Energy Harvesting Transducers

Converting Ambient Energy for Life of Product Power

February 7, 2012

APEC 2012 Industry Session Presented by:

PSMA Energy Harvesting Forum

Energy Harvesting Info & Resources for the Power Electronics Industry

Energy Harvesting Transducers

- Energy harvesting transducers are the key element for converting ambient energy into electrical energy
- Many ambient energies sources can be used
- All EH transducers have unique electrical properties that must be addressed by both the energy conversion electronics and the system as a whole.

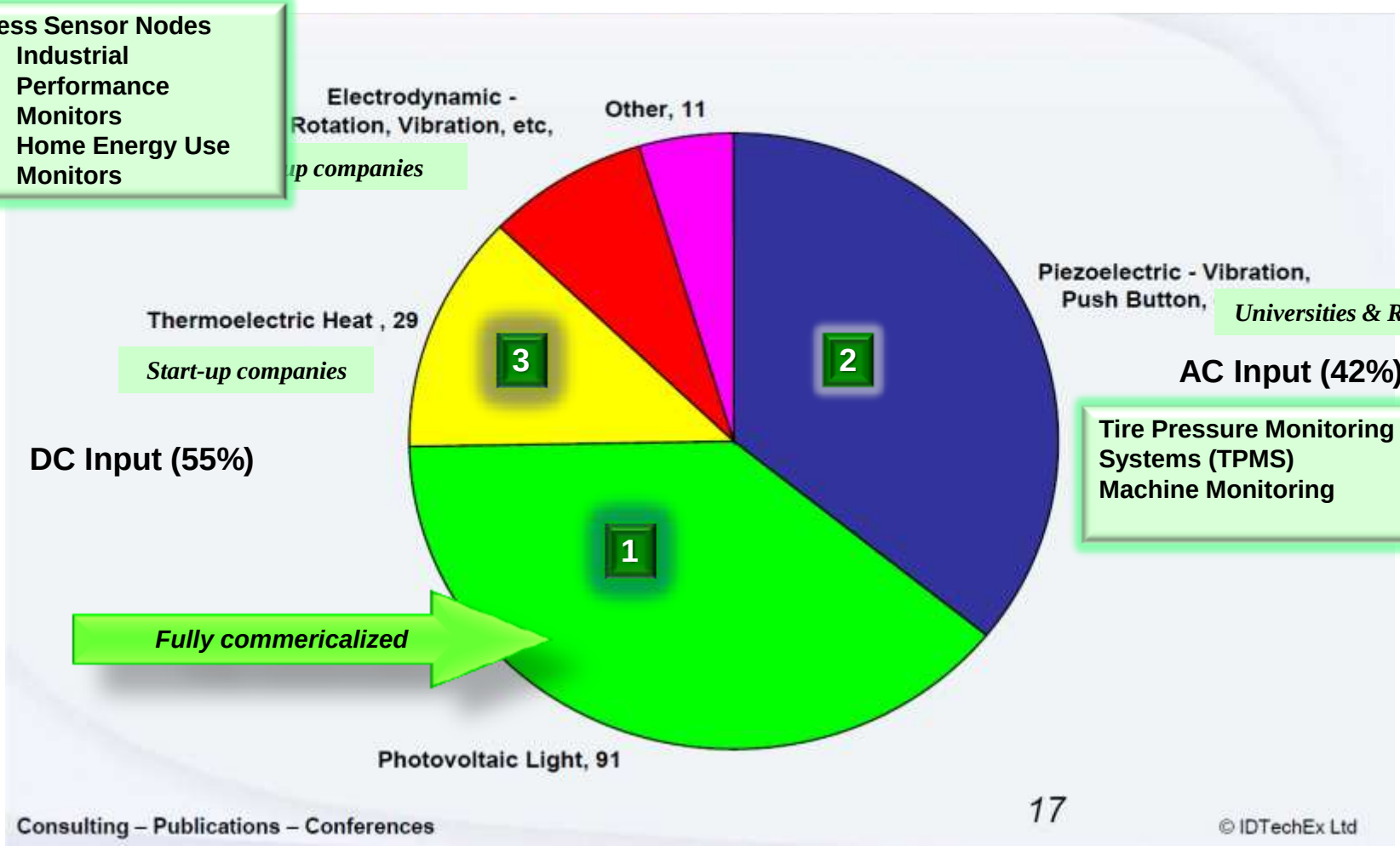
Energy Harvesting Transducers

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.

Harvester Technology Priorities

Wireless Sensor Nodes
- Industrial
- Performance
- Monitors
- Home Energy Use
- Monitors



Start-up companies

Universities & Research

DC Input (55%)

AC Input (42%)

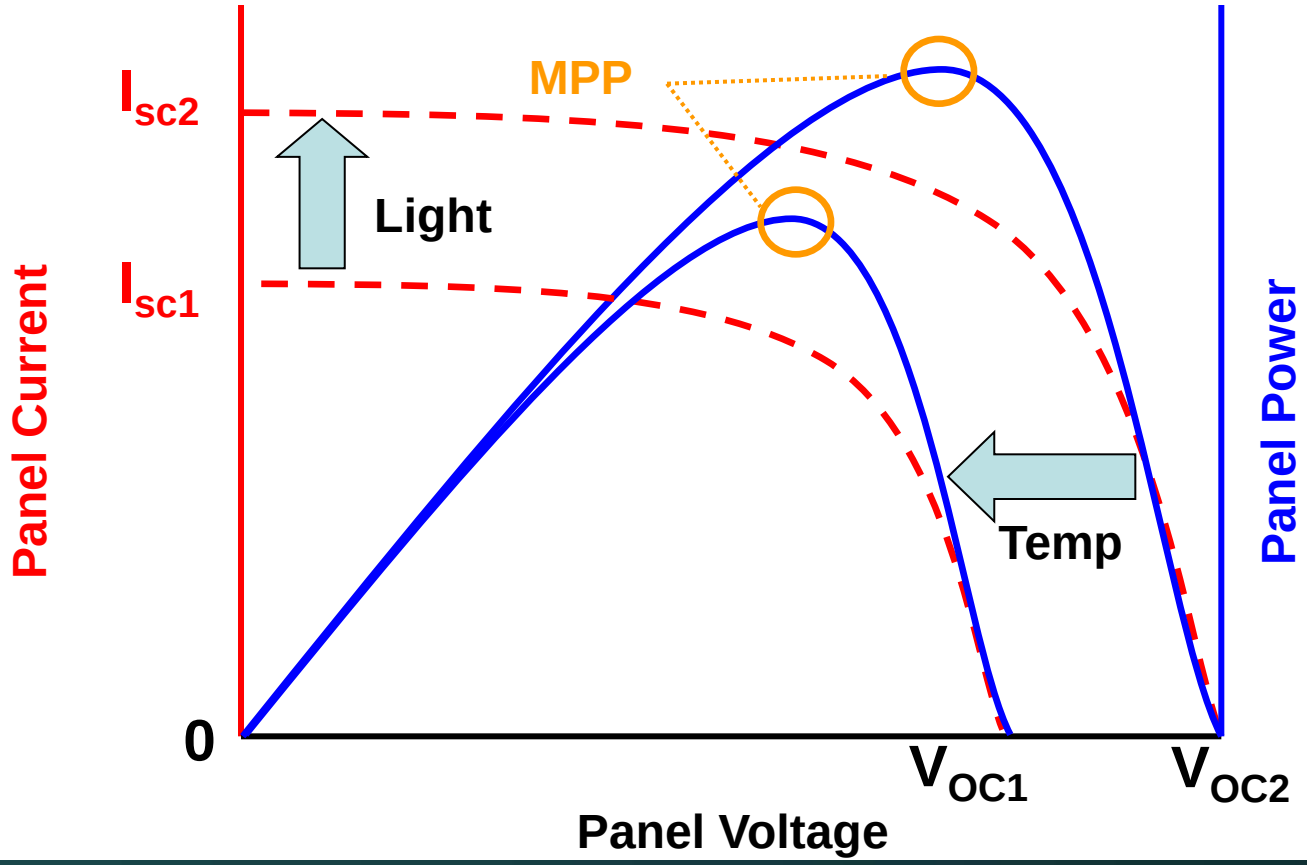
Tire Pressure Monitoring Systems (TPMS)
Machine Monitoring

Fully commericalized

Small Scale Solar Powered Apps

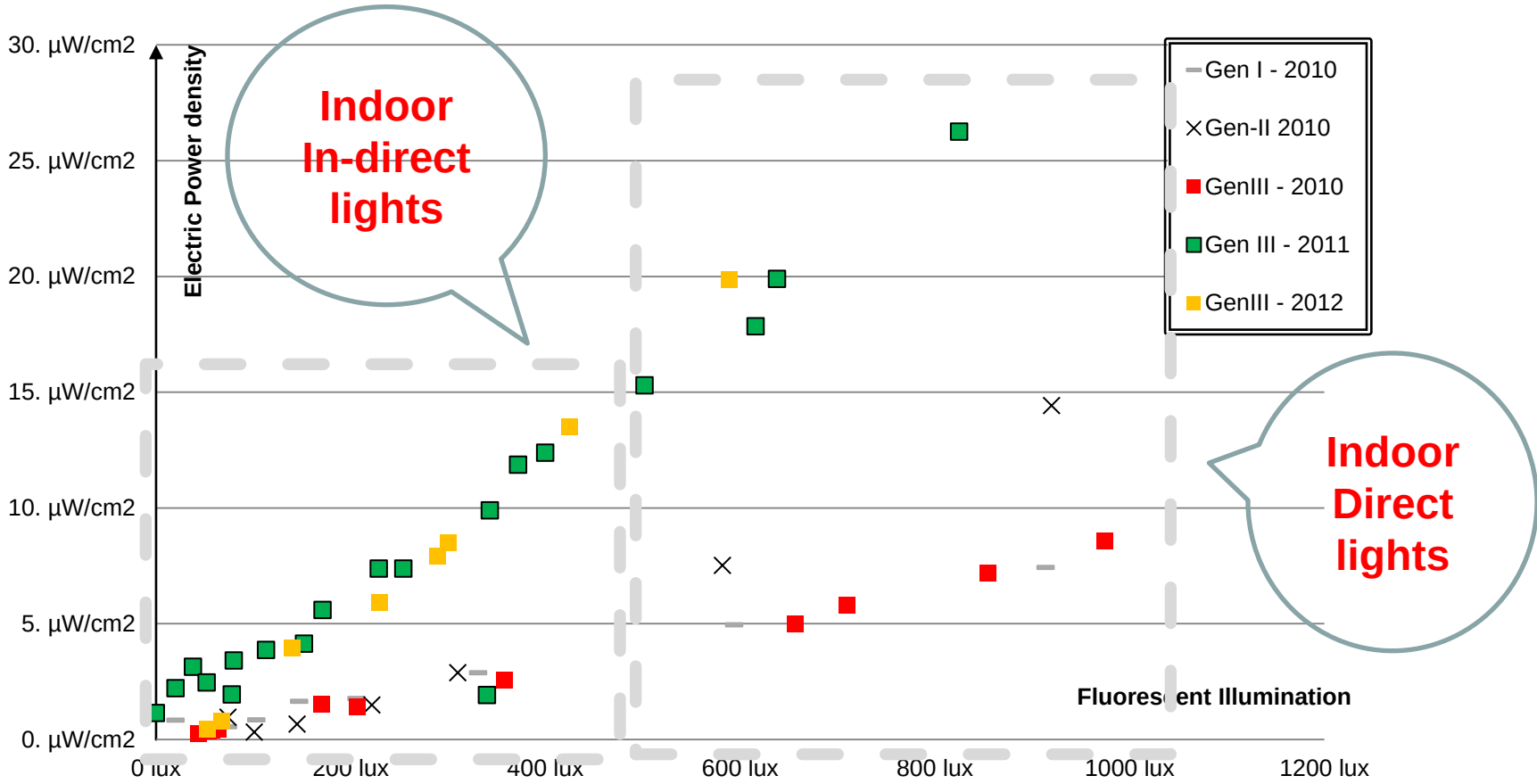
Solar Power Conversion

- Maximum power point (MPP) is influenced by environment
  - 10uW/cm2 (indoor)
  - 10mW/cm2 (outdoor)



Technologies

The differences : Fluorescent lighting < 1000 lux



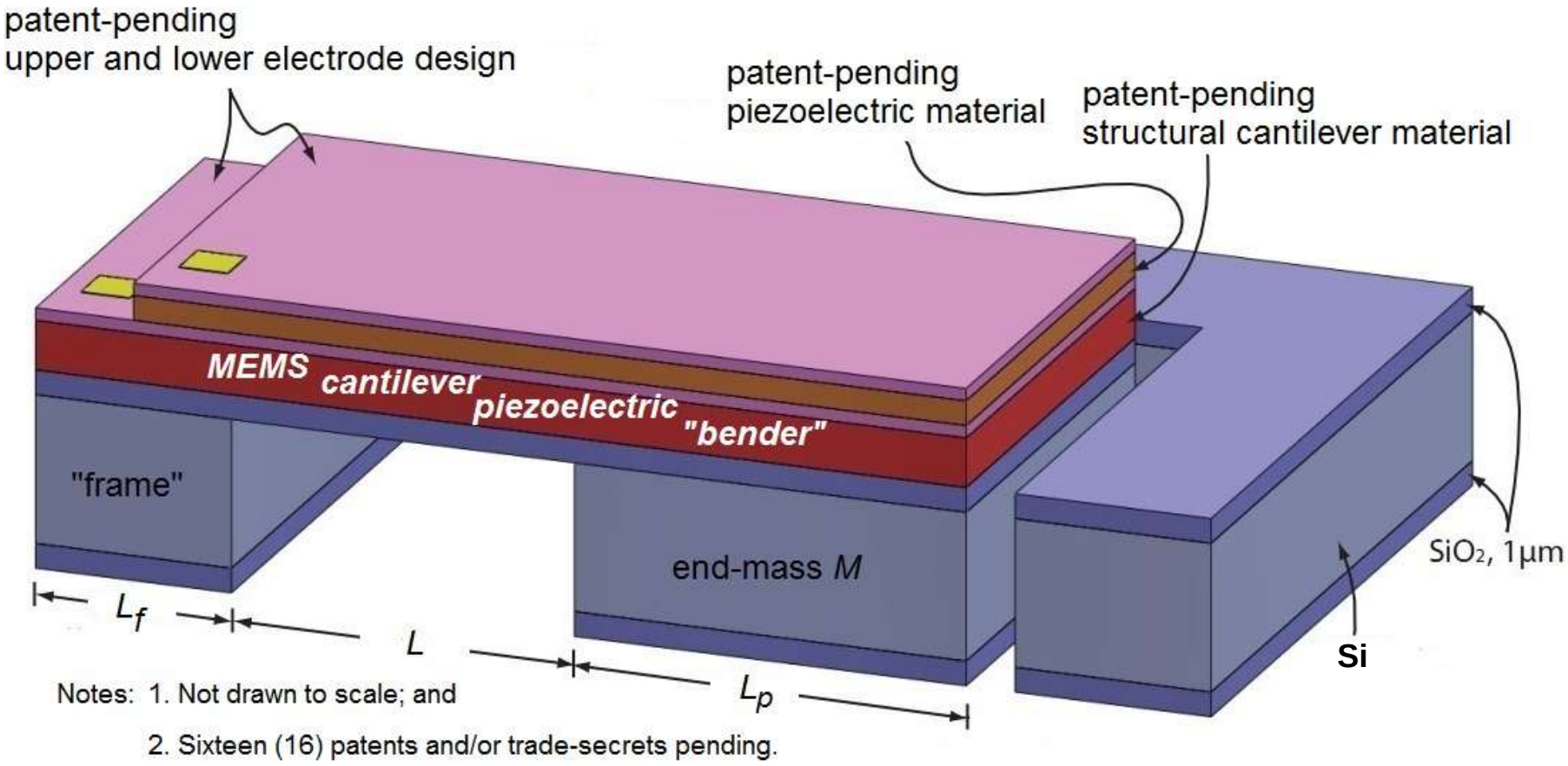
source: TI Solar Lab

Meso-scale Electromagnetic – Vibrational EH

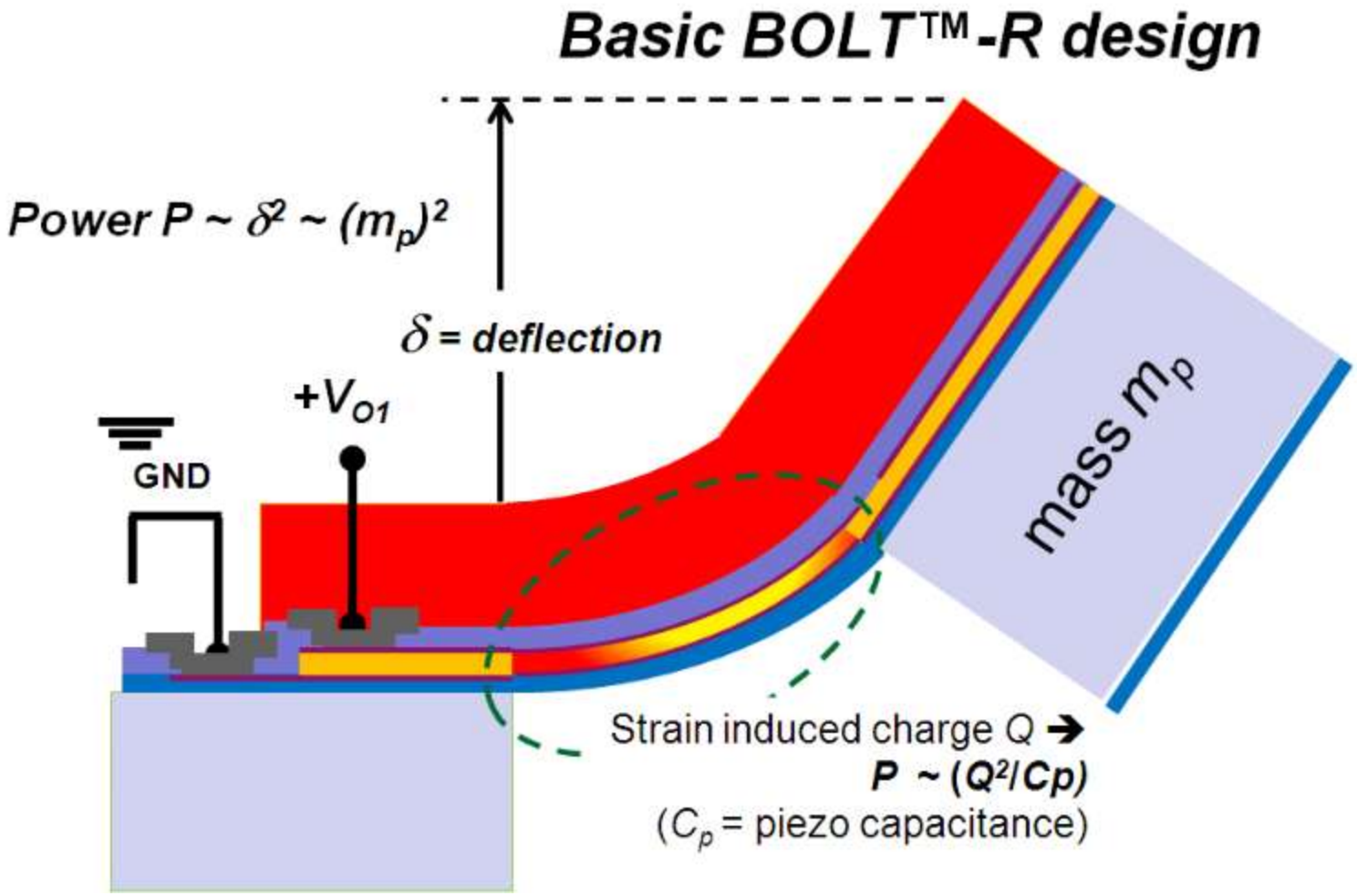
- **Pro's**
  - ✓ Plenty of power for WS
    - 40 to 100 mWatts
    - Power many WS at once
  - ✓ Broad bandwidth capable
  - ✓ Reliability proven
- **Con's**
  - ✓ No vibration, no power
  - ✓ Large and costly ($300+ each)
  - ✓ 1-axis power generation (orientation dependent)
  - ✓ **Not scalable to micro-scale (MEMS)**
    - 10X reduction in size ➔ 10^4 reduction in magnetic force F_B

PMG Perpetuum

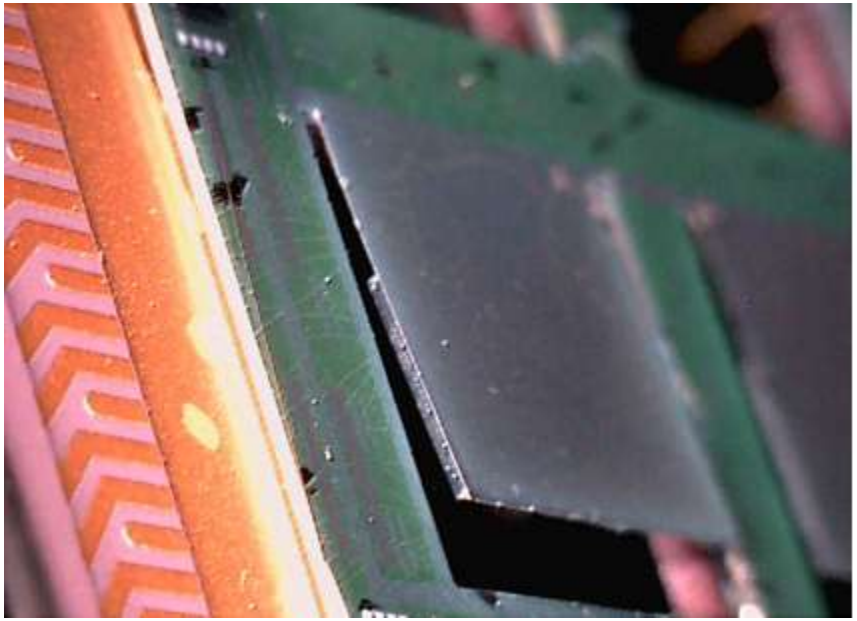
MEMS Piezoelectric - MicroGen

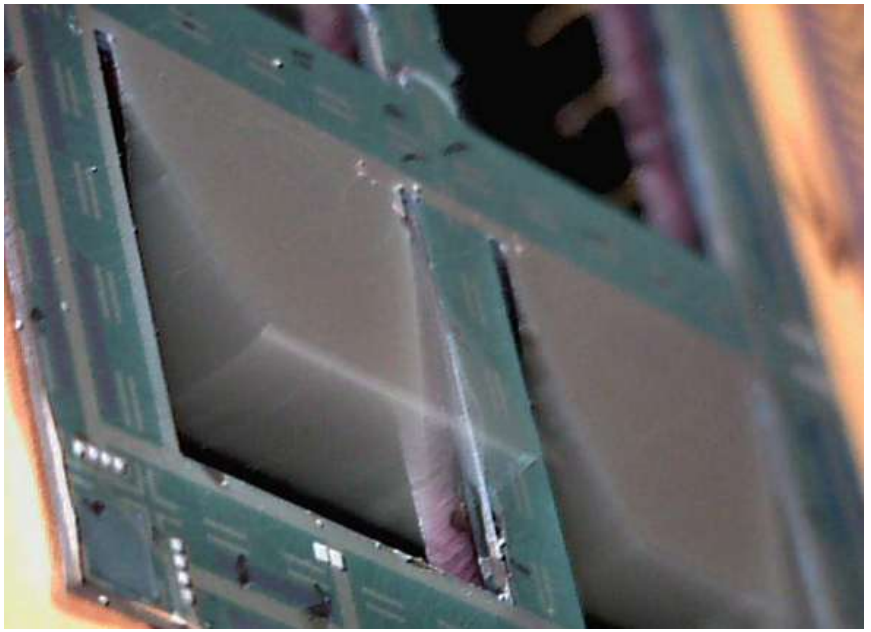


Piezoelectric Energy Creation



MEMS Piezo Harvester in Action





Static

Note: **Patent-pending design and material improvements will quadruple power density yielding a smaller die. This results in more die per wafer and lower production cost.**

Dynamic (60 Hz) –

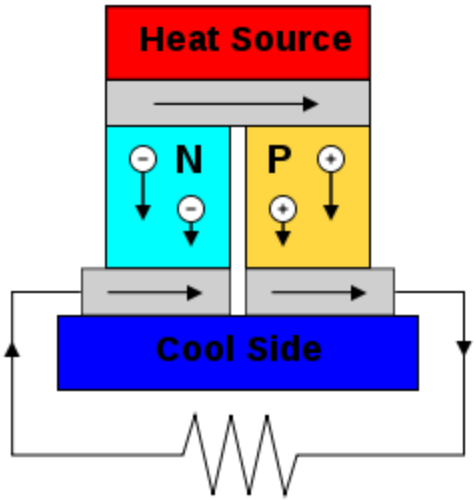
(a) 0.5 *g* ➔ >30 μWatts*

(b) 1.0 *g* ➔ >120 μWatts*

**** 2013 ➔ 2X; 2014 ➔ 4X***

Thermoelectric Generators

- Uses hot and cold surfaces – Seebeck effect
- Performance
  - –High Power
  - –Mid-High Cost



From: Wikipedia (Thermoelectric Effect)

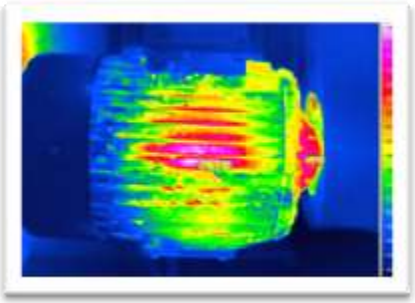
$$V = (S_B - S_A) \cdot (T_2 - T_1)$$

Harvesting Thermal Gradients

Heat energy can be found in many places

Industrial

- **Motors, production robots, vacuum pumps, gear boxes, bearings (e.g. temperature & vibration monitoring)**
- **Wireless process automation sensors (e.g. temperature sensor, pressure sensor)**

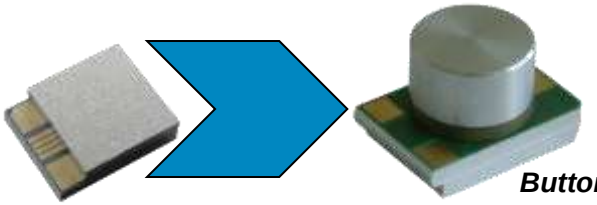


autonomous smart bolt's

Domestic appliances

- **Energy reduction for kitchen equipment (e.g. autonomous smart cooking)**

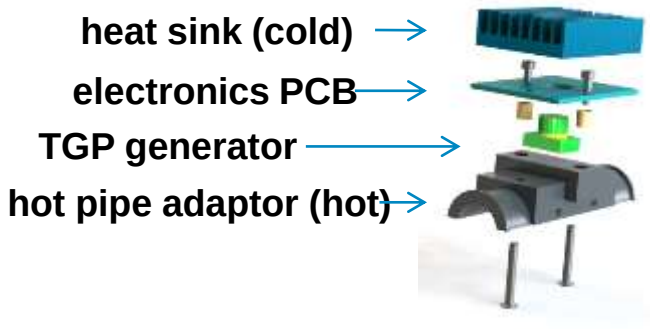
Thin Film Thermal Generators

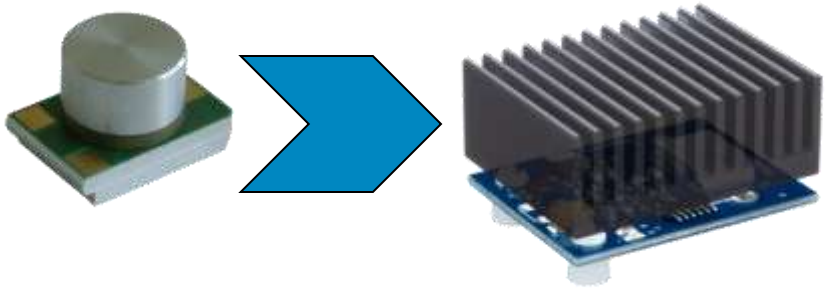


Button-cell generator

TGP: Thermal Generator in Package

- **High output voltage: *TGP-751 > 100 mV/K***
  - **Simple & high-efficient DC-DC Booster**
  - **Operation from small delta T (< 10 K)**
- **SMD component: reflow production**
- **Operates with discrete or 1-chip (*TI bq25504*) DC-DC Booster**
- **Easy mechanical & thermal integration**





TE-CORE: Thermal harvesting module

- **Integrated DC-DC Booster**
- **Fixed 2.4 V output voltage (1.8 V – 4.5 V)**
- **Thin Film Battery can be connected**
- **Starts at delta T < 10 K**
- **Output power depends on heat sink type**

	T_{hot} [°C]	U_{oc} [Volt]	Power [mW]	Year energy [mAh]	Batteries [AA]
TE-CORE	40	0.56	0.36	2102	1-2
	50	0.96	1.1	6424	3-4
	60	1.4	2.2	12848	> 6

Output power indication at ambient of 25 ºC

CYMBET™ CORPORATION

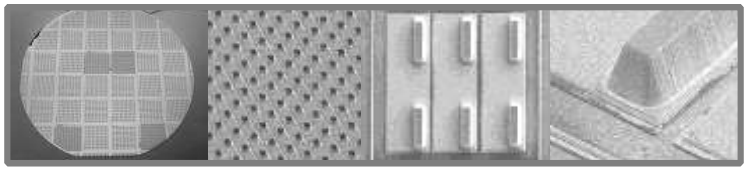
Manufacturing Thermal Generators

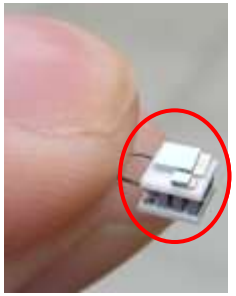
- Availability thin-film thermoelectric technology
  - Micropelt factory opened June 2011
  - Semiconductor quality equivalent

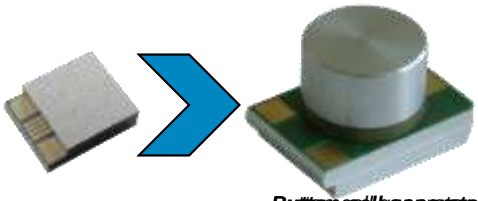
- Microstructures offer high output voltage
  - 400 times more thermoelectric p-n couples compared to bulk Peltier components
    - > 100 mV / K output performance
    - efficient DC-DC Booster
    - low delta T operation possible

- Button-cell generator (TGP)
  - TGP generator outputs 100's of µW to milliWatts and can power miniaturized sensors or actuators
  - Any engineer can create a good thermal concept
  - Suitable for standard reflow processes

Micropelt wafer-based MEMS-like production process





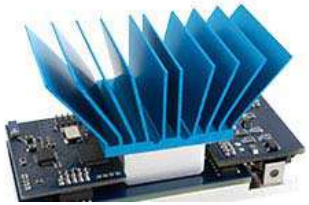


Button-cell generator

CYMBET™ CORPORATION

Wireless Power Charging

- Light / solar energy not always sufficient
- Thermal difference not always available
- Vibration not always available
- RF-based wireless power
  - Send power over distance - µW, low mW
  - Overcomes lack of light, temp diff., or vibration
  - Controllable: continuous scheduled on demand

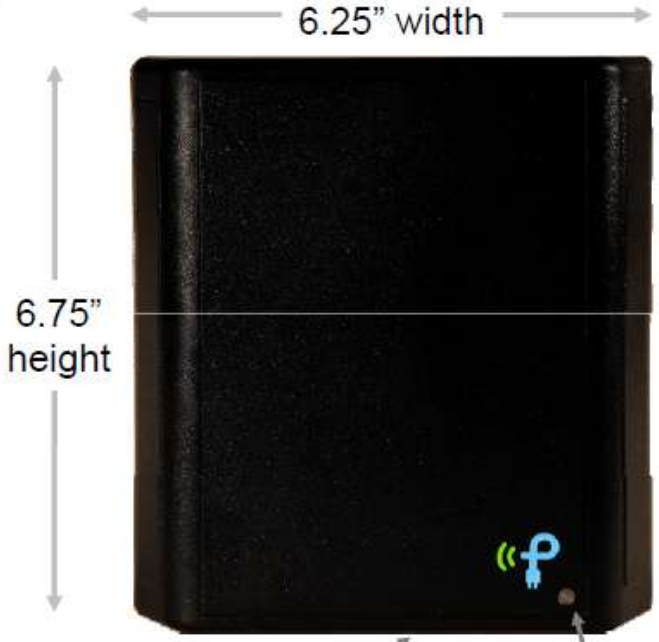


Using Wireless Power

- Micro-power over distance using common radio waves
  - Microwatts (μW) to low milliwatts (mW)
- Micro-power is useful for:
  - Trickle-charging batteries (μA to low mA current)
  - Powering battery-free devices
- Received power is determined by multiple factors:
  - Power of RF source
  - Distance from RF source
  - Size / performance of receiving antenna
  - Transmission frequency (e.g. 915MHz)

Wireless Power Transmitter

TX91501 Powercaster® Transmitter



Power Jacks (2) – 5V
Back – for tabletop placement
Bottom – for wall mounting

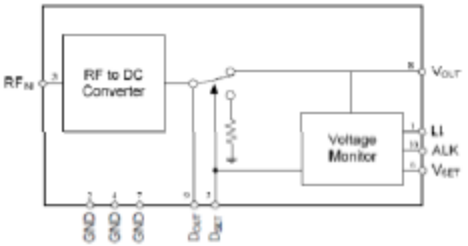
Status Indicator LED
Green – Transmitting
Red – Fault Condition

- 915 MHz center frequency
- FCC and IC certified
- RoHS compliant
- DSSS modulation (power)
- ASK modulation (data)
- 1W or 3W EIRP
  - TX91501-1W-ID
  - TX91501-3W-ID
- ~60° beam pattern
- Data broadcast (factory-set)
- Plug-and-play installation
- Powers virtually unlimited number of Powerharvesters

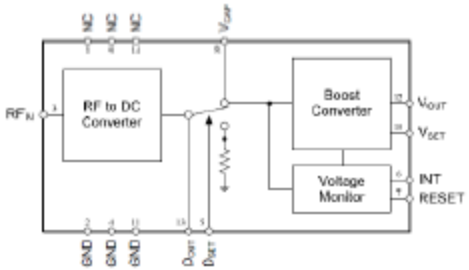
Wireless Power Receiver

- Convert RF input to DC current
- Provide power management
- Frequency range: 850-950MHz
- RSSI and Data output
- Designed for standard 50Ω antennas

P1110



P2110



P1110

Continuous Power Output

- RF range: -5.0dBm to 20dBm
- Output voltage: 1.8V to 4.2V (configurable)
- Range of at least 3 meters

P2110

Pulsed Power Output

- RF range: -11.5dBm to 15dBm
- Output voltage: 1.8V to 5.25V (configurable and regulated)
- Range of at least 10 meters

More Info: www.powercastco.com

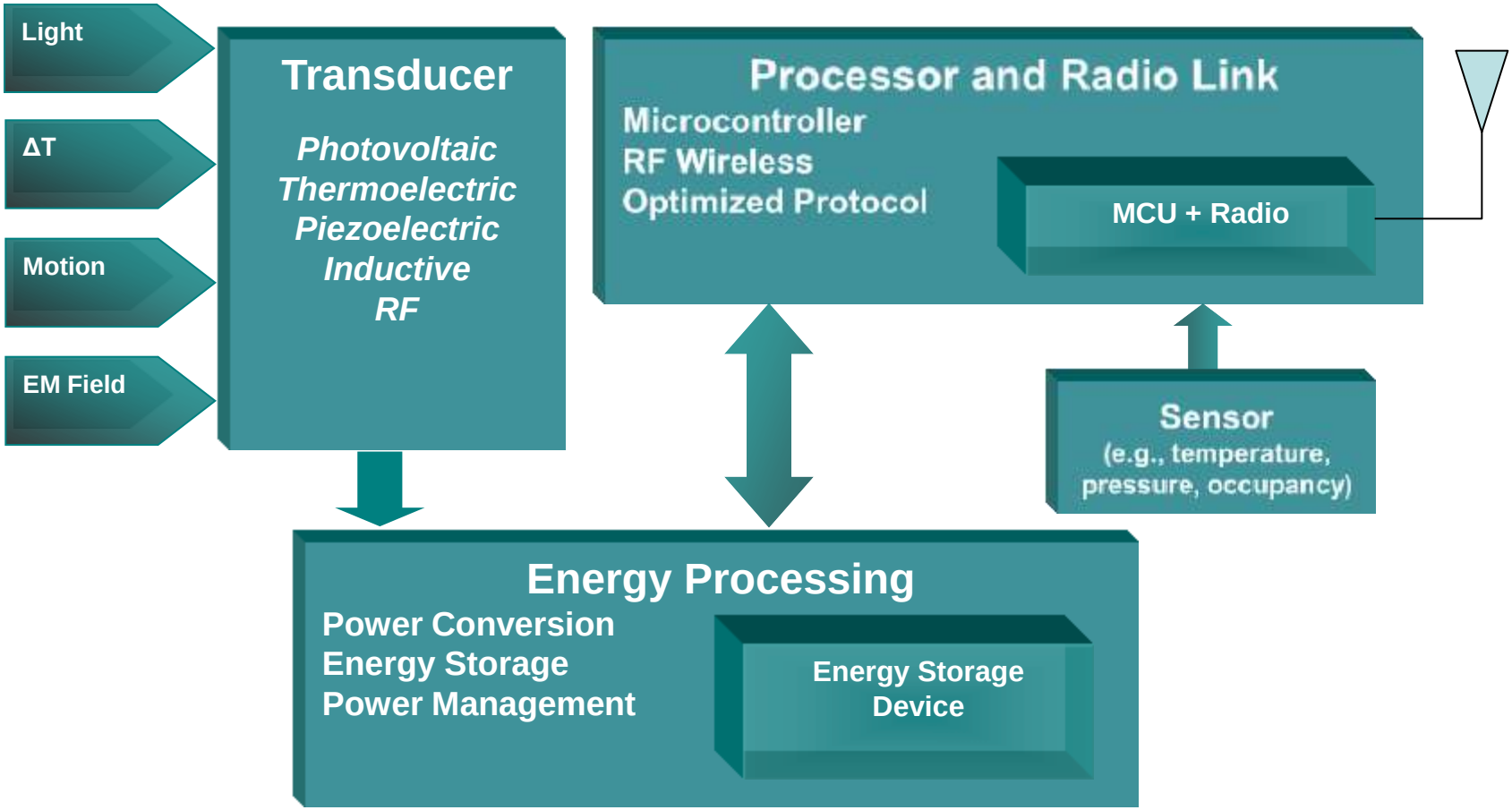
Power Source Trade-offs in Sensors

Sensor Type	Cost	Implementation
Wired Sensors	**Highest initial cost** **Average operating cost**	Simple Reliable Very high installation cost
Battery Powered Wireless Sensors	**Lowest initial cost** **Highest operating cost**	Simple Cheaper than wired Constant battery replacement
Energy Harvesting Wireless Sensors	**High initial cost** **Lowest operating cost**	More complex engineering Lowest lifetime costs

EH Transducer Cost Effectiveness

Transducer	Typical Cost	Power	Notes
Solar -Inside -Outside	 $0.20/uW $0.20/mW	~1.0-1.5 V/cell 10 uW/cm^2 10 mW/cm^2	- Limited power output (indoors) - Can be inconsistent
Thermal	$0.50/mW	~ 1 V @ 10 K 1 mW/(K*cm^2)	- Not counting heat sink size/cost - Reliable & high power
Piezo -Resonant -Random	$20/mW	~ 25 VAC 0.1-0.5 mW/cm^2 ~1 uW/cm^2	- High volume pricing - Resonant: vibration at 1g - Random: low power & inconsistent
RF	$30/mW	Regulated V 1 mW at 2m 10 uW at 10m	- 3W TX w/ 6 dBi gain antenna - Low power output - Low volume pricing

Summary

- Energy can be harvested from the ambient environment using various transducers
- Each EH transducer needs appropriate high efficiency energy conversion electronics
- Small wireless sensors can be built with EH transducers that are becoming smaller through MEMS and miniaturization techniques
- EH transducer costs are decreasing and are now becoming an effective alternative to primary batteries.

EH-Powered Autonomous Wireless Sensor Block Diagram