# Power management solutions and energy harvesting for autonomous sensors

**Roberto Canegallo**

Smart Power Technology R&D

STMicroelectronics

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# Outline

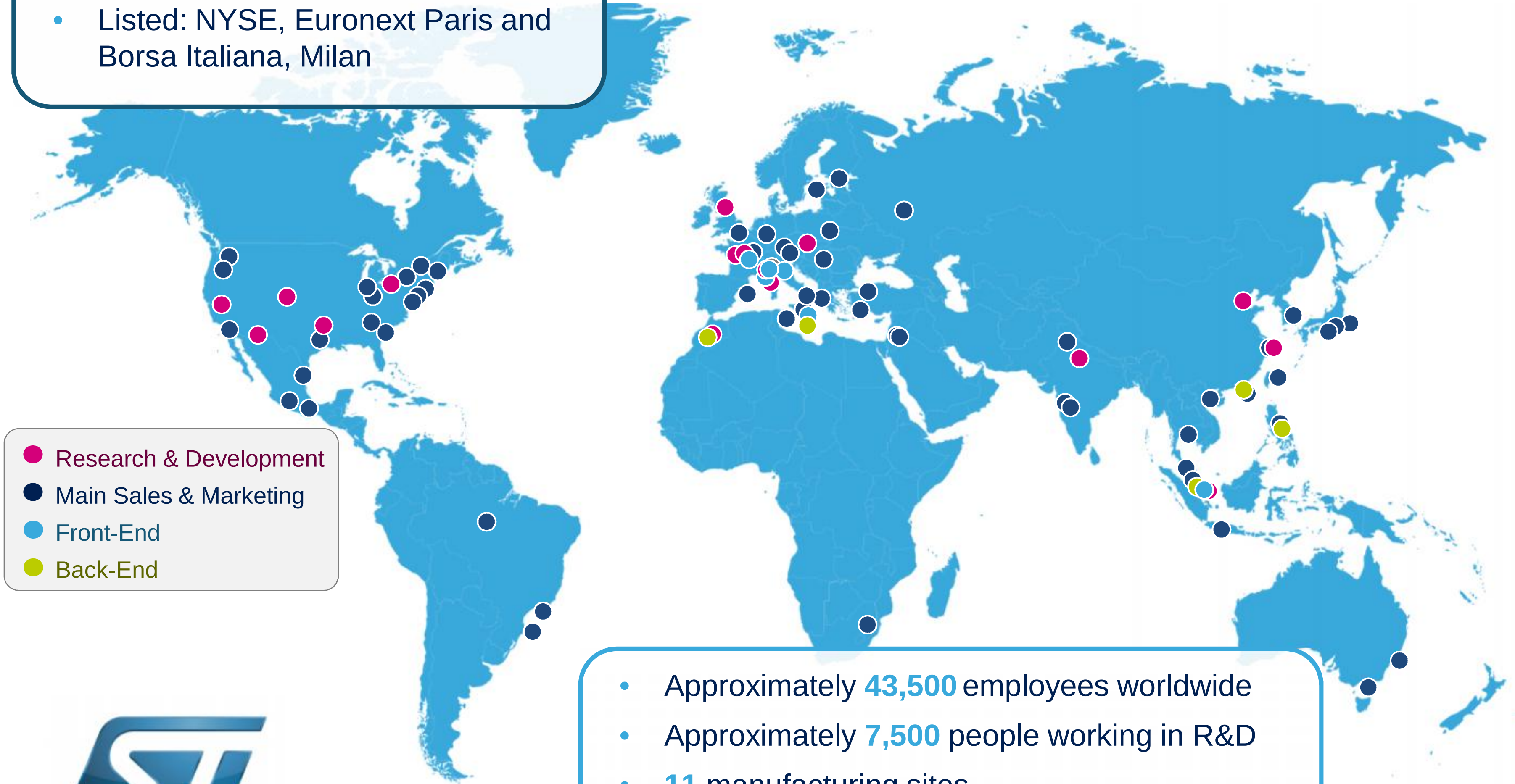


- ST overview
- Sensors everywhere
- Energy for portable electronics
- Energy harvesting overview
- Energy harvesting in ST
- Conclusion

# Who We Are



- A global semiconductor leader
- 2016 revenues of **$6.97B**
- Listed: NYSE, Euronext Paris and Borsa Italiana, Milan




- Approximately **43,500** employees worldwide
- Approximately **7,500** people working in R&D
- **11** manufacturing sites
- Over **80** sales & marketing offices

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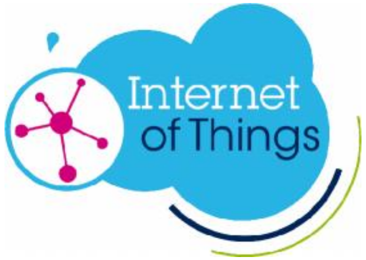
As of December 31, 2016

# Application Strategic Focus



**The leading provider of products and solutions for Smart Driving and the Internet of Things**





| Smart Things | Smart Home & City | Smart Industry | Smart Driving |
|---|---|---|---|
|  |  |  |  |

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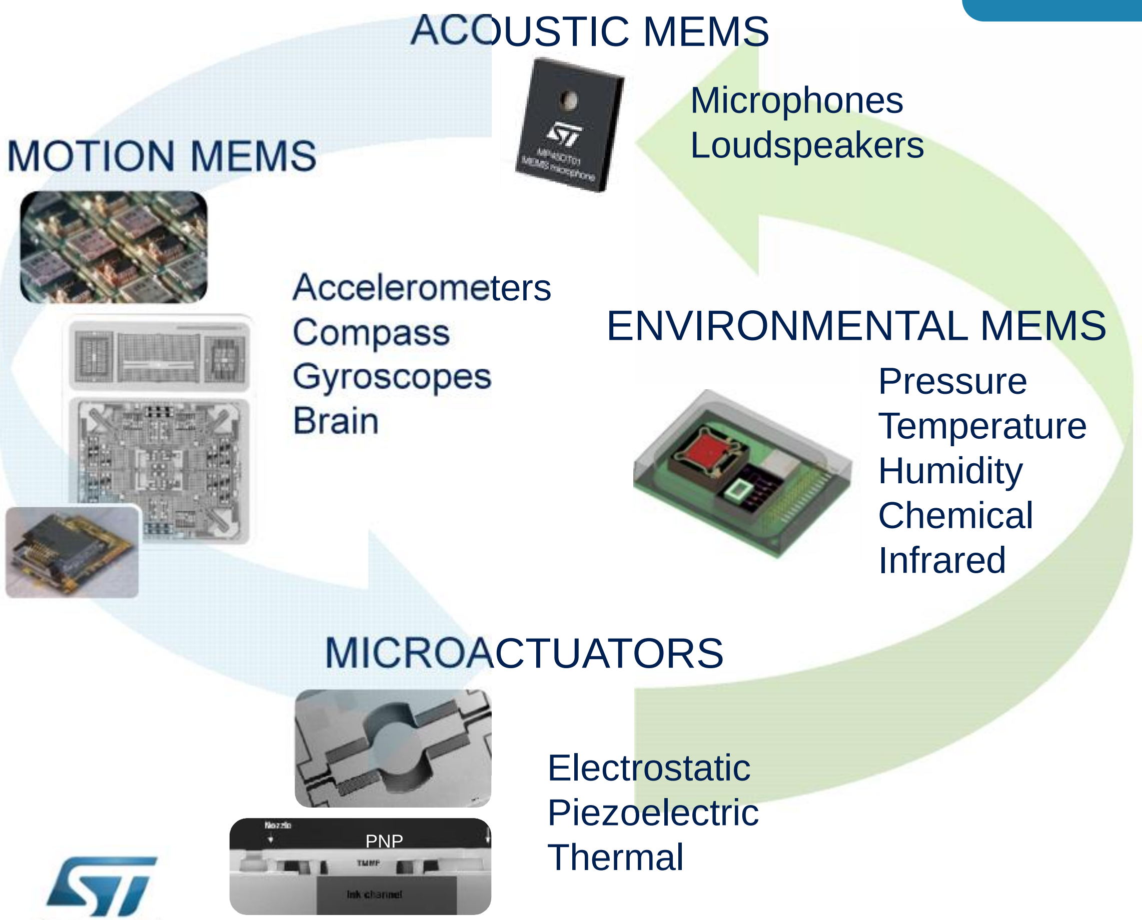
# Current Trend: Sensing the World



**Act autonomously or assist action**

**Sense the world everywhere, all the time**

**Share data, analyze and make decisions**





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# Billions of Sensors in the Smart World



## Limitless applications

### Energy Sensitive Applications

**COMMUNICATION and CONSUMER**

Hybrid AF, Proximity sensing, Gesture, user detection…

**HOME APPLIANCE**

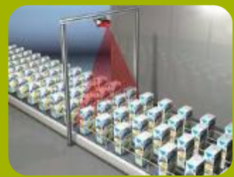
Robot cleaners, Drone, Light control, White goods, Toys…

**GESTURE CONTROL**

Light-on / Switch off an equipment, Dimming, Browsing…

**INDUSTRIAL**

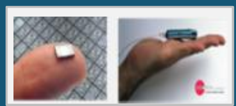
Proximity detection, Door control, Robotics…



**HEALTH CARE**

Blood analysis, continuous glucose test

ECG



Insulin Nano pumps

Glaucoma Lens

**AUTOMOTIVE and SMART DRIVING**

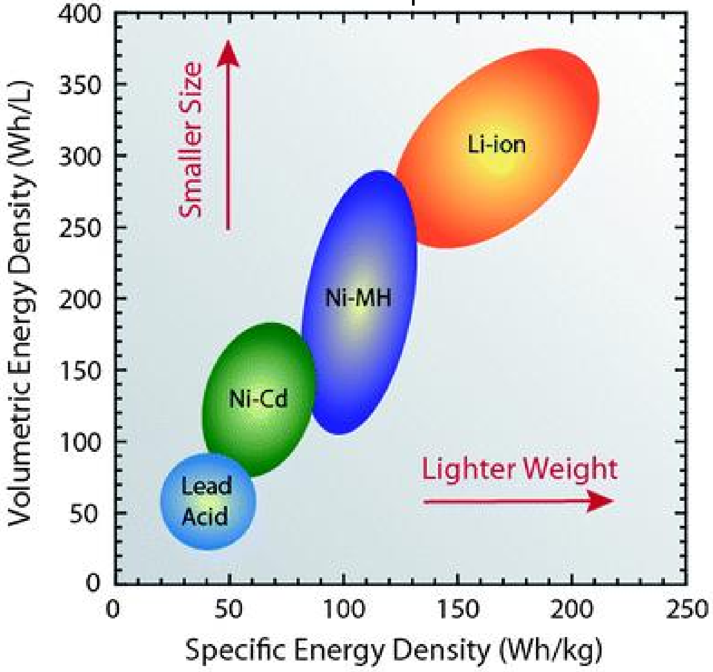
Safer, Greener, More connected…..

# Energy Everywhere
## for Portable Electronics

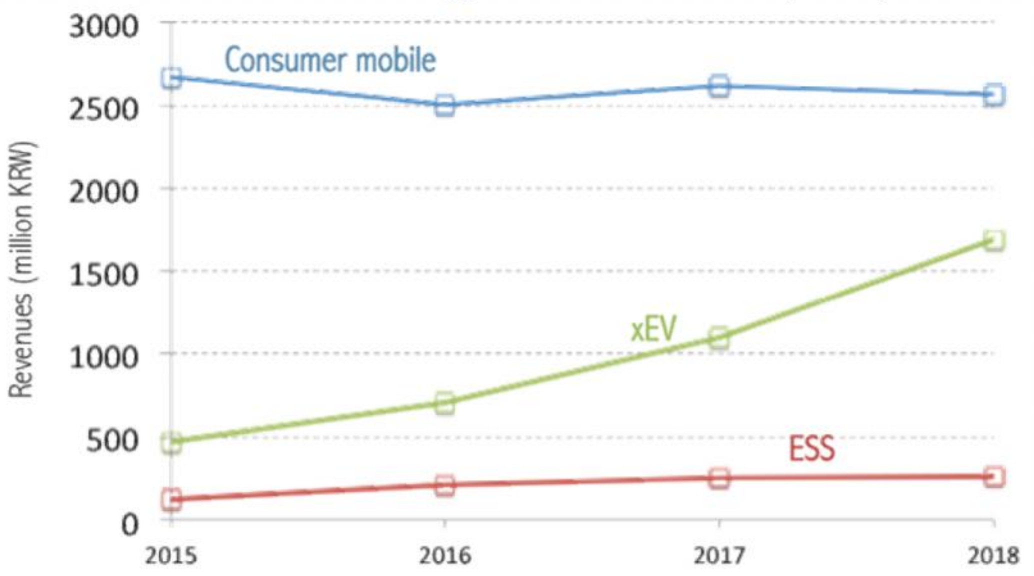
Power consumption of various applications


Source: IDTechEx

Source: www.epectec.com




Current technology - Batteries and supercapacitors



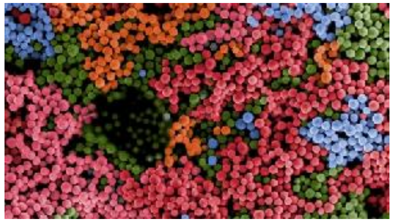

Source: Goldman Sachs' report data from Samsung SDI

# Emerging Technologies



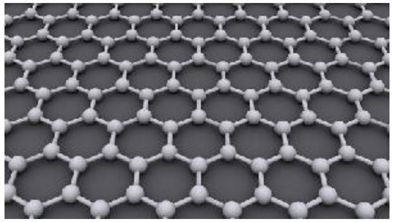
## New battery chemistries

### Amorphous silicon



Source:
Pacific Northwest National Laboratory

### Graphene Anode

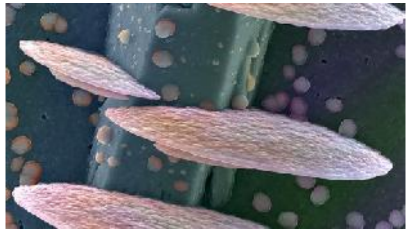


Source:
UCL mathematical and Physical Science

### Sodium -Ion

Source:
NASA's Marshall Space Flight Centre

### Zinc Oxide

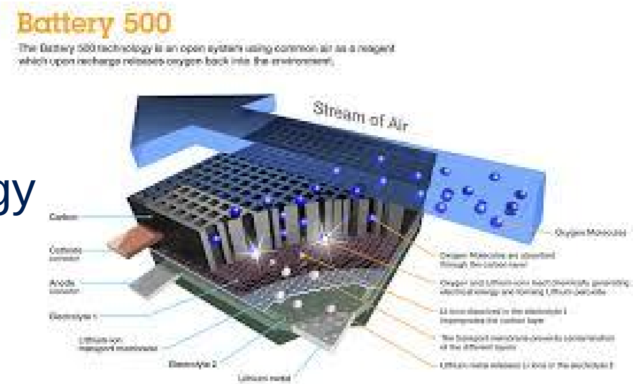


Source:
Pacific Northwest National Laboratory

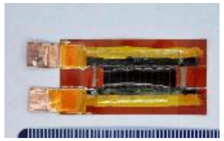
### Lithium Sulfur technology

Source: https://oxisenergy.com/

### Lithium Air technology




Source: IBM battery 500 project



### Laser-made micro-supercapacitors

Source: Rice University

### Organic metal-free flow battery

Flexibility ,
fast charging & high energy density


Source:  Harvard School of Engineering and Applied Sciences

Source:  NEC

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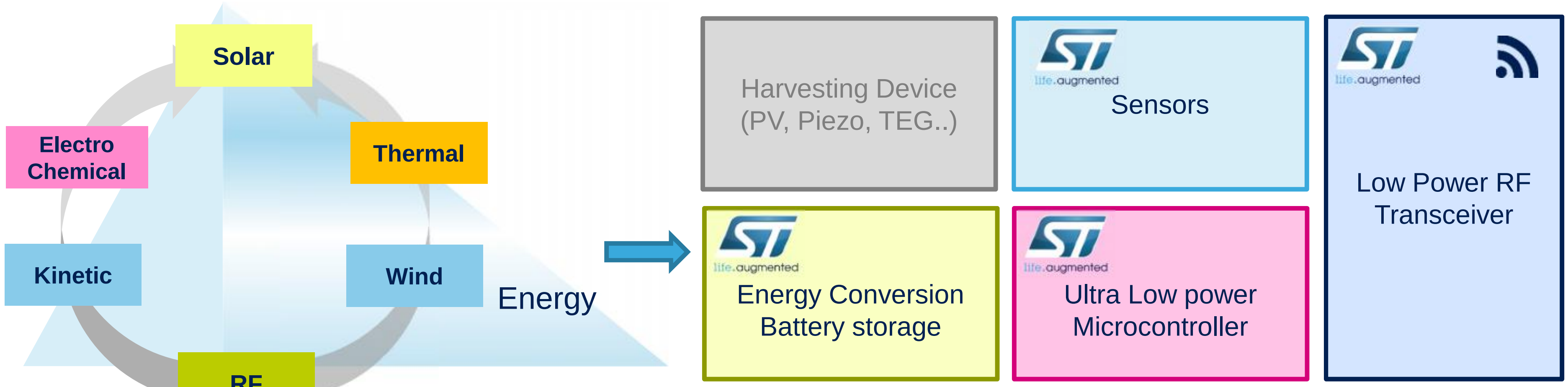
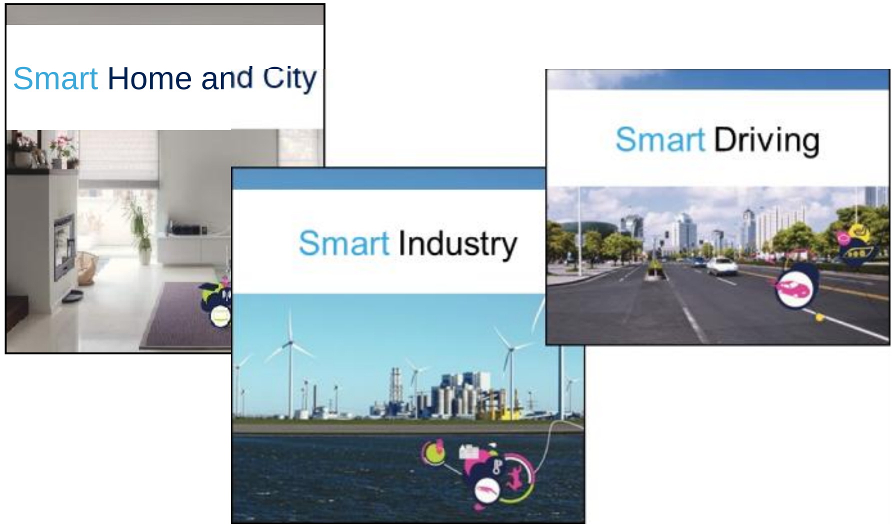
# Energy Harvesting

## Solution for smart systems and wireless sensor node




Autonomous Wireless Sensor Node

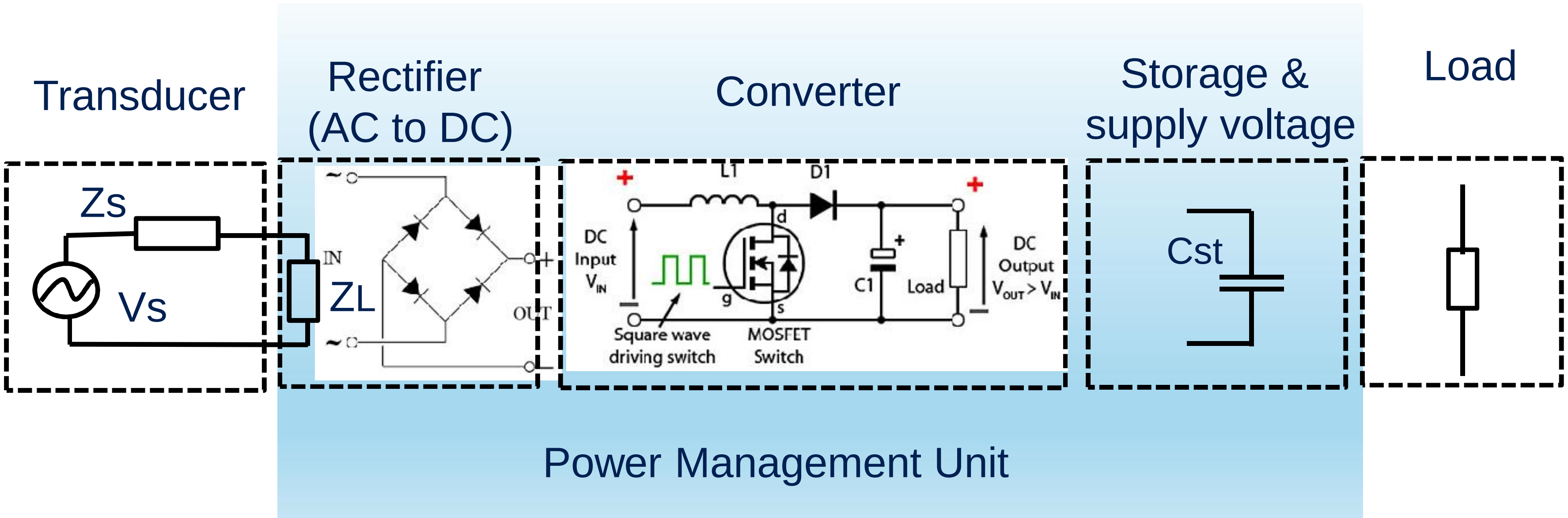



*Enabling IOT applications for energy autonomy*

# Energy Harvesting Circuit



- Typical block diagram of energy harvesting circuit: voltage rectifier, power converter and storage



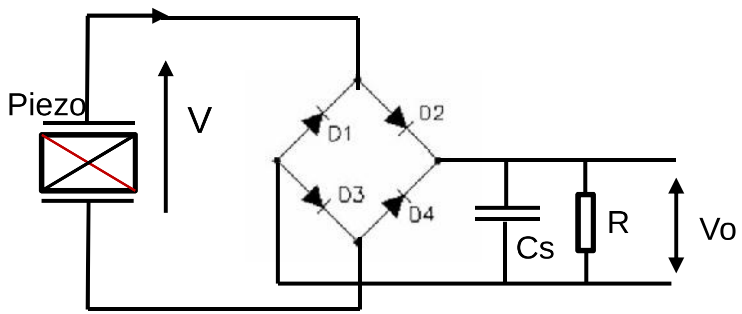

- Implementation of low power electronics is critical to minimize the circuit loss
- Key parameters: efficiency and impedance matching ( $Z_S = Z_L$)

Impedance matching is the first reason of losses

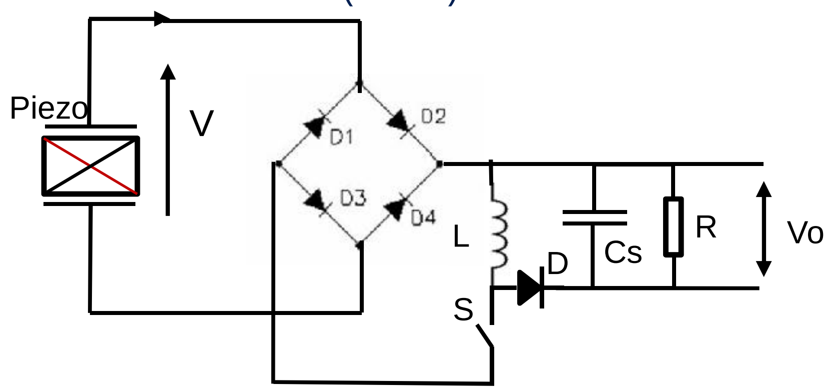
# Design Consideration
## in vibrational harvester

- Common types of energy extraction interface for improving efficiency in vibrational energy harvesting

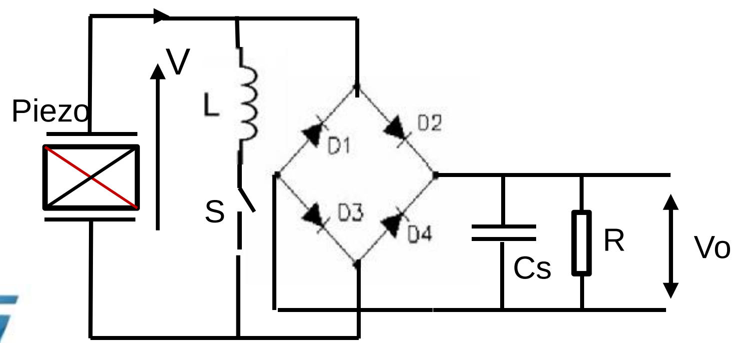
Standard Energy Extraction



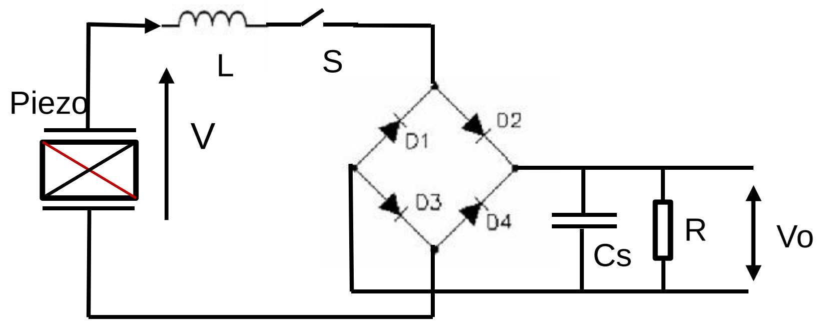

Synchronous Electric Charge Extraction (SECE)




Parallel Synchronous Switch Harvesting on Inductor (parallel SSHI)



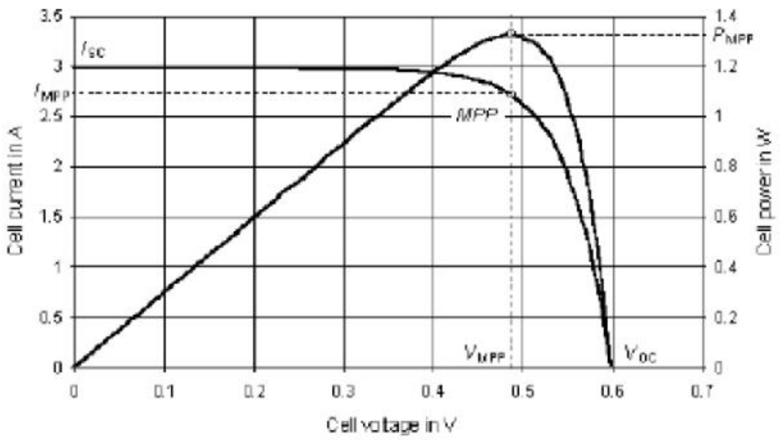

Series Synchronous switch Harvesting on Inductor (series SSHI)



# Design Consideration in DC Harvester 

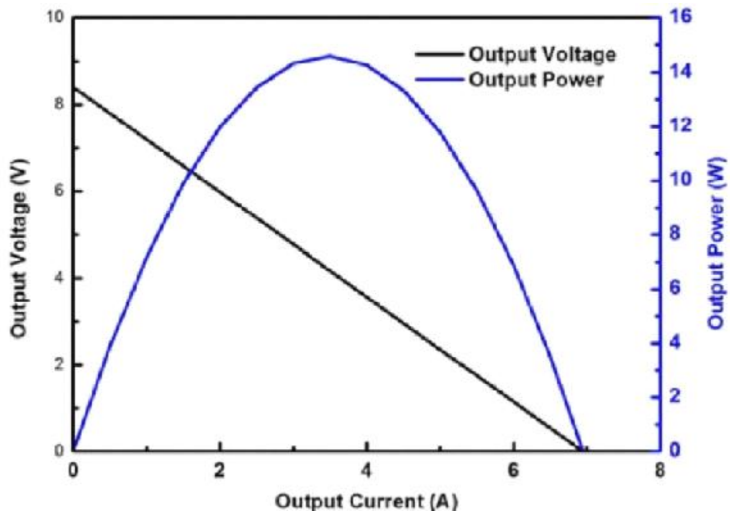
Maximum Power Point Tracking (MPPT) is essential to maximize the harvested power from **DC sources**

Solar Cell I-V Characteristic Curve




- For PV cells the voltage at maximum power stays between 70% and 80% of open circuit voltage

Thermoelectric generator (TEG) Characteristic Curve




- For TEG the voltage at maximum power stays is half of open circuit voltage ($V_{OC}/2$)

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# Commercial Energy Harvesting Solutions



**PAVEGEN**


**VIMAR & EnOcean**

Energy harvesting light switch


**CHERRY**

Piezo Harvesting

**KIEBACK & PETER**

**ABB**

Wireless Temperature Transmitter
based on Thermoelectric
harvesting

Thermoelectric Harvesting

**GCell**

E-reader


**Logitech**

Solar keyboard Folio

Photovoltaic Harvesting

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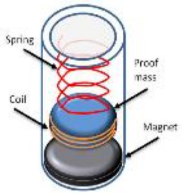
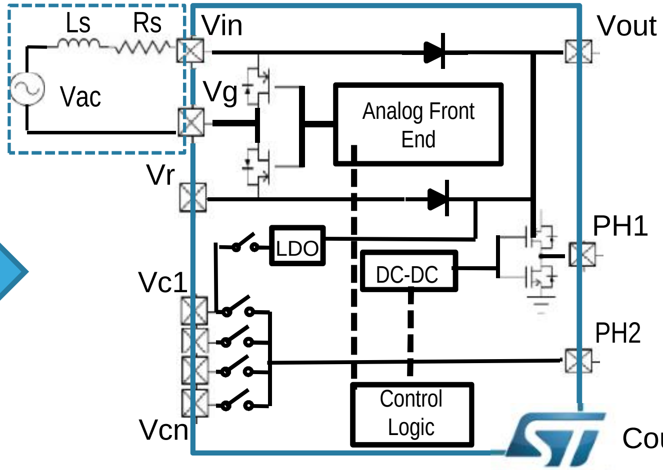
# Energy Harvesting Solution @ ST



## Vibrational energy harvesting

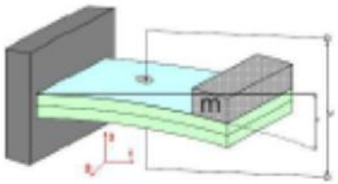
Piezo harvester

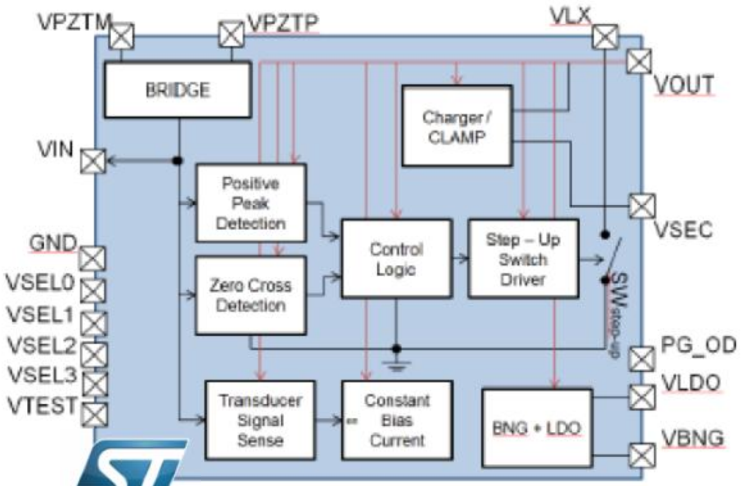



Tire Pressure Sensors

Courtesy of A. Gasparini




Smart Shoes

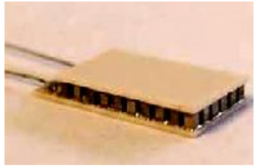
Courtesy of V. Bottarel

# Energy Harvesting Solution @ ST

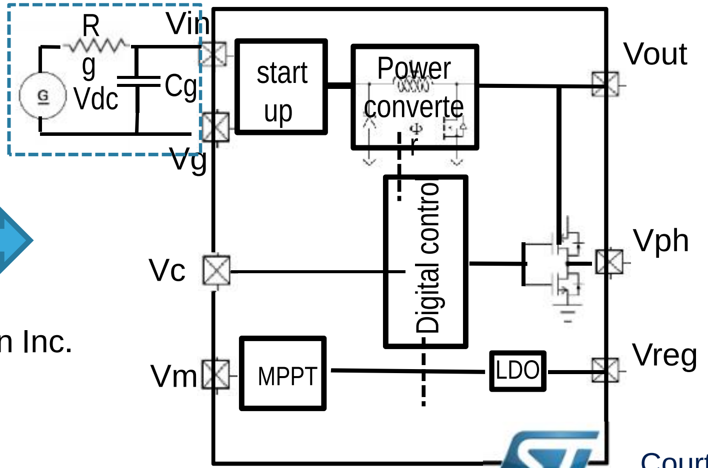


## PV solar and TEG energy harvesting

### Thermoelectric generator (TEG)



Source: Nextreme Thermal solution Inc.



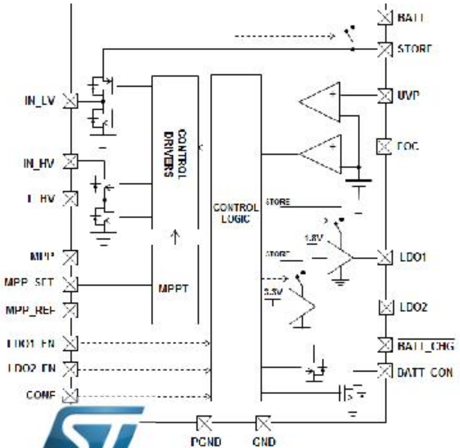

Courtesy of A. Gasparini

### Wearable sensor


### TEG & PV harvesters

TEG Micropelt.


Indoor PV Sanyo





Courtesy of A. Nicosia

# Energy Harvesting Research



## Multi source and RF energy harvesting

Courtesy of M.Dini , A.Romani, M.Tartagni:
ARCES University of Bologna, Cesena Campus

Input: 5 Piezo , 2 DC LV ,2 DC HV

<u>ST smart power technology BCD6S</u>


IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 30, NO. 10, OCTOBER 2015

# A Nanocurrent Power Management IC for Multiple Heterogeneous Energy Harvesting Sources

Michele Dini, Aldo Romani, Matteo Filippi, Valeria Bottarel, Giulio Ricotti, and Marco Tartagni, *Member, IEEE*

***Abstract*—This paper presents a fully autonomous power converter IC for energy harvesting from multiple and multitype sources, such as piezoelectric, photovoltaic, thermoelectric, and RF transducers. The converter performs an independent self-adapting input power tracking process for each source. The peak power conversion efficiency measured during single-source operation is 89.6%. With all sources enabled, the intrinsic current consumption is as low as 47.9 nA/source. A self-starting battery-less architecture has been implemented in a 0.32-$\mu$m STMicroelectronics BCD technology with a 2142 $\mu$m $\times$ 2142 $\mu$m die area. The IC only re-**

transducers (PZs) for generating power from vibrations, photovoltaic (PV) cells for sunlight or artificial indoor light, thermoelectric generators (TEGs) for heat flows in wearable and industrial applications, rectifying antennas for incident electromagnetic waves. However, the available power is in most cases constrained down to few microwatt or less [5]. Hence, in order to achieve sufficient efficiency it is necessary to couple energy transducers with specific power conversion and management circuits [6]–[9], with very low power consumption. In this con-

# Perpetual Energy Module
## for autonomous sensors

- Combines robust and long service life time battery with Energy harvesting transducers to offer low power but Inexhaustible energy source
- Autonomous node → positive energy balance
  - Battery is only an energy “buffer”
  - All the charge supplied by the battery for an operation have to be harvested in the next time and provided to the rechargeable battery

$$E_{m\,HARV} \geq E_{m\,SYS}$$

thermal electrical energy harvesting and solid-state thin-film battery

ST EnFilm™ battery + Micropelt TEG MPG-D751

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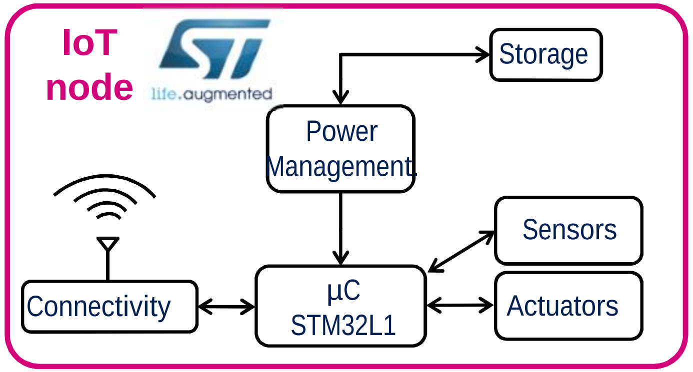
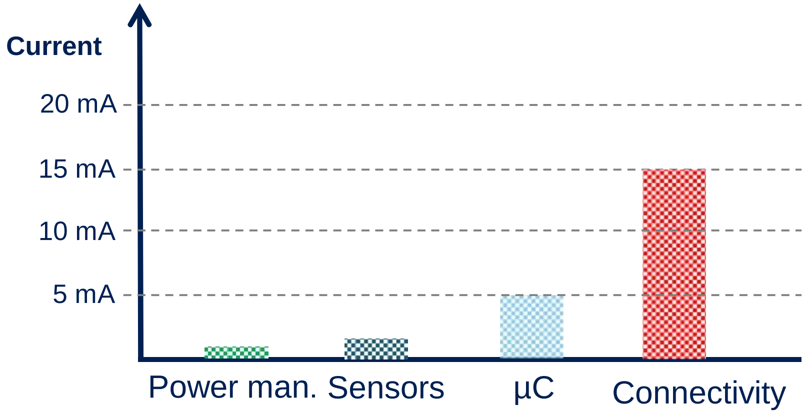
Courtesy of I. Bimbau

# Design Challenges
## for autonomous sensing





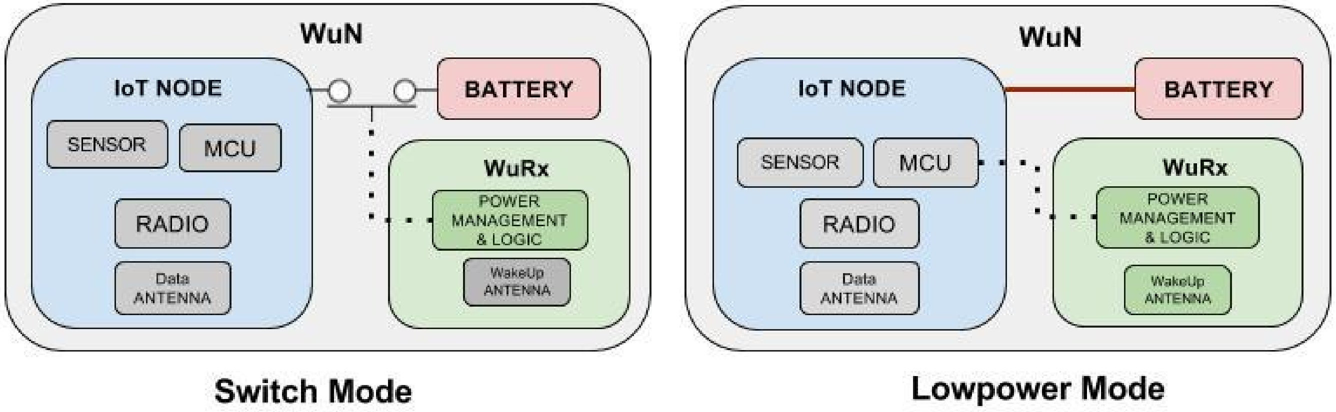




*Duty cycle approach*

- Common approach in WSNs to extend the lifetime of a sensor node
  - radio component is turned off,
  - microcontroller (MCU) is set into a sleep mode and a timer is used to turn the node active periodically.
- In WSN application duty cycling is controlled by Communication protocol to achieve synchronization for data TX and RX.

# Low Power Solution in WSN:
## RF wake up radio






- Main functions:
  - The main RF transceiver is turned off and all the others parts of the node are in sleep mode
  - When a RF signal is detected, the node is waked up from sleep mode and start reception/transmission

- Main requirements:
  - Ultra low power consumption (orders of magnitude lower than main RF transceiver)
  - High sensitivity / long range
  - Addressing capability
  - Fast wake up
  - Bandwidth efficiency not important ( modulation) → Low bit rate



Courtesy of R. La Rosa

# Conclusion

## Energy for Smart Things



ST offers the **simplest**, **fastest** and **most robust** way to develop Smart Things for the IoT

### Unique & complete product portfolio

Sense & Actuate | Process | Secure | Connect | Power | Translate

**A complete portfolio of sensors and micro-actuators**

- Motion & environmental sensors, MEMS microphones, ranging sensors (ToF)

**The full range of low-power, high-performance 32-bit MCUs**

**Advanced secure solutions**

**Wireless communications technologies**

- Bluetooth Low Energy, Wi-Fi, Sub-GHz SPIRIT

**Ultra-efficient power-conversion, monitoring & control technologies**

**A broad selection of analog products to complete every design**

### Platform ready solutions & ecosystem

**Microcontrollers**

- Discovery kits
- Evaluation platforms
- STM32 Nucleo development platforms
- Third party tools

**Sensors Connectivity Power & Analog**

- Evaluation platforms
- STM32 Nucleo expansions
- Third party tools

STM32 Open Development Environment

### Addressing a broad variety of application

Wearables – Smartphones – Healthcare devices – Virtual Reality Drones – Home consumer– Entertainment

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# Power Management by Application



Industrial

- Factory automation
- Photovoltaic
- Home appliances
- Metering

Consumer (TV & collateral)


- LCD and PDP TV
- Set-top box
- LCD monitor
- DVD/ Blue Ray player

Consumer (portable)

- MP3/Portable media player
- Smart phones,Tablet
- Battery chargers
- Digital camera
- PDAs, DSC
- Fitness portable devices
- Portable printers

Computing & Storage


- Desktop PC
- Notebook PC
- Server
- HDD, SSD

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# Thank You