Energy Harvesting End-to-End:
Technologies and Techniques for Building Zero Power Systems

February 7, 2012

APEC 2012 Industry Session Presented by:

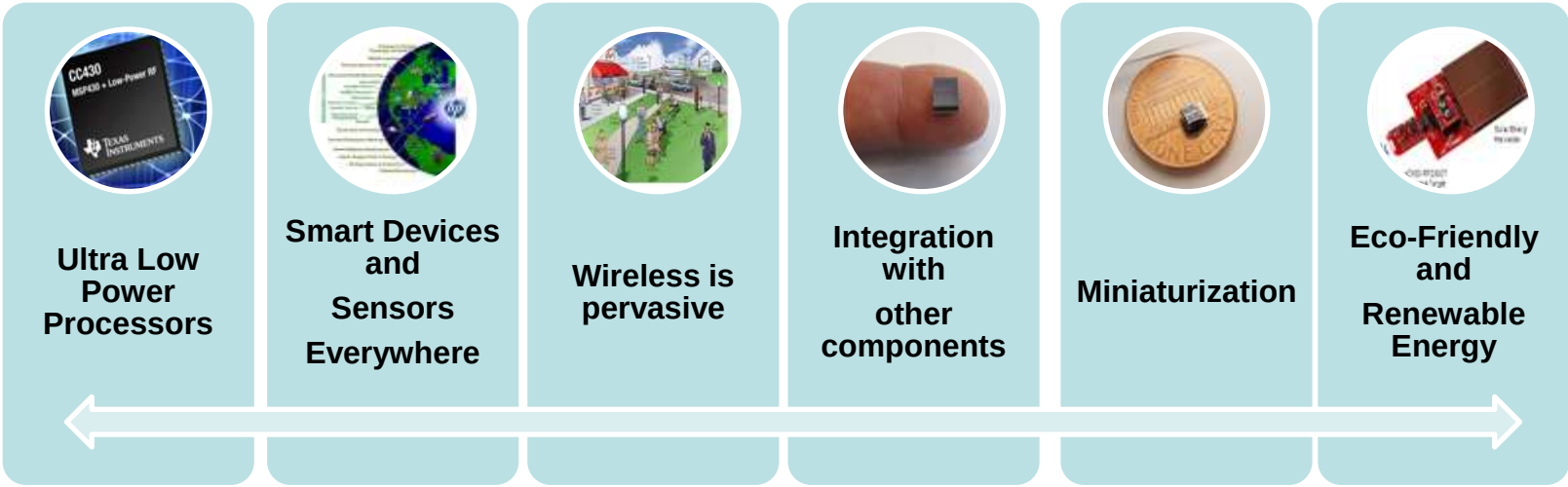
PSMA Energy Harvesting Forum

Energy Harvesting Info & Resources for the Power Electronics Industry

Energy Harvesting End-to-End

- Identify key trends and market forces driving the need for Energy Harvesting-based power
- The economics behind Energy Harvesting
- Diagram the system architecture of an EH-based system – networked or stand-alone
- What are the high level design considerations
- Energy Harvesting technology enablers

Key Trends Driving Innovation



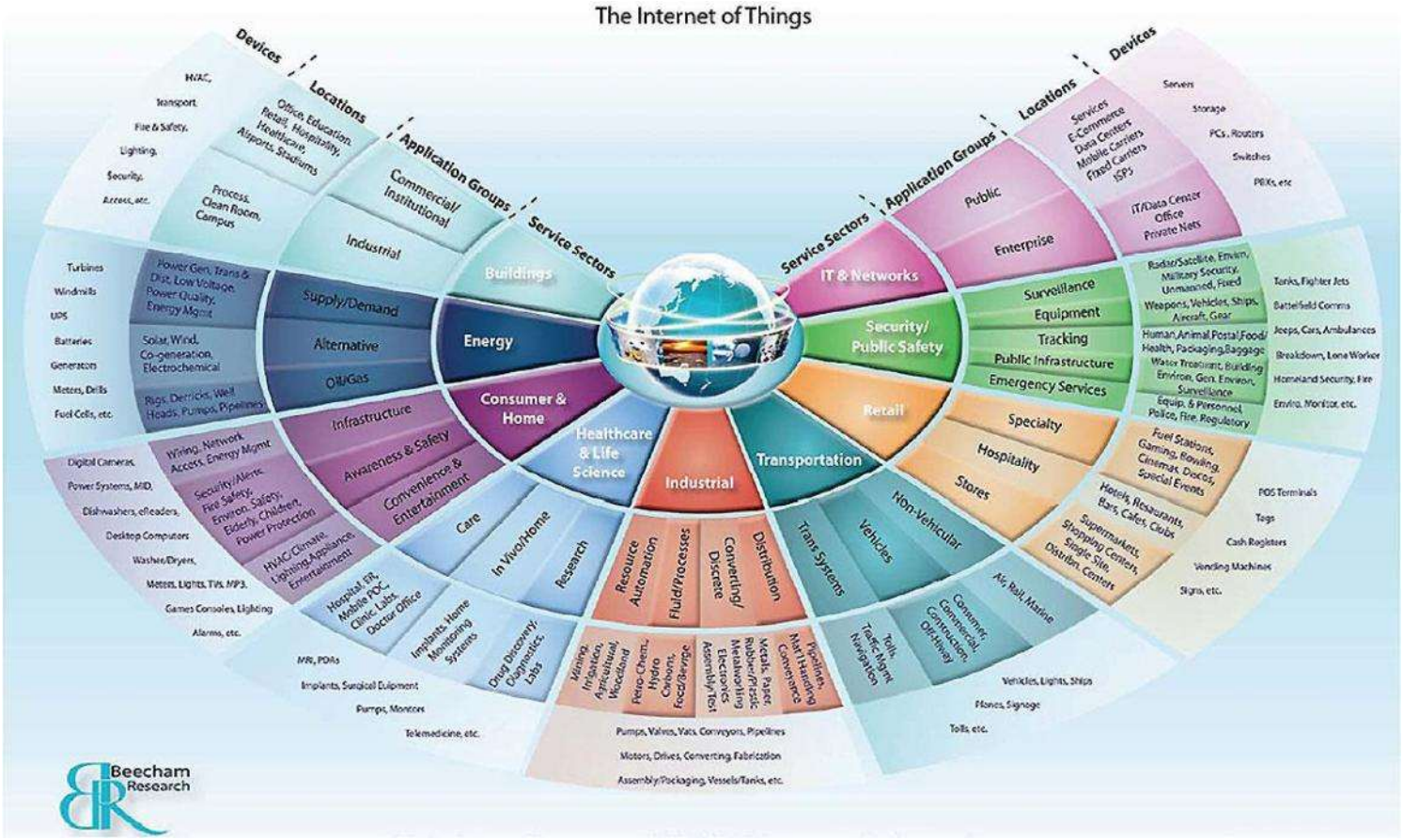
- New innovative products are smarter, smaller and wireless
- Smart devices with status indications
- There will be billions of new networked smart devices
- Body area networks, Personal area networks, Ad hoc nets
- New Powering solutions are required

Introducing Energy Harvesting:

Life of Product Energy Generation and Storage…

- Energy can be harvested from almost any environment:
  - Light, vibration, flow, motion, pressure, magnetic fields, RF, etc.
- Energy Harvesting applications found in every industry segment
- EH-powered systems need reliable energy generation, storage and delivery:
  - Must have energy storage as EH Transducer energy source is not always available: (Solar @night, motor vibration at rest, air-flow, etc.)
  - Longer operating times – high-efficiency minimizes charge loss
  - Self-Powered allows remote locations & lower installation costs
  - High cycle life enables extended operation – fewer service calls
- Ideal solution is a highly-efficient, eco-friendly, power generation system that can be cycled continuously for the life of the product

Energy Harvesting Powering The "Internet Of Things"



Market forecasts show billions of smart wireless sensor nodes over the next 10 years in all industry market segments and application areas with high Return on Investment

HP CeNSE, IBM Smarter Planet

Giving the Planet a Voice with Sensors

CeNSE

Central Nervous System for the Earth

– Awareness of planet

– Measurement of impact

– Taste/Smell/Touch/Sound/Sight

– Safety

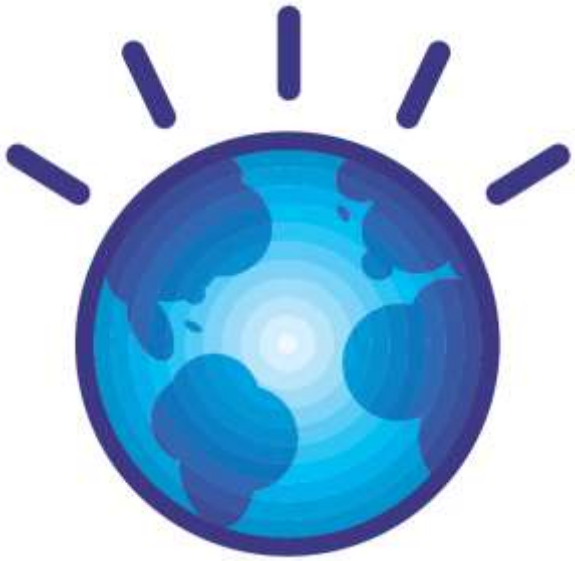
– Sustainability

– Security

~1 trillion sensor network

Quantity of data creates quality of data

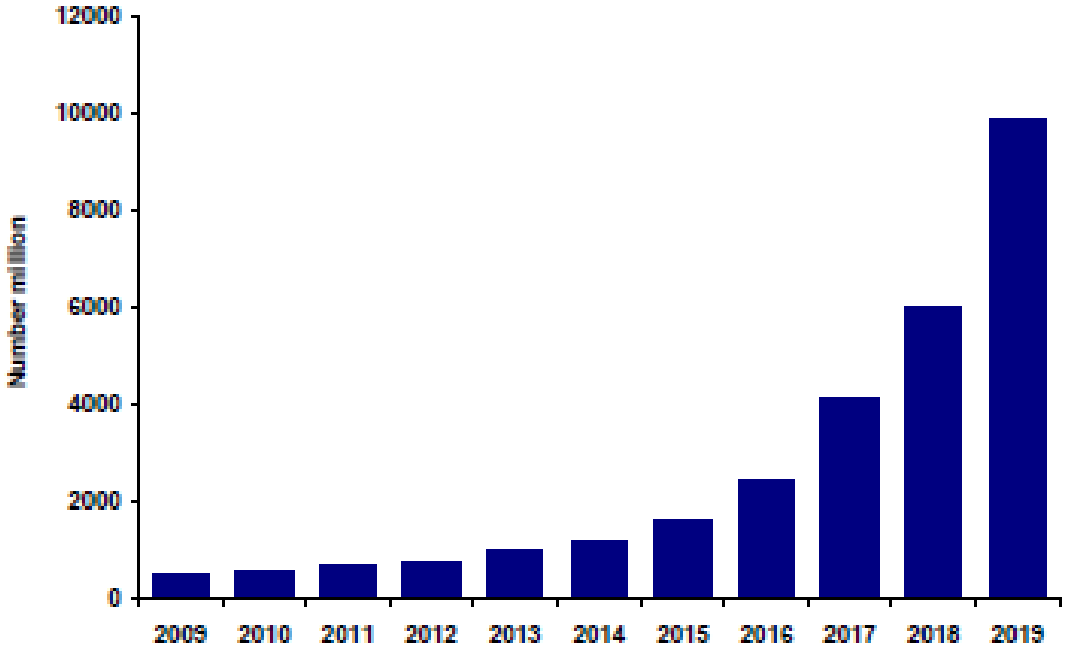
IBM Smarter Planet



"Trillions of digital devices connected to the Internet, are producing a vast ocean of data…"

Who's going to change 1 Trillion Batteries????!

Energy Harvesting Market Forecasts



From the IDTechEx EH Study:

- **90% of envisaged use of wireless sensor networks are impractical without EH**
- **Many installations are inaccessible or prohibitively expensive for replacement**
- **Sensors such as bionics or embedded devices need life of product power**
- **Many standalone products need "off-the-grid" powering solutions**

Internet of Things using BLE , ZigBee, or IPV6 in Many Industries

IP Address per Industrial Sensor

IP Address per Ag Sensor

Energy Harvesting Smart Metering

IP Address per Environmental Sensor

Sensors in Moving Equipment

Smart Grid Appliances

Hand Held Mobile Devices Can Serve as Gateways

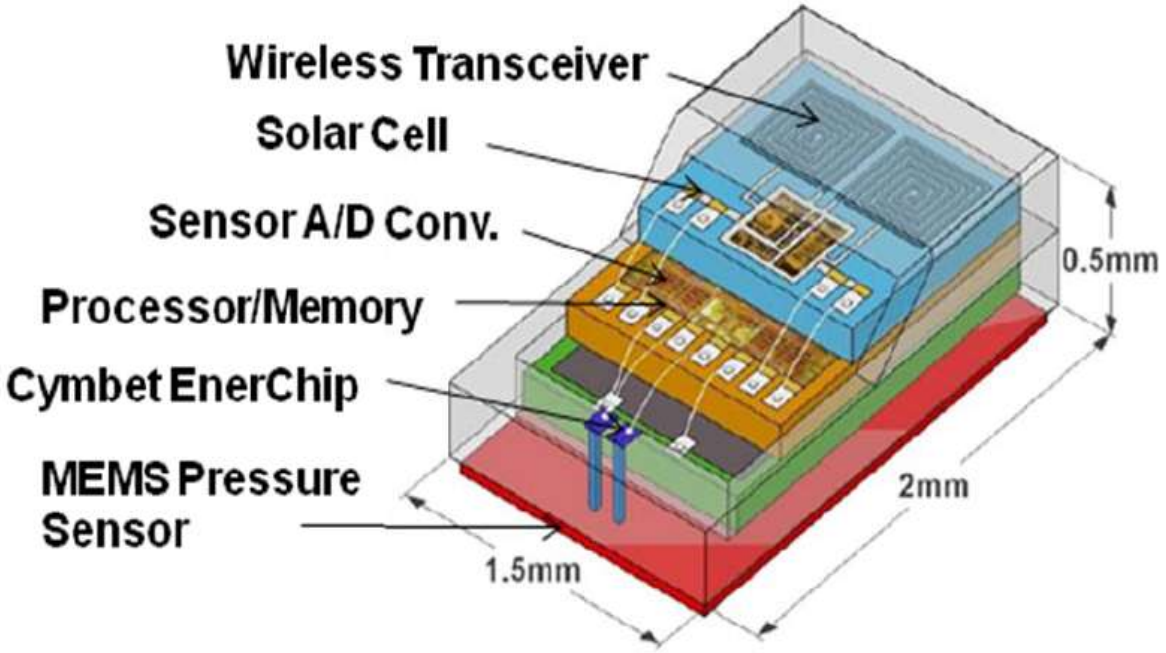
IP Address Switch and Light Bulb

IP Address per HVAC Sensor

Unique IPV6 Address per Pill

IPV6 Tiny Wireless Sensor

Detail of Wireless EH-Powered Intra-Ocular Pressure Sensor



University of Michigan ISSCC Paper: ***http://www.cymbet.com/design-center/wireless-sensors.php***

Design Considerations for EH

1. Determine energy available from your environment
   - Indoor solar is in tens to hundreds of microwatts
   - Thermoelectric in tens to hundreds of microwatts based on delta T
2. Harvest energy as efficiently as possible
   - Design for Maximum Peak Power Point
   - Avoid components with excessive leakage or quiescent current
3. Calculate application power requirements and minimize to fit available input EH power
   - Use sleep modes of components when possible
   - Write Energy- Aware code -> no polling loops, check Vcc before running
4. Size storage for times when energy is not available

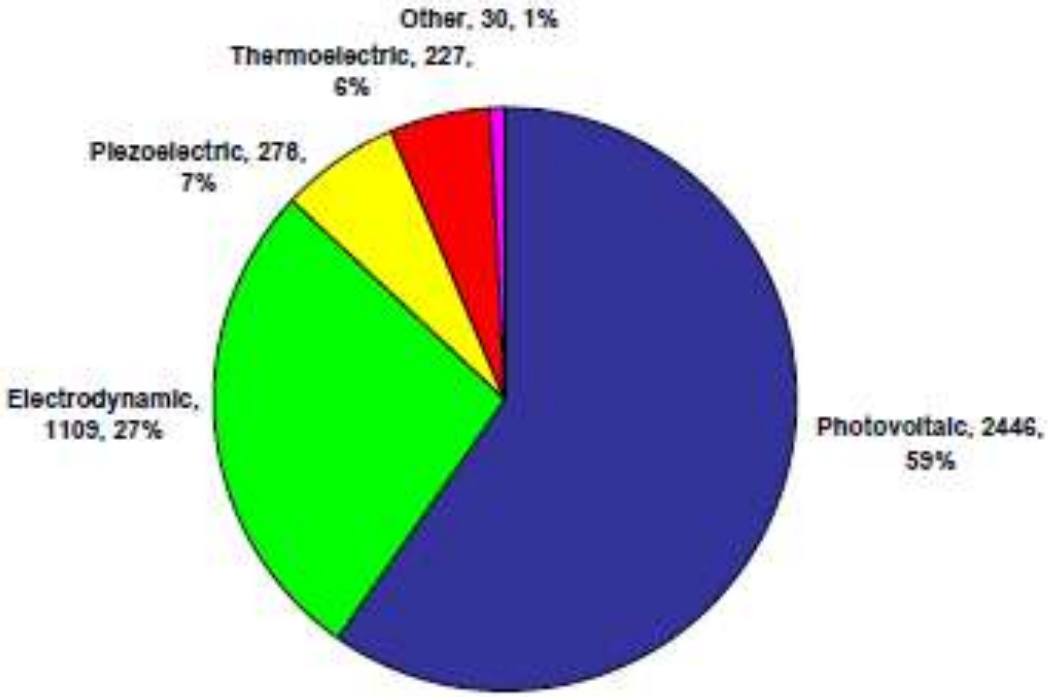
   Bigger battery is not always better: don't fill the pool with a paper cup!

Energy Harvesting Transducers

Energy Source	*Challenge*	*Typical Electrical Impedance*	*Typical Voltage*	*Typical Power Output*
Light 	**Conform to small surface area; wide input voltage range**	***Varies with light input*** ***Low kΩ to 10s of kΩ***	***DC: 0.5V to 5V [Depends on number of cells in array]***	**10µW-15mW (Outdoors: 0.15mW-15mW) (Indoors: <500µW)**
Vibrational 	**Variability of vibrational frequency**	***Constant impedance*** ***10s of kΩ to 100kΩ***	***AC: 10s of volts***	**1µW-20mW**
Thermal 	**Small thermal gradients; efficient heat sinking**	***Constant impedance*** ***1Ω to 100s of Ω***	***DC: 10s of mV to 10V***	**0.5mW-10mW (20°C gradient)**
RF & Inductive 	**Coupling & rectification**	***Constant impedance*** ***Low kΩs***	***AC: Varies with distance and power*** ***0.5V to 5V***	**Wide range**

Designs must deal with different: Impedance, Voltages, Output power, etc.

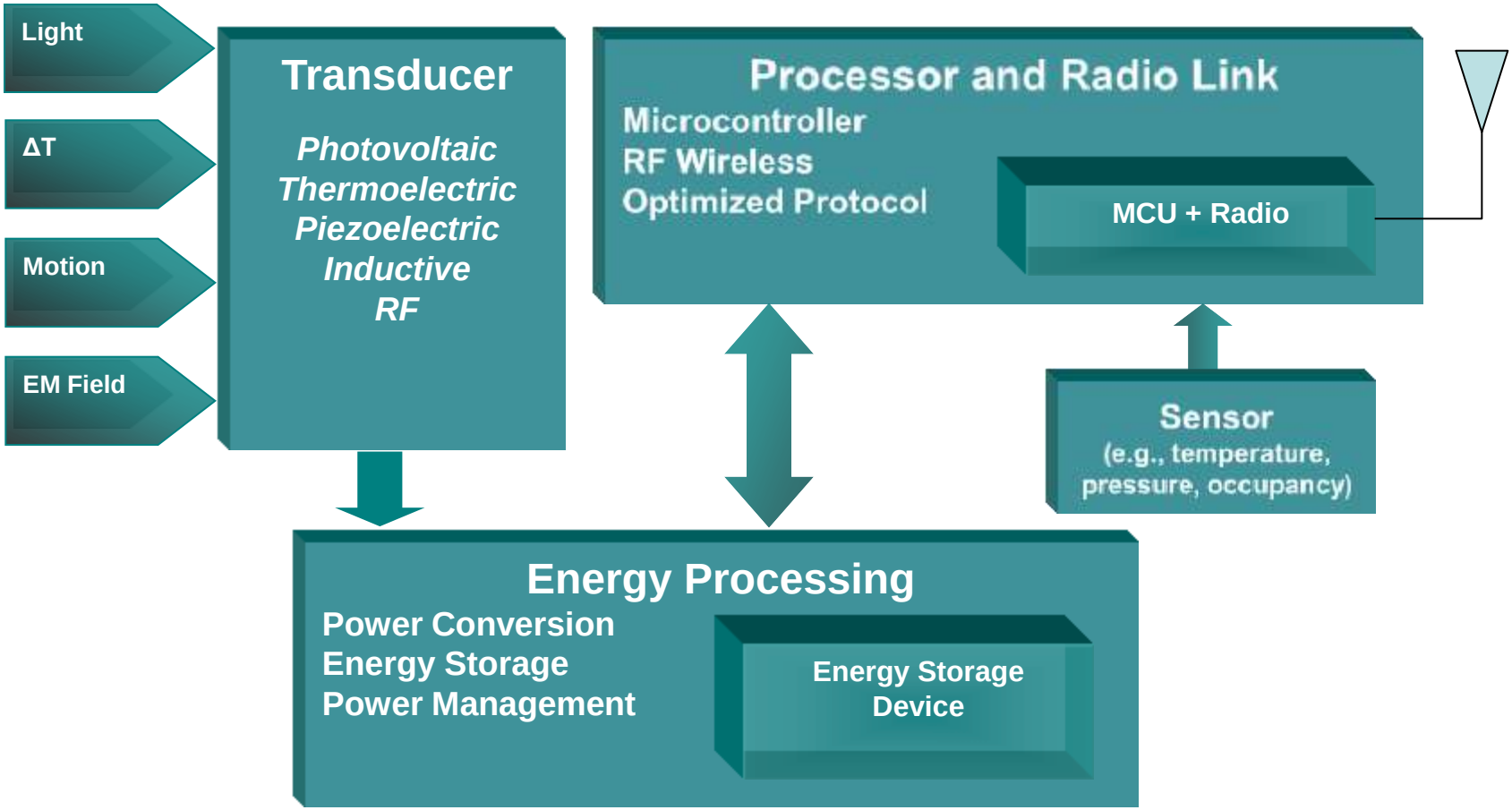
Total Market Value by EH Technology 2019



From the IDTechEx EH Study:

- **EH from light is 60% of applications**
- **Electrodynamic/Electromagnetic is 27%**
- **Vibration and Thermal 13% but may be low by some estimates**
- **What new energy harvesting technologies are coming???**

EH-Powered Autonomous Wireless Sensor Block Diagram



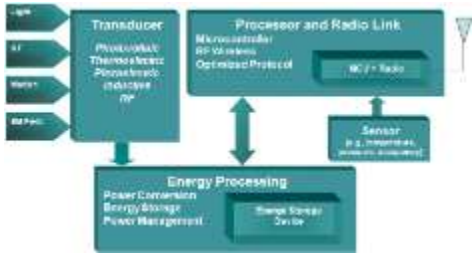
Industry is Providing Lower Power Building Blocks

- Low Power Microprocessors with nanoAmp sleep currents.
- Low Power Radio Transceivers:
  - IEEE 802.15.4 standards 2.4Gigahertz
  - MilliAmp to tens of milliAmps currents for transmitters and receivers
  - Quick startup with low sleep power
- Energy Efficient Radio Protocols:
  - Proprietary Ultra-low power protocols
  - ZigBee and ZigBee Green
  - Bluetooth LE
  - ANT+, EnOcean Alliance
  - Dust Networks IP 6LoWPAN
- Micropower Sensors with low sleep currents:
  - Passive IR, Temp, Humidity, Acceleration, Pressure, etc.
- Lower quiescent current peripheral circuits:
  - Clocks, power management chips, etc.

Summary

- Billions of smart devices deployed over the next 10 years need:
  - Powered autonomously and be “off-grid”
  - Have a power source that lasts the life of the device
  - Be small, integrated and cost effective
- Energy Harvesting solutions can provide these powering needs
- Success is based on the EH Ecosystem converging:
  - EH Transducers
  - High Efficiency power conversion
  - Life of Product Energy storage
  - Ultra low power Microcontrollers and Sensors
  - Low power wireless radios and protocols
  - Optimized system architecture, hardware and firmware

Session Agenda



1. Energy Harvesting for Zero Power Devices
   Steve Grady – Cymbet
2. Multiple Harvesting Transducer Optimization
   Chris Link– TI, Steve Grady - Cymbet
3. Low Power Converter Technology for EH
   Henrik Zessin – Fraunhofer Institute
4. Energy Harvesting Storage Technologies
   Joe Keating – Infinite Power Solutions
5. Ultra-low Power Microcontrollers, Sensors, Firmware
   Mark Buccini – Texas Instruments
6. The Spectrum of Low Power Wireless Solutions
   Roman Budek– *NXP*
7. The Design of Energy Harvesting Systems
   Heath Hoffman – University of Michigan

Session Co-chairs – Arnold Alderman – Anagenesis, Chris Link – Texas Instruments