The More than More domain in the IRDS: white paper and perspectives

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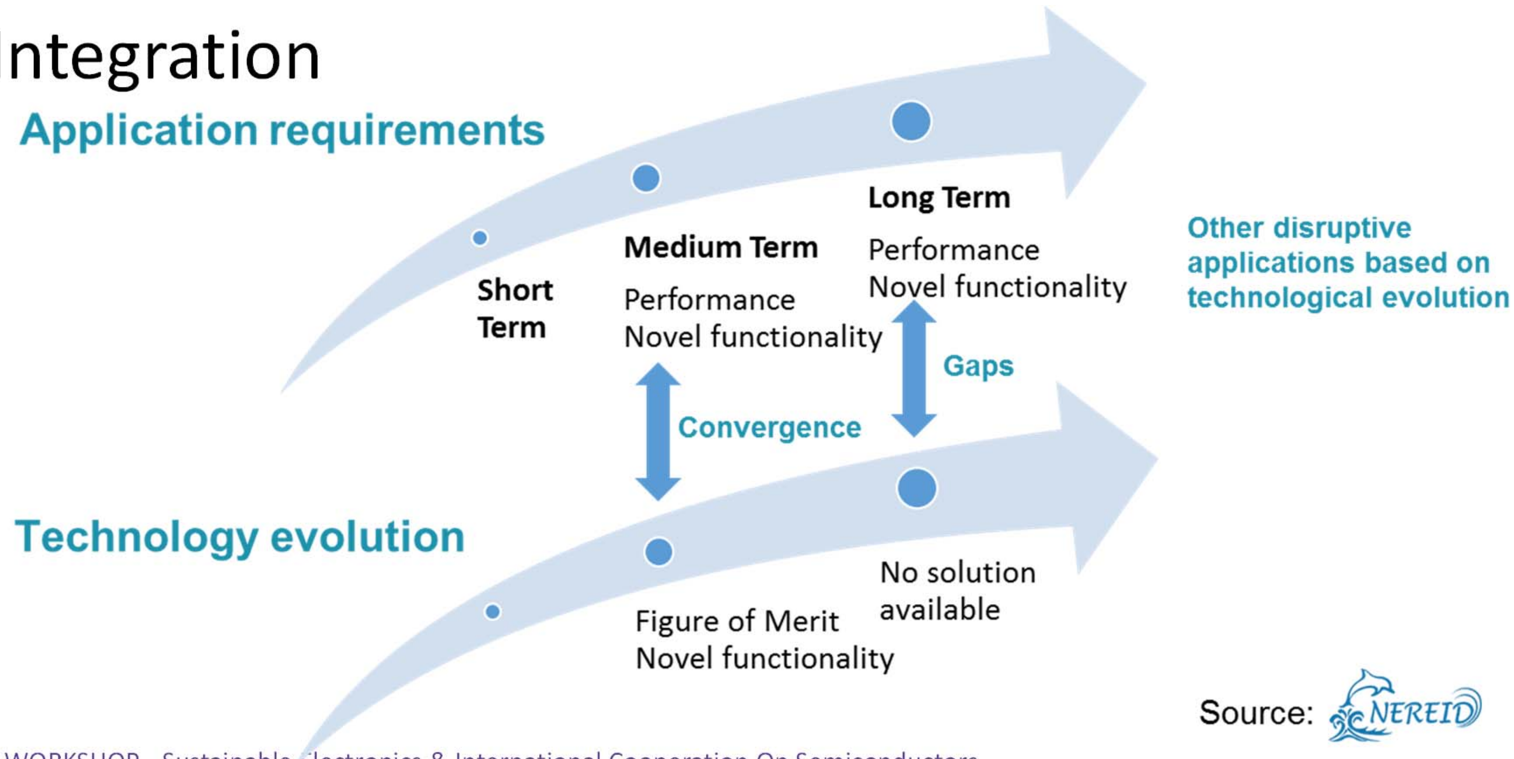
Outline

- The More than More IRDS Domain and Sub-Chapters
- The MtM Domain White Paper: results at glance
- Future work: Teams, Topics, FoM's

More than More

- Driven by applications (not by technologies)
- Multifunctionalities
- Heterogeneous Integration



Source: NEREID

ITRS MtM Domain Sub-chapters

Smart Sensors : automotive, healthcare, environmental, agri-food

Smart energy: Si-based power devices, GaN, SiC, wide bandgap semiconductors

Energy Harvesting: mechanical, electrostatic, piezoelectric, electromagnetic, thermoelectric, energy storage, power management

Wearable, flexible and printed electronics

ICOS
International Cooperation
On Semiconductors

ITRS MtM Smart Energy

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These focus areas are covered

- GaN-DEVICES AND SUBSTRATES
- SiC-DEVICES AND SUBSTRATES
- ALTERNATIVE WIDE BANDGAP SEMICONDUCTORS
  - AlN native substrate
  - Gallium oxide (Ga_2O_3)
  - Diamond

Roadmaps for smart power need to cover different sectors, as follows:

- New highly efficient power devices based on wide band-gap semiconductor materials, like GaN, SiC and later diamond on silicon or nanowire-based materials
- Integrated and smart power device and system solutions
- New cost-efficient, Si based power devices to enable high efficiencies for mass-market applications
- Power management for very high voltage applications making use of new wide bandgap materials, is required on the main power supply in order to minimize or avoid fluctuations on the power line caused by e.g., solar panels and windmills. In addition, developments such as artificial intelligence (AI) and battery management are important in this respect.
- Power management for very low-power applications, as required for IoT, including the development of power scavenging technology
- High-temperature capable packages employing new materials and 3D technologies with lifetimes fulfilling highest requirements and the integration capabilities

Challenges

Difficult Challenges 2019-2025

- GaN-on-Si substrates, large diameter (8”), low defectivity and low cost.
- GaN Devices—Low leakage, reliability, avalanche capability
- GaN MIS—Gate structures
- GaN Devices—Regrown ohmic contacts
- GaN Devices—On-Chip Integration
- GaN modules

- Channel conduction in 4H-SiC trenchMOSFETs
- Ohmic contacts on p-type 4H-SiC for body-diode and bipolar devices
- 4H-SiC devices on 8-inches substrates
- Development of equipment able to guarantee processes
- Low wafer cost of $800 (8-inch)

International Cooperation On Semiconductors

ITRS MtM Smart Sensors

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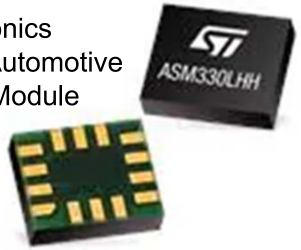
SMART SENSORS

- Smart sensor technology is widely used in healthcare, automotive, environment, agriculture and energy applications
- Market valued at 97.6 Billion USD in 2021, expected to reach 338 Billion USD in 2030, at a compound annual growth rate (CAGR) of 14. 8%
- Technology maturity and requirements vary greatly depending on the application field

Google Nest
Programmable smart thermostat that learns your schedule and the temperatures you like and programs itself to help you save energy and stay comfortable

Application fields

STMicroelectronics
ASM330LHH Automotive
6-axis Inertial Module



Motion sensors

Bosch Sensortec
BMP581 Barometric
Pressure Sensor

Pressure sensors

image devices, radar sensors,
laser and ultrasonic sensors

Advanced Drive
Assistance Systems
(ADAS)

Grove - Laser PM2.5
Sensor HM3301

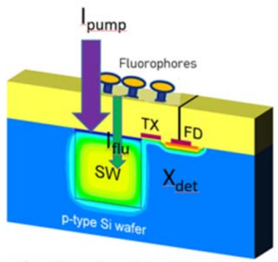
Environmental
sensors

Nano-copper agricultural
nitrate run off sensor

Agri-food
sensors

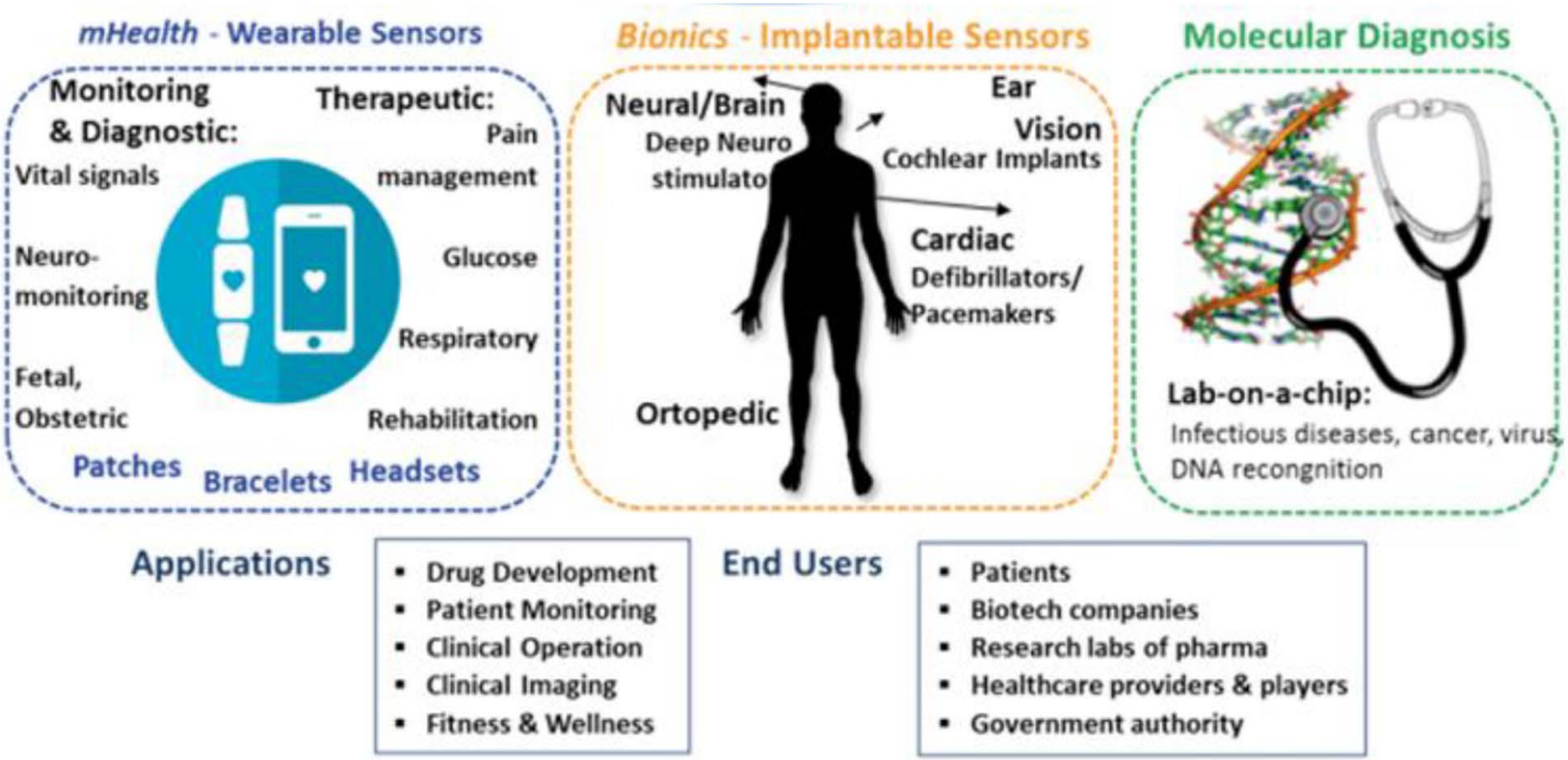
Wearable, Implantable and
Molecular Diagnosis

Medical and
Healthcare



Molecular
Diagnostics

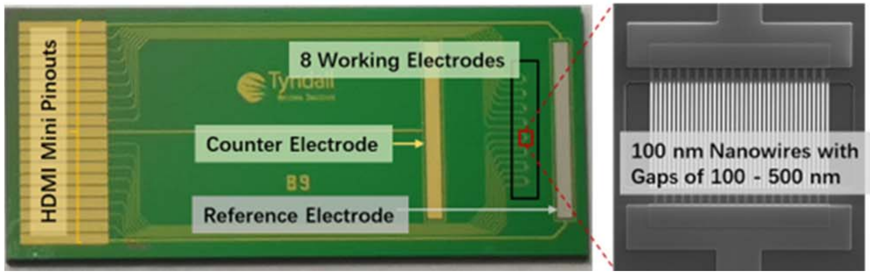
Example 1: Medical Devices

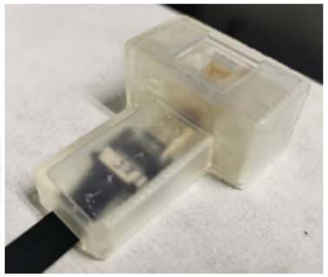


Example 2: Agri-food sensors

Existing approach: laboratory-based assay

- Costly and time-consuming processes
- High-cost instrument and experts required





Solution: Developing new smart sensor system for real-time nitrates sensing in soil (H2020 Sarmenti project)

Difficult challenges

❖ Examples of challenges per technology (not exhaustive).

Field	Smart Sensors	Difficult Challenges (2022-28)	Difficult Challenges (2029-37)
Automotive	image sensors, LiDAR, infrared sensors, and radar sensors	-Improve sensitivity with smaller pixel size -Flicker-free and HDR n-cabin near-IR global shutter -3D cameras -Improve resolution -Long, short/medium range radar -Silicon, Silicon germanium	-Local computer vision -Photodetectors -Reduce cost -Data fusion with CMOS imaging sensor -Microbolometers -Higher integration into a small module, laser scanner -New sensing layers
Healthcare	Implantable sensors	-Vision, ear, orthopedic, cardiac, neural/brain -Difficult, expensive and time consuming validation tests and certifications. -A few centimeters implant depth	-Vision, ear, orthopedic, cardiac, neural/brain -Packaging solutions, power solutions for >10 cm implantation depth available -Electrophysiology meters directly at cellular level

Main recommendations

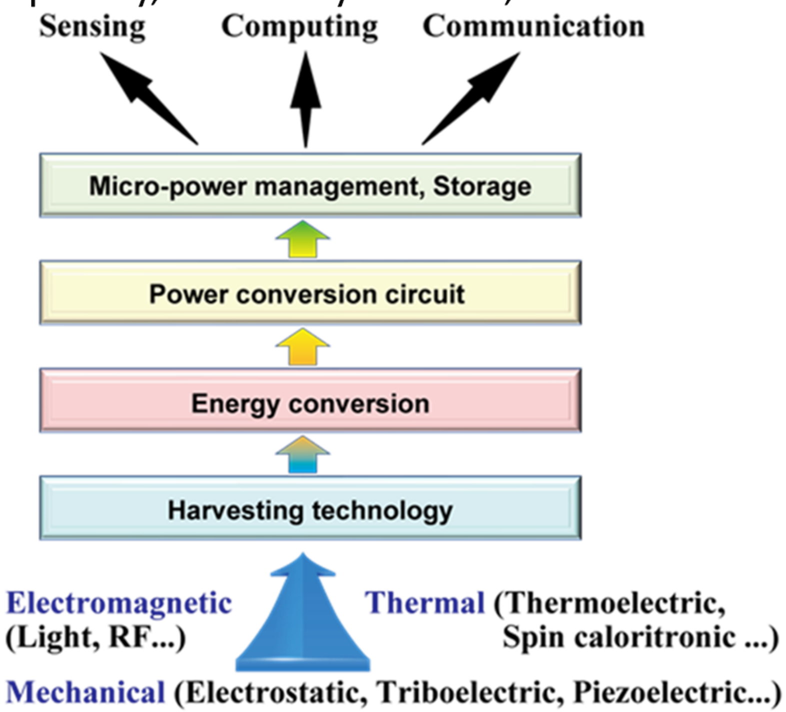
- Key challenges remain to develop smart sensor systems that are fit-for-purpose for final deployments with suitable integration and packaging
- Key requirements for sensing technologies include sensitivity, selectivity, repeatability, robustness, precision and accuracy
- Edge (AI) analytics will be key, not only to reduce power consumption, but essential to achieve these requirements.
- Adoption of innovative power management circuits, energy storage and generation, will enhance the efficiency of deployments.
- The use of nanotechnologies is foreseen to increase the performance of all the concepts in general.
- Flexible and low cost approaches with an emphasis on environmentally benign deployment paradigms such as "Deploy and Forget" of "Deploy and Dissolve" should be explored.

Energy Harvesting

Team : **Gustavo Ardila** – Grenoble Alpes Univ. / Grenoble INP (Team leader), **Aldo Romani**, IUNET/Univ. of Bologna (co-leader), **Hiro Akinaga**, National Institute of Advanced Industrial Science and Technology (AIST), **Philippe Basset**, Univ. Gustave Eiffel, **Alessandro Bertacchini**, IUNET/Univ. of Modena and Reggio Emilia, **Alessandra Costanzo**, Univ. of Bologna, **Mike Hayes**, Tyndall, **Maciej Haras**, Warsaw Univ. of Technology, **Anne Kaminski**, Grenoble INP, **Michail Kiziroglou**, Imperial College London **Ivona Mitrovic**, Univ. of Liverpool, **Yoshiyuki Nonogushi**, Kyoto Institute of Technology **Kankana Paul**, Tyndall, **Alessandro Piovaccari**, Univ. of Bologna, **Kafil M Razeeb**, Tyndall, **James Rohan**, Tyndall, **Saibal Roy**, Tyndall, **Thomas Skotnicki**, Warsaw Univ. of Technology, **Hiroshi Toshiyoshi**, Univ. of Tokyo, **Eric Yeatman**, Imperial College London

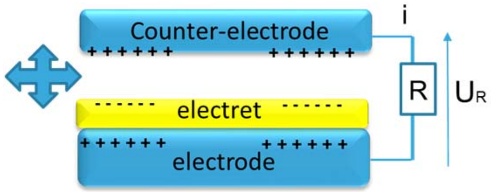
ENERGY HARVESTING (EH)

- Market growth on connected devices (factor of 200x) : IoT, healthcare, wearables, home automation…
- Energy supply is essential (<mW, tens of μW) → Energy harvesting
- EH is important in applications with specific requirements : simple battery is not enough, cords would increase the cost / complexity, too many devices, harsh environment, implants…

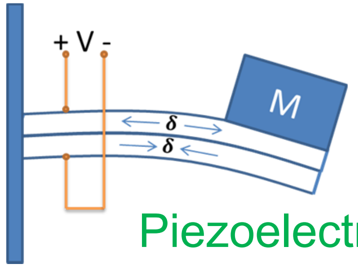


Technologies covered so far…

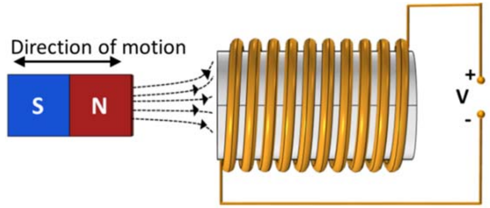
Mechanical EH with different transduction technologies



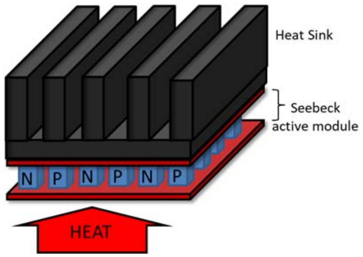
Electrostatic



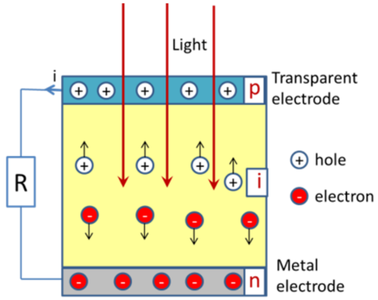
Piezoelectric



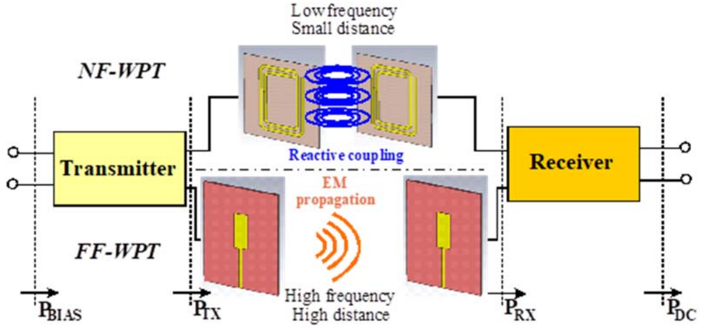
Electromagnetic



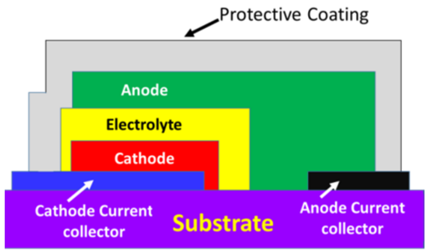
Thermal EH

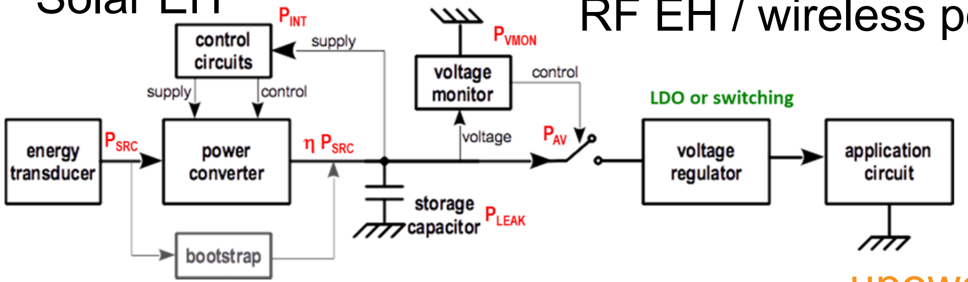


Solar EH



RF EH / wireless power transfer



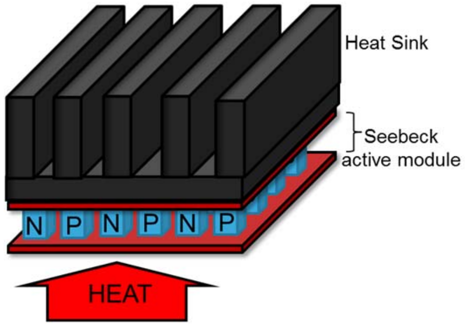


µpower management

Energy storage (µbatteries)

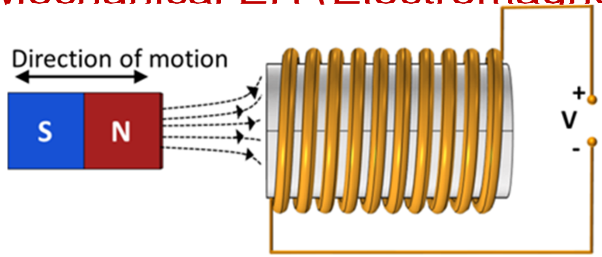
2 examples: Thermal and Mechanical EH

Thermal EH



- Thin film technology adapted to autonomous wireless sensors
- Efficiency depends on temp. range
- Commercial devices based on Bi_2Te_3 (Rare/toxic), ZT ~ 1.
- Stakeholders: Micropelt, Laird …

Mechanical EH (Electromagnetic)



- Devices tuned at a specific vibration frequency
- Macro-devices well developed and on the market
- MEMS devices less explored (issue performance drastic drop)
- Stakeholders : EnOcean, Perpetuum…

- Examples of FoMs

FoMs	2023	2027	2030	2033	2036
ZT (Thermal)	>2.6	2.8	3	3.3	>3.3
Miniaturized devices (f<100Hz, G<0.5) - Volume power density (mW/cm^3) (Electromagnetic)	5	7	10	12	15

Difficult challenges

❖ Examples of challenges per technology (not exhaustive).

EH Technology	Challenge	Potential solution (2022-28)	Potential solution (2029-37)
Mechanical (Ex: Electrostatic)	Improve efficiency/power with smaller surface/volume	New materials (Fluorin polymers)	Surface texturation
Thermal	Replacing Bi_2Te_3 by "green" materials	Nanostructured materials / SiGe based solutions	Nanostructured materials / Si based solutions
PV	Improve output power density (Indoor)	Organic, DSSC (dye sensitized solar cells), a-Si…	Perovskite, Multi-junction, nanostructured materials…
µpower management	Perform battery-less start-up from fully discharged state.	Integrated step-up converters aided by external magnetic or piezoelectric transformers down to few mV.	Miniature systems with embedded micro-transformers (magnetic or piezoelectric) at package level starting from few mV

Among others: Mechanical EH (piezo and electromagnetic), energy storage, RF power transfer…

Main recommendations

- development "green" materials.
- comprehensive system design for increasing the power generation efficiency.
- A general limitation towards industrial adoption of EH is its reliance on environmental conditions (e.g. energy availability). The combination of EH and wireless power transfer (on-demand charge) could solve this issue.

Wearable, flexible and printed electronics

- **Team** : **Benjamin Iniguez** – URV (Team leader), **Alessandra Costanzo -** Univ. of Bologna, **Danilo De Marchi** - IUNET, **Thanasis Dimoulas** - NCSR Demokritos, **David Esseni** - IUNET , **Paul Galvin** - Tyndall , **Hoël Guérin** – Xsensio, **Monica Lira** - ICN2, **Brendan O'Flynn** – Tyndall, **Luca Roselli** – IUNET, **Tsuyoshi Sekitani** - Osaka University

Motivations

- Flexible and wearable electronics systems promise to achieve full independence of off grid energy with lower power consumption.
- Flexible and stretchable electronics is also needed in devices monitoring patients' health with electronic assistance from their homes.
- Growing importance of paper electronics and, in general, biodegradable substrates, such as paper.
- Both small molecules and polymers are being used to manufacture OLED displays (TV and mobile phone displays).
- IGZO materials are also used in commercial TFT displays.
- At 2023 CES, CLAP introduced its OTFT based sensors.

Challenges and possible solutions

- TFTs: increase mobility values, reduce voltage operating range and threshold voltage stability
- Complementary TFT technology is still a challenge
- Devices in fully biodegradable substrates
- Challenges in design (CAD)
- Improved efficiency for Organic Photovoltaics (OPVs) technologies (20%)
- Microwave flexible electronics is still a major challenge

Next actions in Sensors

- Expand the contributing team with US and Japan sensor experts to avoid focus on technologies and applications specific to Europe only
- Consider de-prioritizing or reducing thematic areas / application fields that have diminished in interest or market potential or are completely under industrial roadmap control in the past few years, e.g. pressure sensors
- Consider including new thematic areas / application fields that are showing signs of increasing value in the past few years, e.g. quantum sensing
- Increase quantification, i.e. move as many qualitative sensor attributes as possible towards quantitative performance metrics/figures-of-merit to facilitate roadmap activities
- Improve taxonomy / FoM definitions so as to increase generality and homogeneity over different sensing technologies and application fields

Next actions in Energy Harvesting

- In the short / medium-term : actualize the white paper, complete FoM tables for several technologies : Photovoltaics, RF / Wireless power transfer, Microbatteries (Energy storage).
- In the long-term : consider other EH harvesting technologies, energy storage technologies.

Next actions in WFP Electronics

- Refocus the contributing team adding US and Asian experts to avoid focus on technologies and applications specific to Europe only
- Consider de-prioritizing or reducing thematic areas / application fields that have diminished in interest or market potential
- Consider including new thematic areas / application fields that are showing signs of increasing value in the past few years
- Increase quantification, i.e. move towards quantitative performance metrics/figures-of-merit to facilitate roadmap activities

Next actions in Smart Energy

- Add max 1-2 non-EU experts
- Complete the FOM's portfolio
- Update on the Electrification path EU/USA/Asia
- Estimate the total sustainable benefit by converting power electronics to WBG

ICOS International Cooperation On Semiconductors

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SiNANO Institute

IRDS International Roadmap for Devices and Systems

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WORKSHOP - Sustainable Electronics & International Cooperation On Semiconductors

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