthcare sensors also have the potential to radically change the care of the elderly to a more sustainable and scalable automated monitoring rather than present expensive labour intensive methods.</p> <p>To achieve such goals, Europe needs to invest in research and development programmes to be first to deliver these technologies to market. The potential market for energy harvesters for ICT alone is predicted to be €5.7 Bn by 2021 whilst autonomous sensors in healthcare have the potential to save up to €171 Bn per annum through improved delivery of healthcare services. Therefore the potential for positive return on investment for developing ZEROPOWER technology is enormous.</p>	
Contents	
Executive Summary	1
Contents	1
Introduction and Background	2
Energy Efficient ICT	2
Micro- and Nano-scale Wireless Sensors	2
Matching Problems with Solutions	4
Relationship to Other Roadmaps	5
Potential Impact, Applications and Markets	5
Standards and Metrology	6
Potential Ethical and Societal Issues	7
Outreach and Public Engagement	8
Present Investment in Energy Harvesting	9
European Industry	9
European Level and EU National Programmes	9
Competitor Analysis	11
Conclusions	13
Abstract, Pages, Comments, Page	
Page 1	
23/01/2012	

Available on [www.zero-power.eu](http://www.zero-power.eu)

www.zero-power.eu



ZEROPOWER group



# NANOENERGY2013

[www.nanoenergy2013.eu](http://www.nanoenergy2013.eu)



## International Conference July 10-13, 2013 – Perugia (IT)

The first International Conference on Nanoenergy will be held in Perugia, Italy during July 10-13 2013.

### Important dates

- **Paper Submission** - April 1, 2013
- **Notification of Acceptance** - April 15, 2013
- **Early Registration** - May 1, 2013
- **Final registration** - June 1 2013
- **Conference Dates** - July 10-13 2013

### Latest News

[Submission procedure now open](#)



[www.nanoenergy2013.eu](http://www.nanoenergy2013.eu)

You are invited to participate and send students/researchers to the summer school