Embedded Energy and Energy Processors for High Efficiency Energy Harvesting Applications

APEC 2011 - Steve Grady

New Product Innovation
Key Technology Trends and Drivers

1. Ultra Low Power Electronics – MCUs, DSP, MEMs
2. Smart devices in everything
3. Sensors everywhere – data capture and retention
4. Wireless is pervasive
5. Miniaturization
6. Integration
7. Eco-Friendly – safe transportation, use and disposal
8. Renewable Energy Sources – rechargeable and EH

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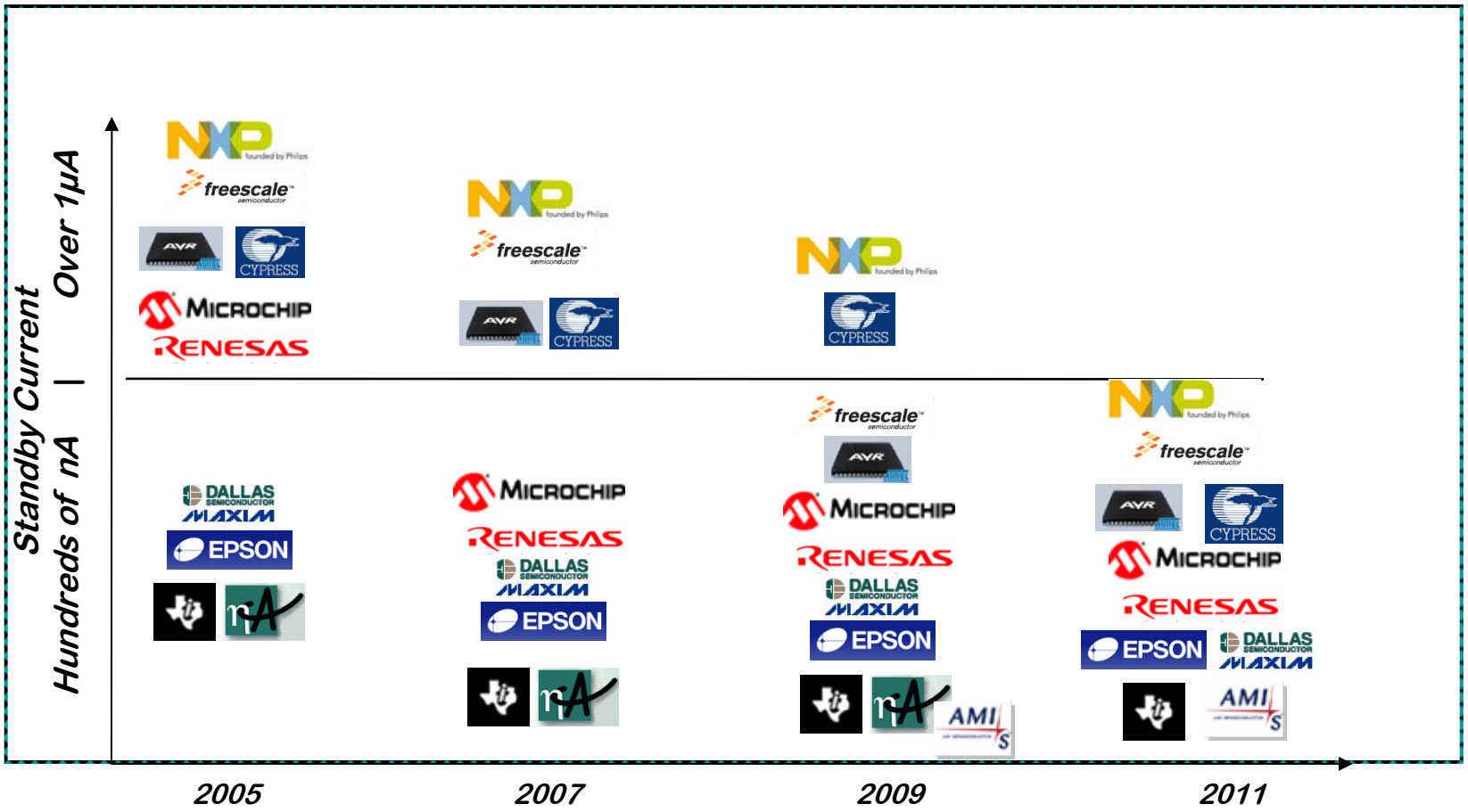
Semiconductor Power Reductions

Trend 1: from microWatts to nanoWatts



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Smart Devices in Everything

Trend 2: Intelligence in all products

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Sensors Everywhere

Trend 3 : Gathering data from everything

- Awareness of planet
- Giving a voice to the planet
- Integration of sensors
- Taste/Smell/Touch/Sound/Sight

- Safety
- Sustainability
- Security

~1 trillion sensor network

Source: HP Semicon West 2010 MEMS Sensor Presentation

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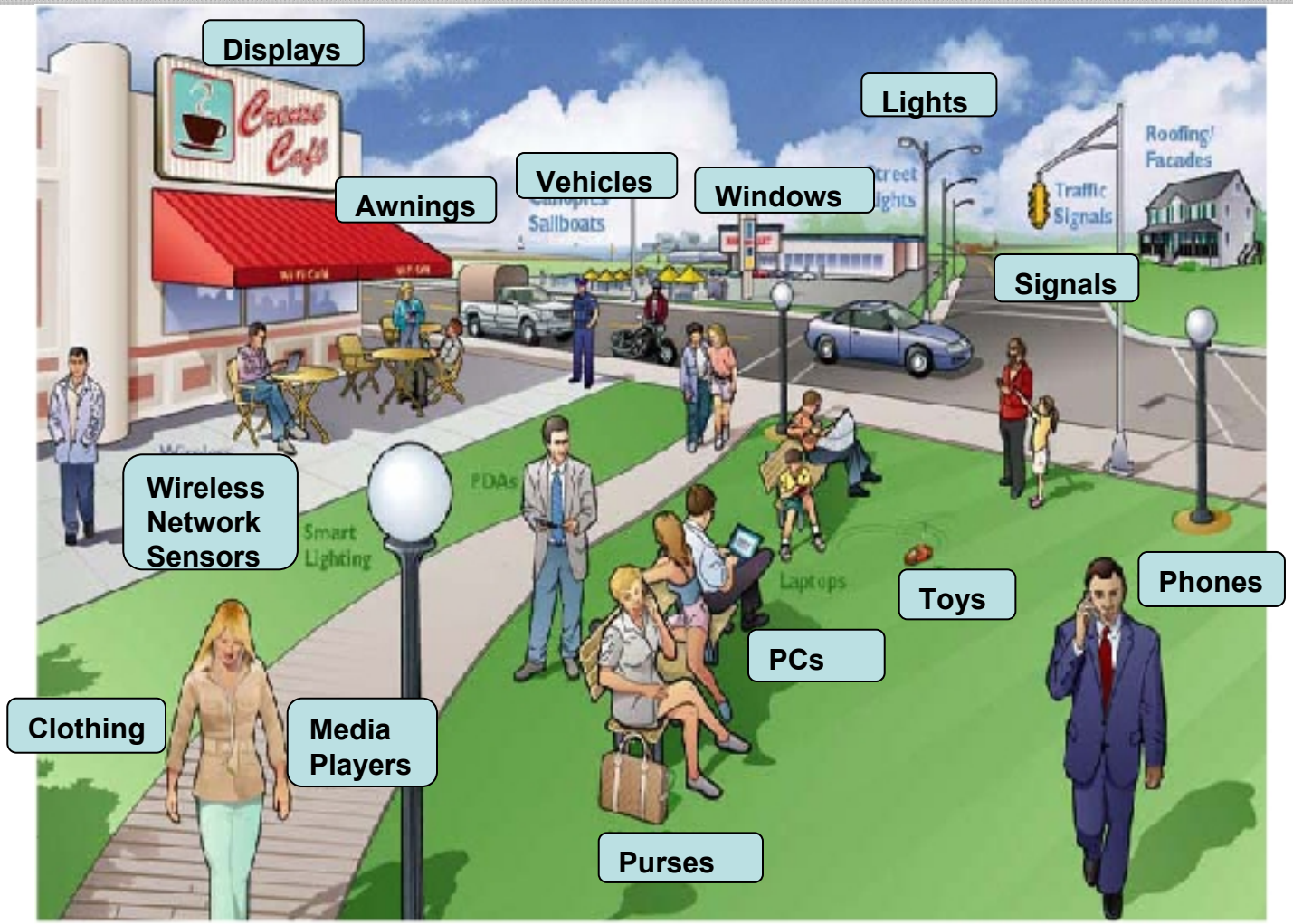
Wireless is Pervasive

Trend 4: no cords for Data and Power



Source Konarka

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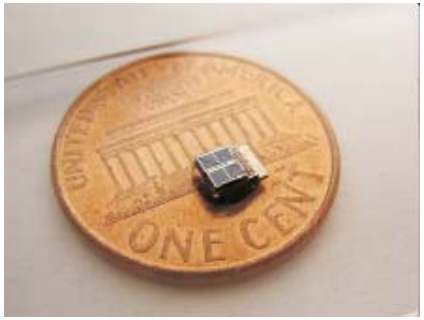
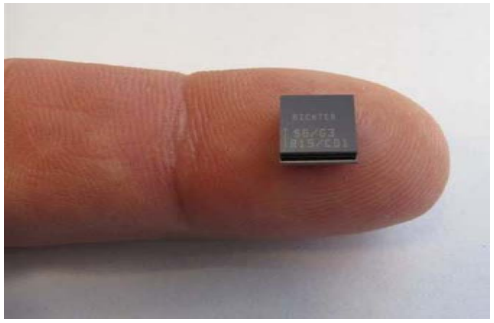
Miniaturization and Integration

Trends 5 & 6: Everything is getting tiny

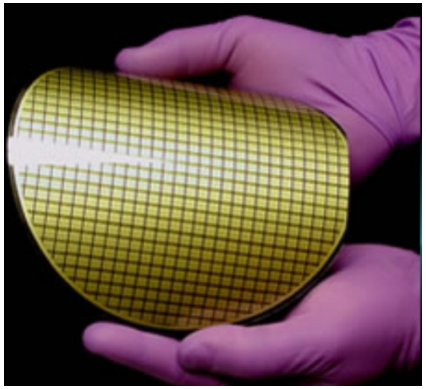
Complete Solar Energy Harvesting Sensor



3-Axis Accelerometer from HP – 1000X higher resolution



Advanced Flexible Microelectronics



Pillcam for Medical Imaging

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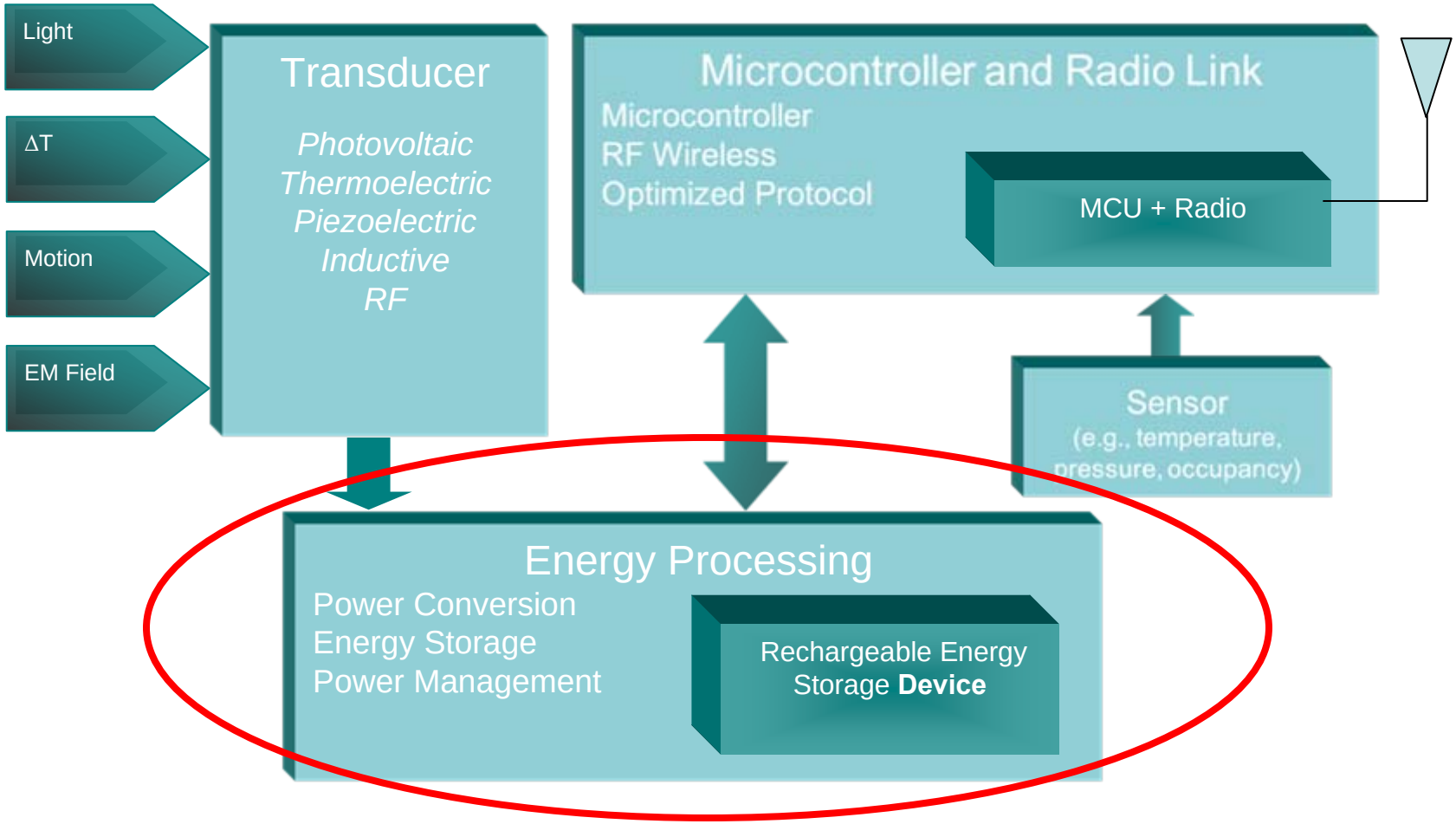
Energy Processing is a key Enabler of Energy Harvesting Systems



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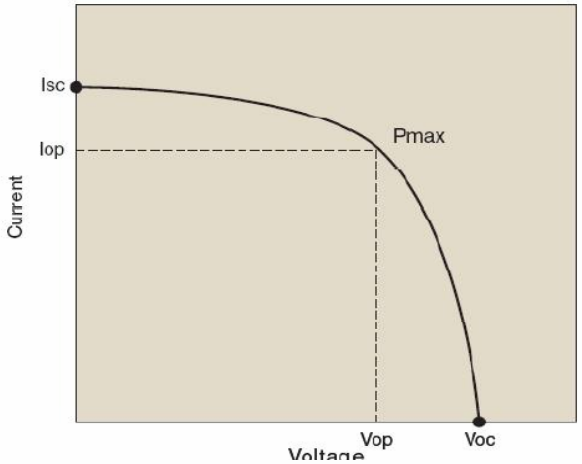
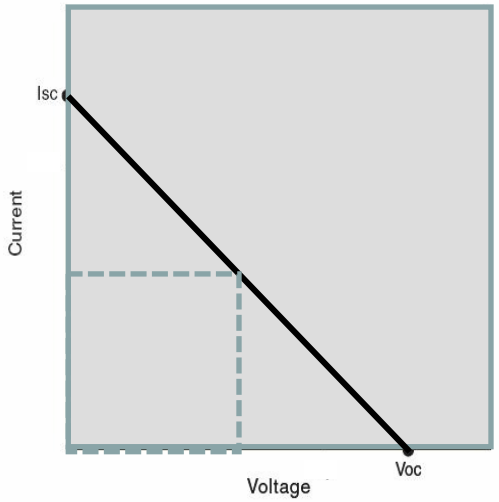
Transducer Impedance Differences

Variable Impedance Example Photovoltaic Cell



VOC: Open-circuit voltage
ISC: Short-circuit current
VOP: Optimum operating voltage
IOP: Optimum operating current
PMAX: Maximum operating power

Constant Impedance Examples: Thermoelectric Generators, Piezoelectric Materials, Electromagnetic



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Current-Voltage Curve

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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

The ideal power conversion stage matches the transducer impedance with the system load impedance.

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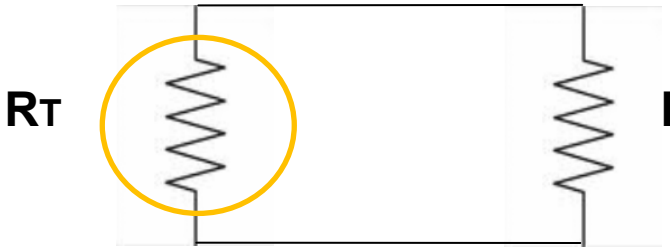
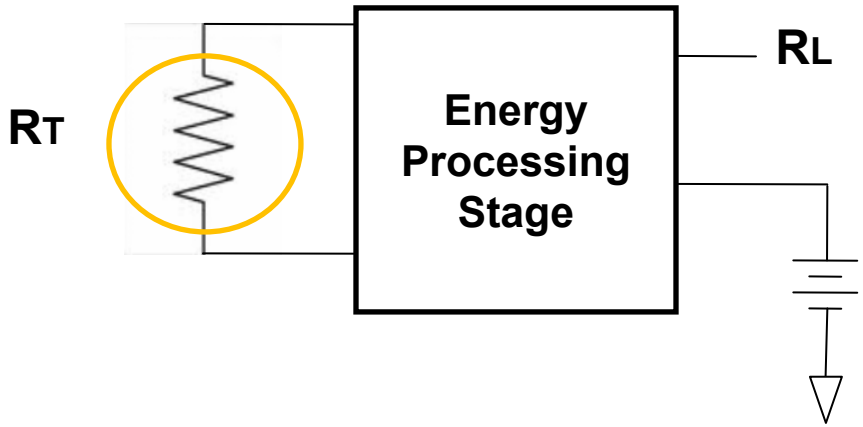
Impedance Matching is Critical



Reach P_{MAX} when $R_T = R_L$

Impedance mismatch means significant lost power



EP stage matches transducer impedance for high efficiency power conversion and optimal power management to load

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What are the Requirements for Ultra Low Power Management?

- Accept wide input voltage range
- Match the R_T and R_L impedances
- Ultra low power – active and quiescent
- Manage battery charging and cutoff
- Regulated output voltage
- Mode control
- Status indicators
- A drop-in solution

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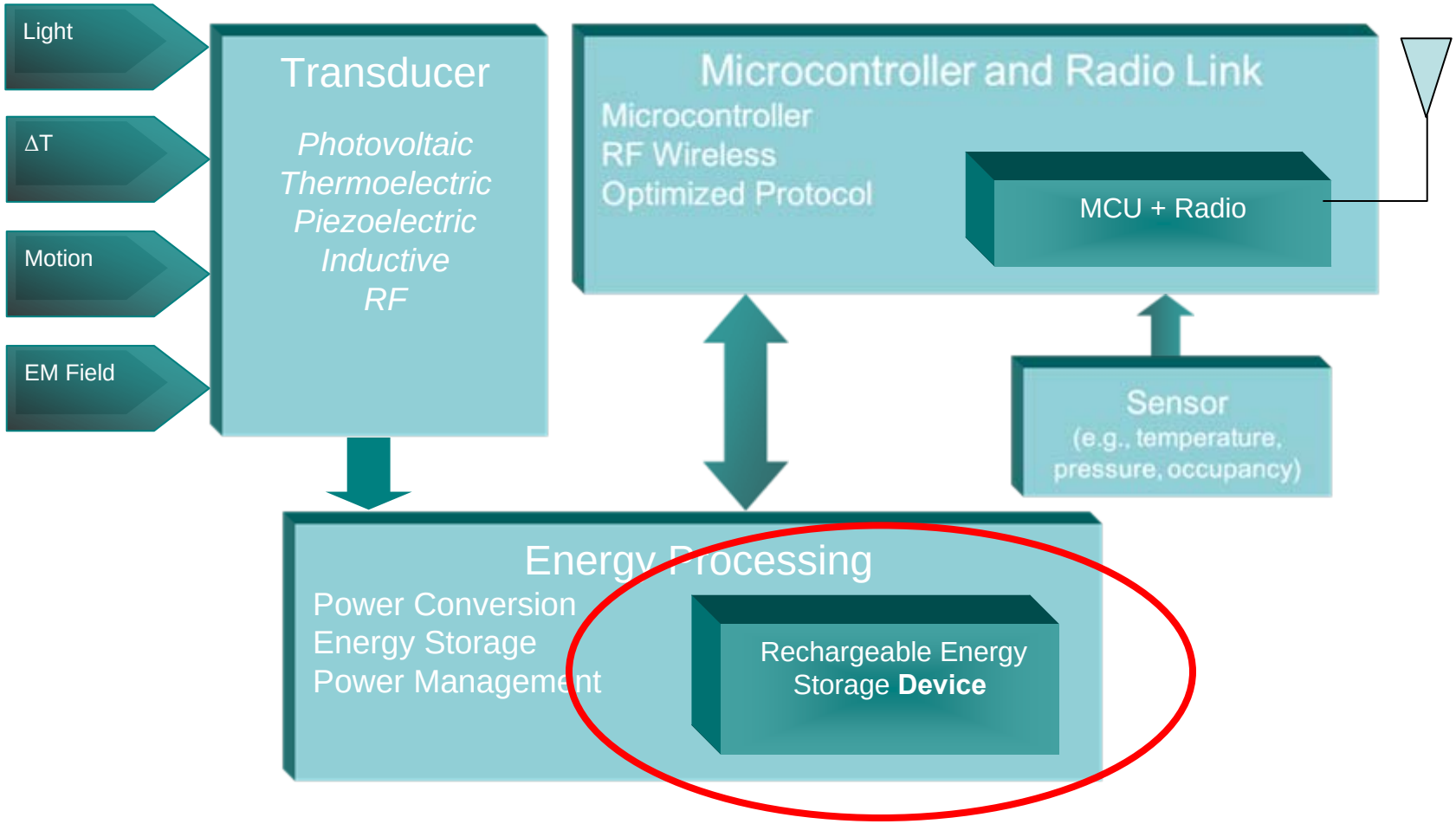
EH-based Systems Must Have an Energy Storage Component



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What are the Requirements for Micro Power Energy Storage?

- High Energy Density
- Small Footprint
- Rechargeable
- Permanent for life of product
- Safe and Reliable
- Eco-friendly throughout lifecycle
- Package compatible with other ICs
- Cost effective

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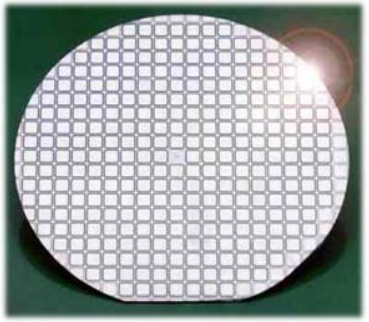
Solid State Batteries

SMT and Reflow Solder Tolerant

Wafer

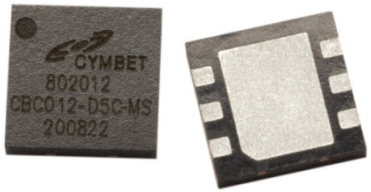


Diced

Bare Die

Packaged

Packaged Part



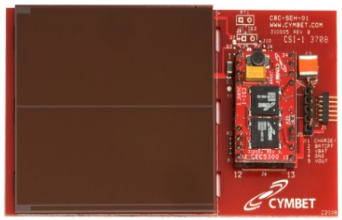
Tape & Reel

To Surface Mount Machine

To Reflow Solder

Final Assembly

SSB on Board



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Solid State Energy is Eco-Friendly :

Trend 7: Safe Transport, Use and Disposal

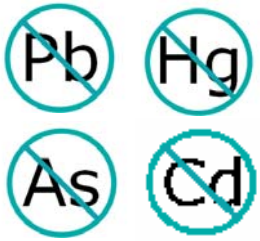
Completely safe to transport via air

WEEE compliant dispose like other Integrated Circuits

RoHS compliant for US and EU

REACH compliant for EU

China RoHS Compliant



Solid State Energy devices contain no toxic heavy metals

CE is not applicable to this product

CE mark does not apply to these devices

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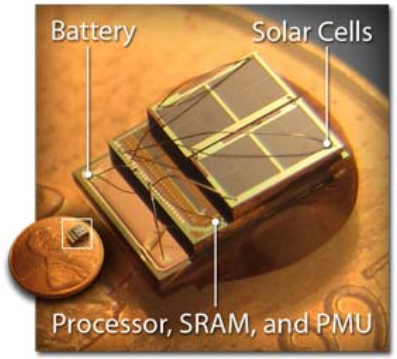
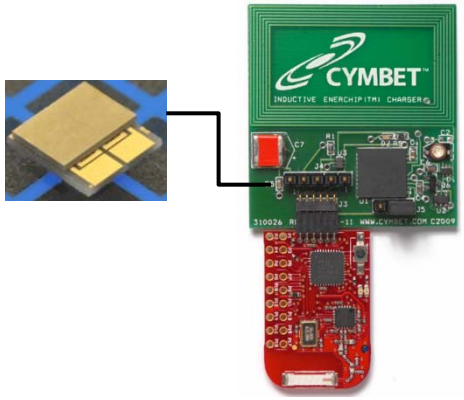
Energy Harvesting Examples
Trend 8 : Renewable Energy Sources

Univ. of Mich. Micro Sensor



TI eZ430-RF2500-SEH Kit

Nanomaterial-based Thermoelectric Generator EH Sensor



Piezo MEMS EH Transducer using Energy Processor

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Summary

- Leveraging the Innovation Drivers is key to developing successful new products
- Efficient power systems for zero power devices can be built using energy harvesting techniques
- Given the ultra-low power nature of energy harvesting systems, designers must utilize advanced Energy Processing techniques and technologies to optimize energy conversion, energy storage and power management
- Rechargeable solid state batteries are an ideal solution for systems relying on energy harvesting circuits
- Systems must be designed holistically using ‘energy-aware’ techniques

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