Energy Harvesting for Embedded Systems

Powering your Devices with Ambient Energy

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SHA2017 Hardware Hacking
6 August 2017

¯_(ツ)_/¯

SHA2017
STILL HACKING ANYWAY

Incentives: toxic waste

Incentives: environmental destruction

Environmental Energy

Light

Thermal

Kinetic

Radiation

Chemical

Energy Harvesting

MW

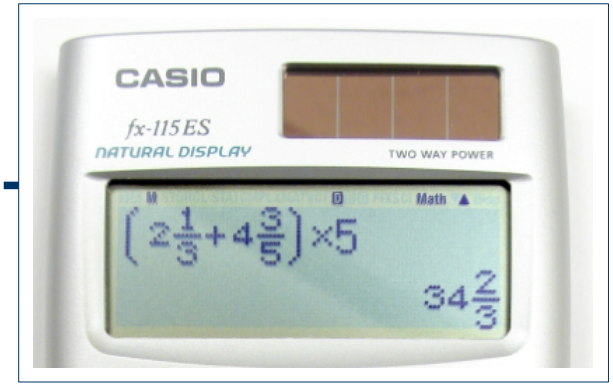
kW

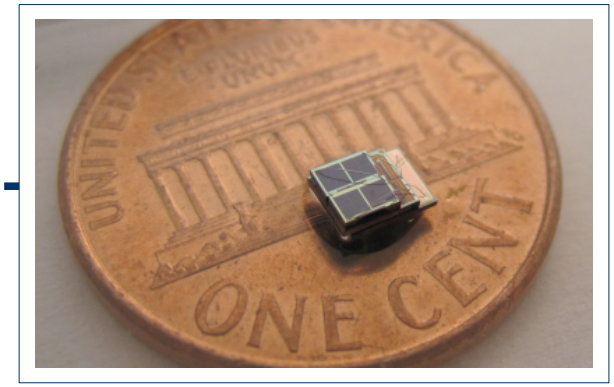
W

mW

µW

< µW





Energy Harvesting = renewable energy on a small scale

Scalability

Challenge: scaling renewable energy technology to low power levels

?

MW W µW

Energy Harvesting vs. Energy Scavenging

Harvesting from an otherwise wasted source

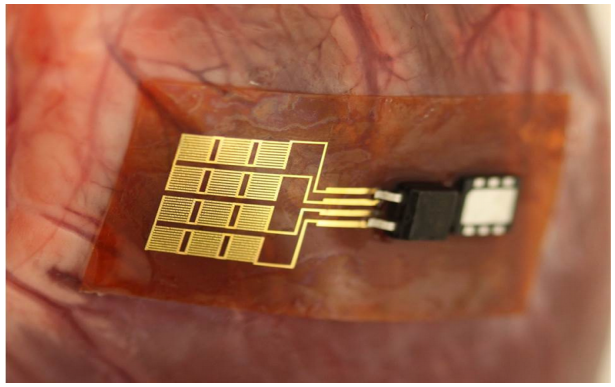
Harvesting a fraction of a useful energy source

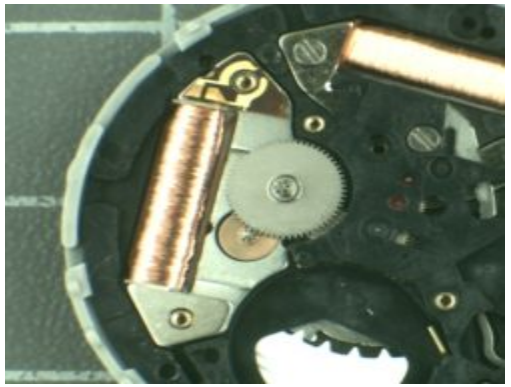
Harvesting from a dedicated energy source

Greenenergy

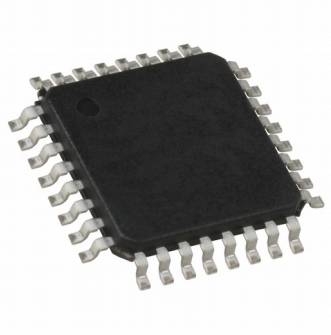
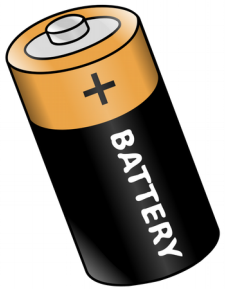
Problem: conversion efficiency of many harvesters is very low!!

Autonomous Electronic Systems

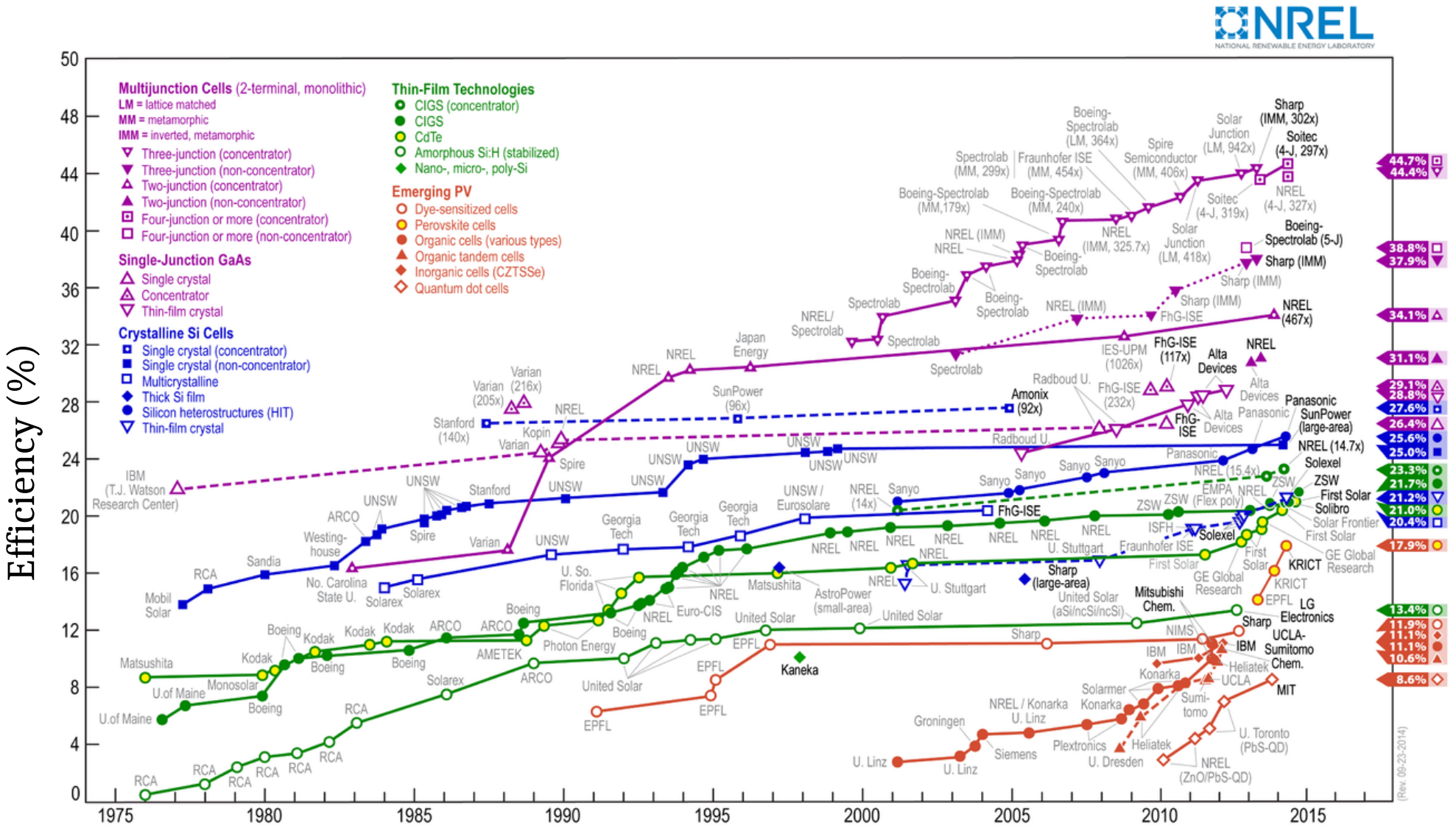




The 5 Pillars of Autonomous Electronics

1	2	3	4	5
				
Harvesters	**Sensors**	**Processing**	**Storage**	**Actuators**

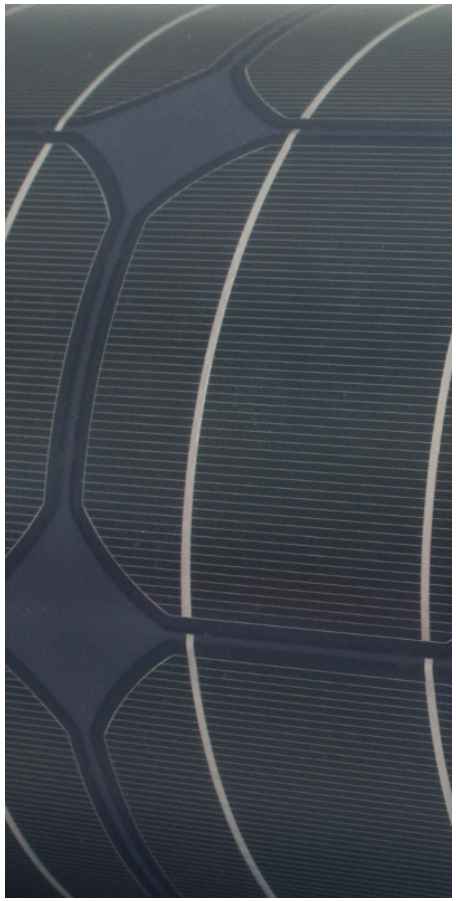
Harvesting light



Solar Cell Types

pc-Si	**mc-Si**	**a-Si**	**CdTe**
20.4%	25.0%	13.4%	21.0%



Solar Cell Types (cont'd)

Emerging technologies

- Multijunction cells (Sharp, 44.7%)
- CIGS (ZSW, 21.7%)
- DSSC (Sharp, 11.9%)
- Perovskite (KRICT, 17.9%)
- Organic (IBM, 11.1%)
- Quantum dots (MIT, 8.6%)

Thin Film technology enables low cost **flexible** cells

Harvesting vibrations

Harvesting vibrations with **piezoelectricity** through **elastic mechanical deformation** of appropriate materials

Natural materials

- Quartz, topaz, ...
- Sugar
- Bones

Synthetic materials

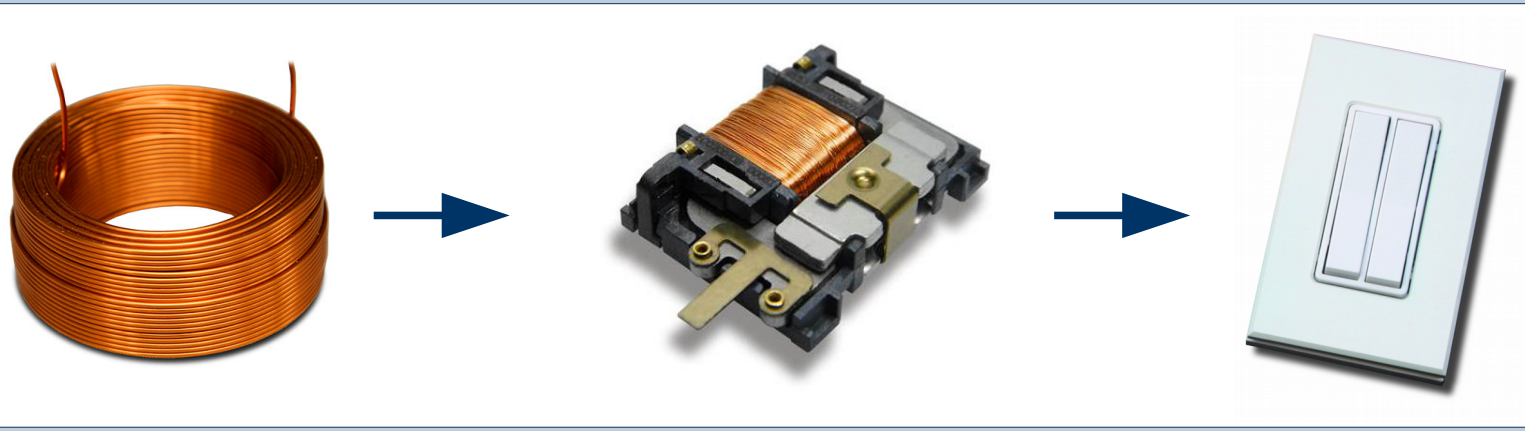
- PZT
- PVDF
- Langasite

Harvestable frequency range is determined by the **frequency range** and **natural frequency** of the material

Harvesting vibrations (cont'd)

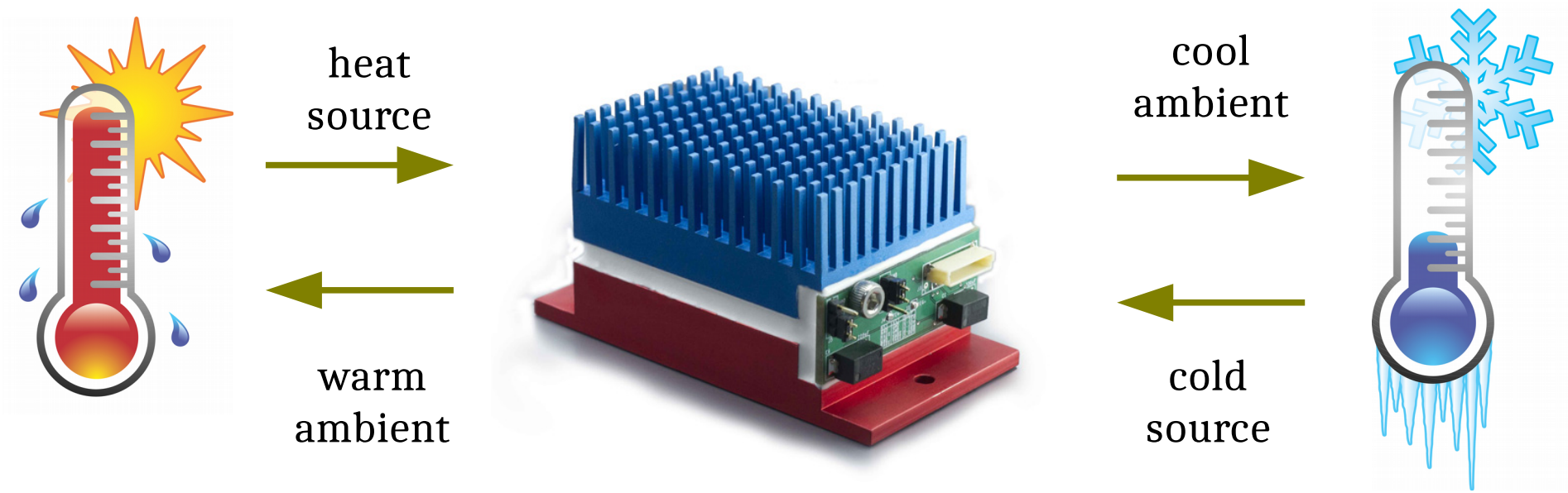
Piezoelectric

Magnetic



Harvesting heat

Seebeck effect:
using a **temperature gradient** to generate electric current...



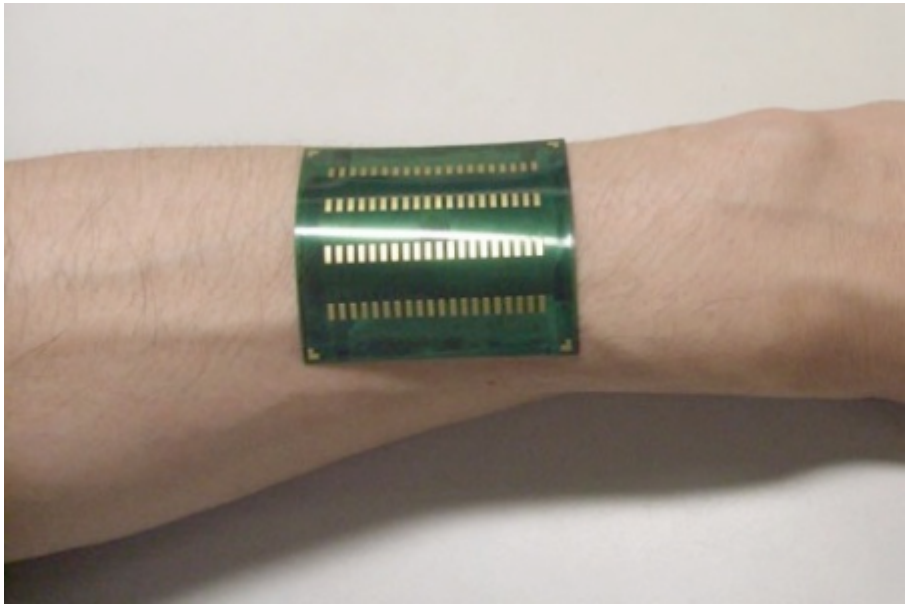
...as long as a temperature difference can be **maintained**.

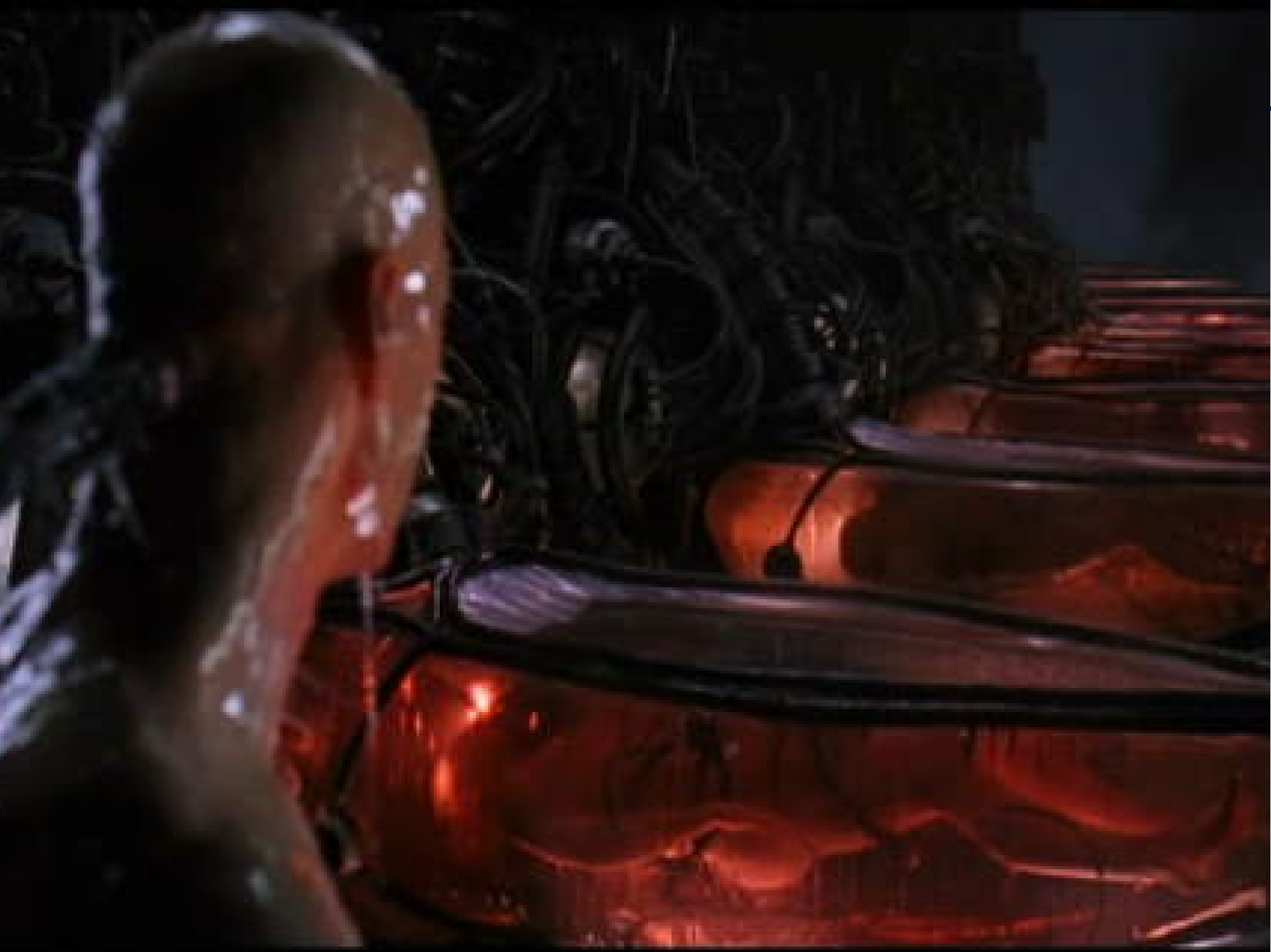
Harvesting heat (cont'd)

- ⊕ Highest power density of any harvester
- ⊕ Small footprint
- ⊕ Retrofittable with existing heat sinks

- ⊖ Heat flow may reduce Carnot efficiency
- ⊖ Requires good thermal conductivity with source

Heat Sources?





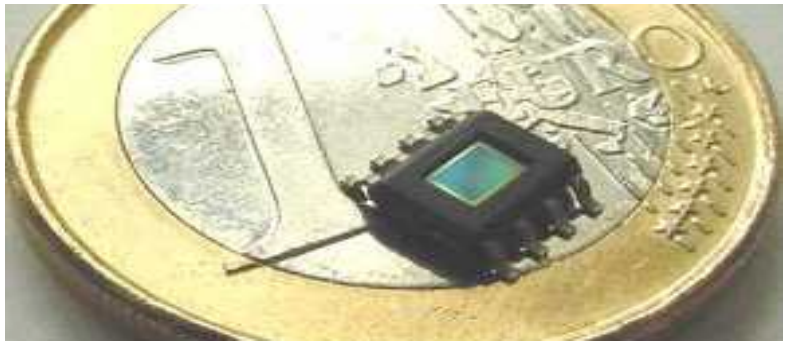
MEMS

New miniaturization opportunities:

Micro**E**lectro**M**echanical **S**ystems

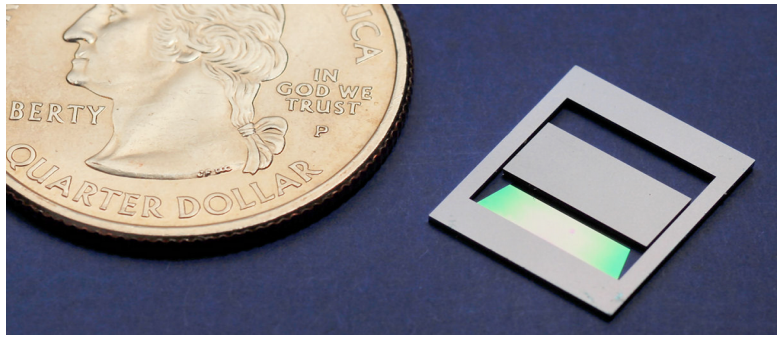
MEMS Sensors

- Gyroscopes
- Accelerometers
- Gas sensors



MEMS Harvesters

- PZT cantilevers
- Thermopiles



Energy harvesting in the real world

Benchmarking the environment:

- types of ambient energy?
- how much power?
- when available?

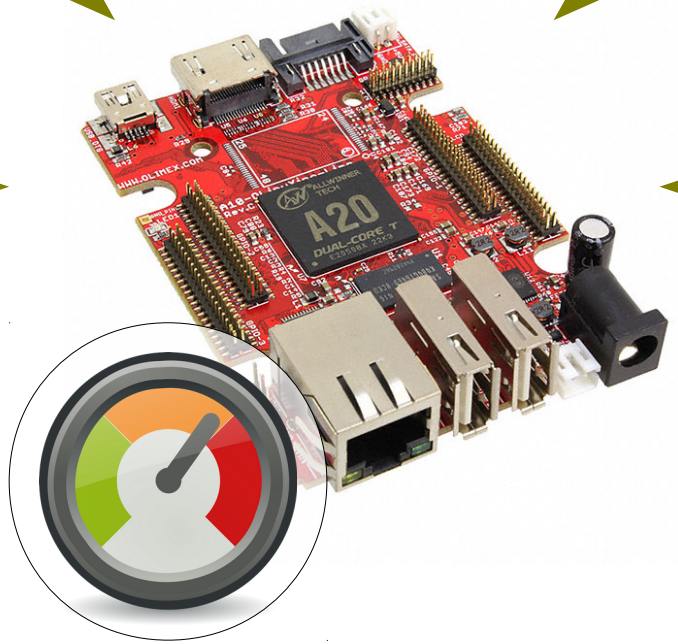
Environmental energy data acquisition

RF
< 1µm

light
(µm – nm)

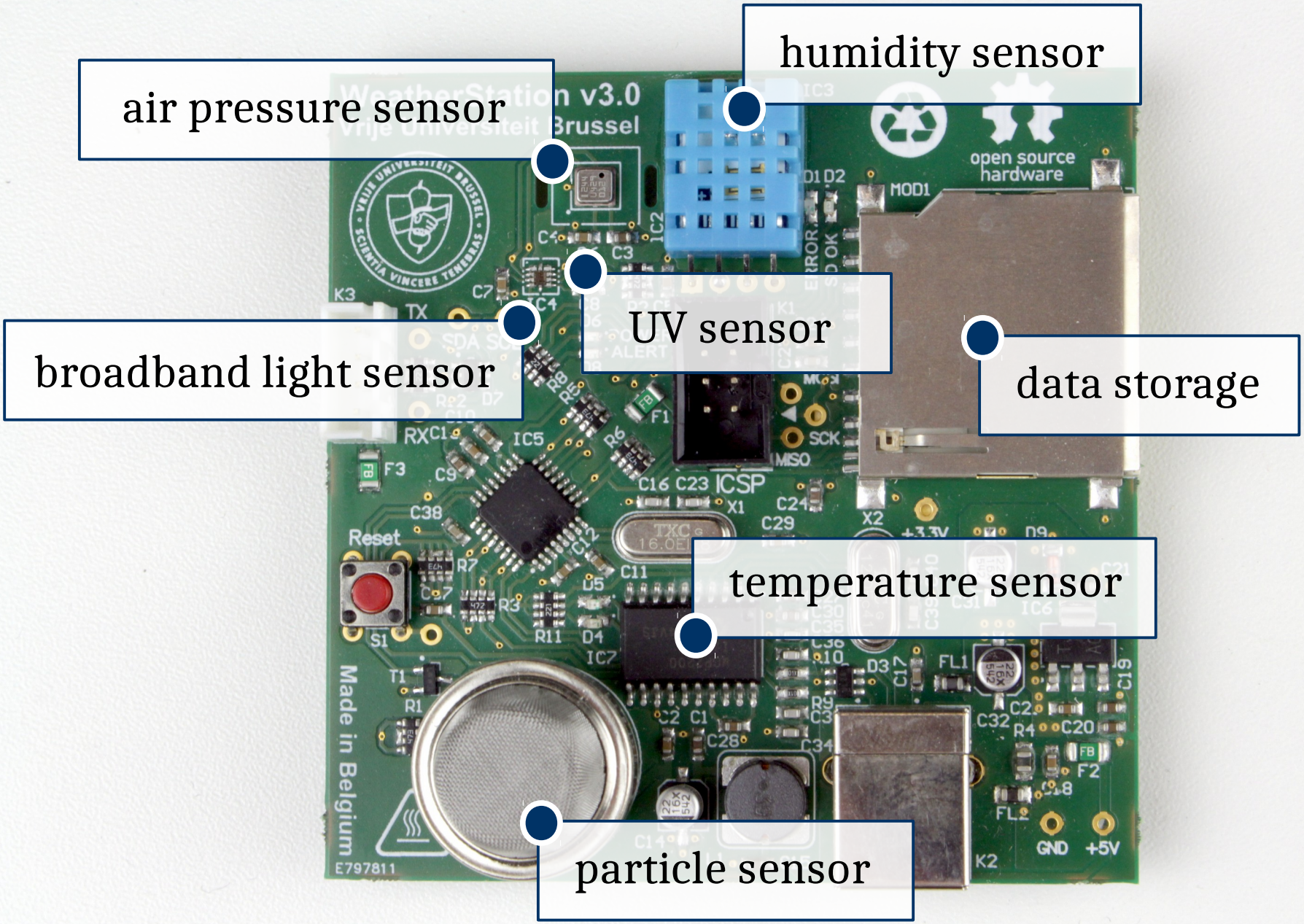
heat

flow
(wind, water)

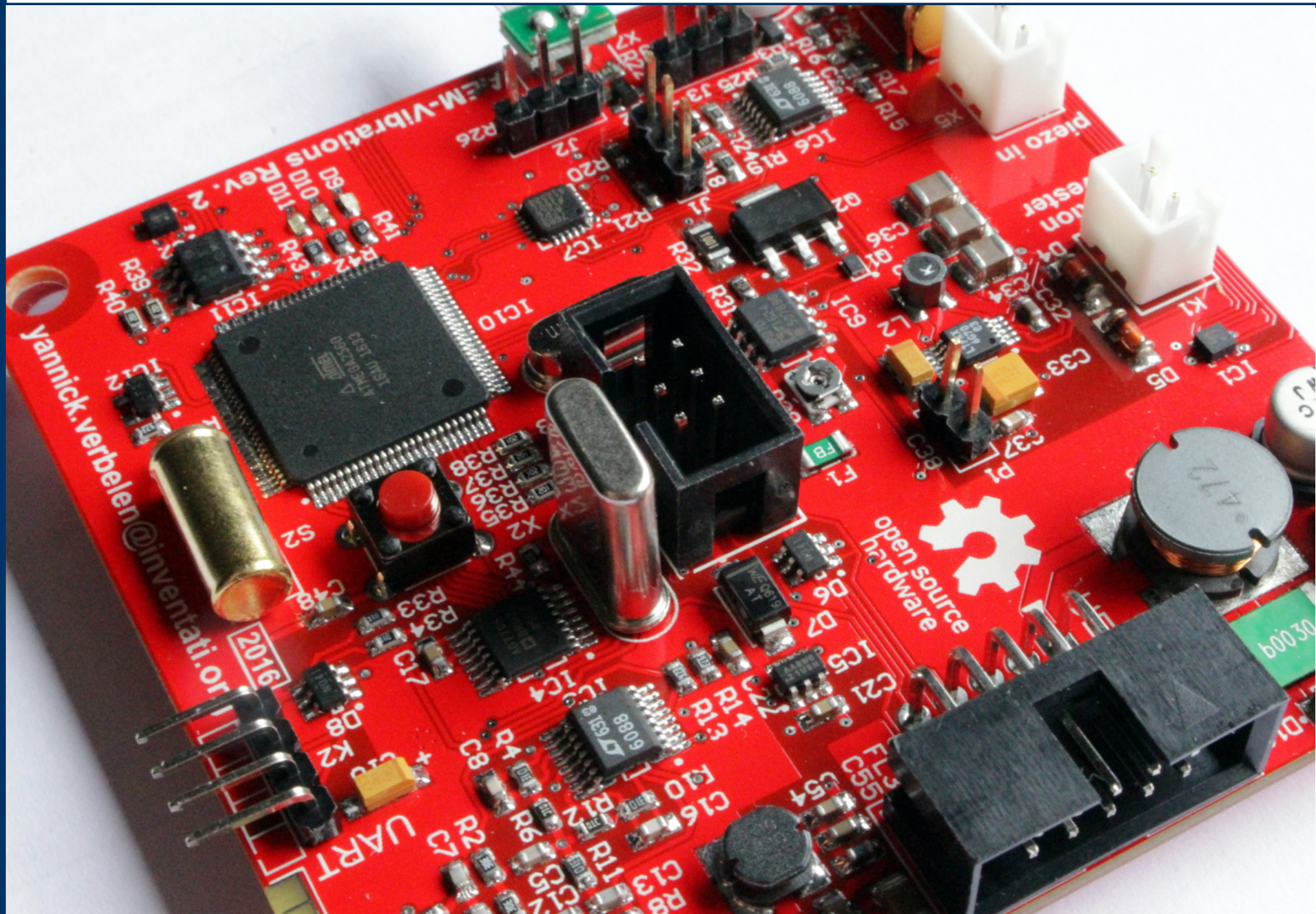


vibrations

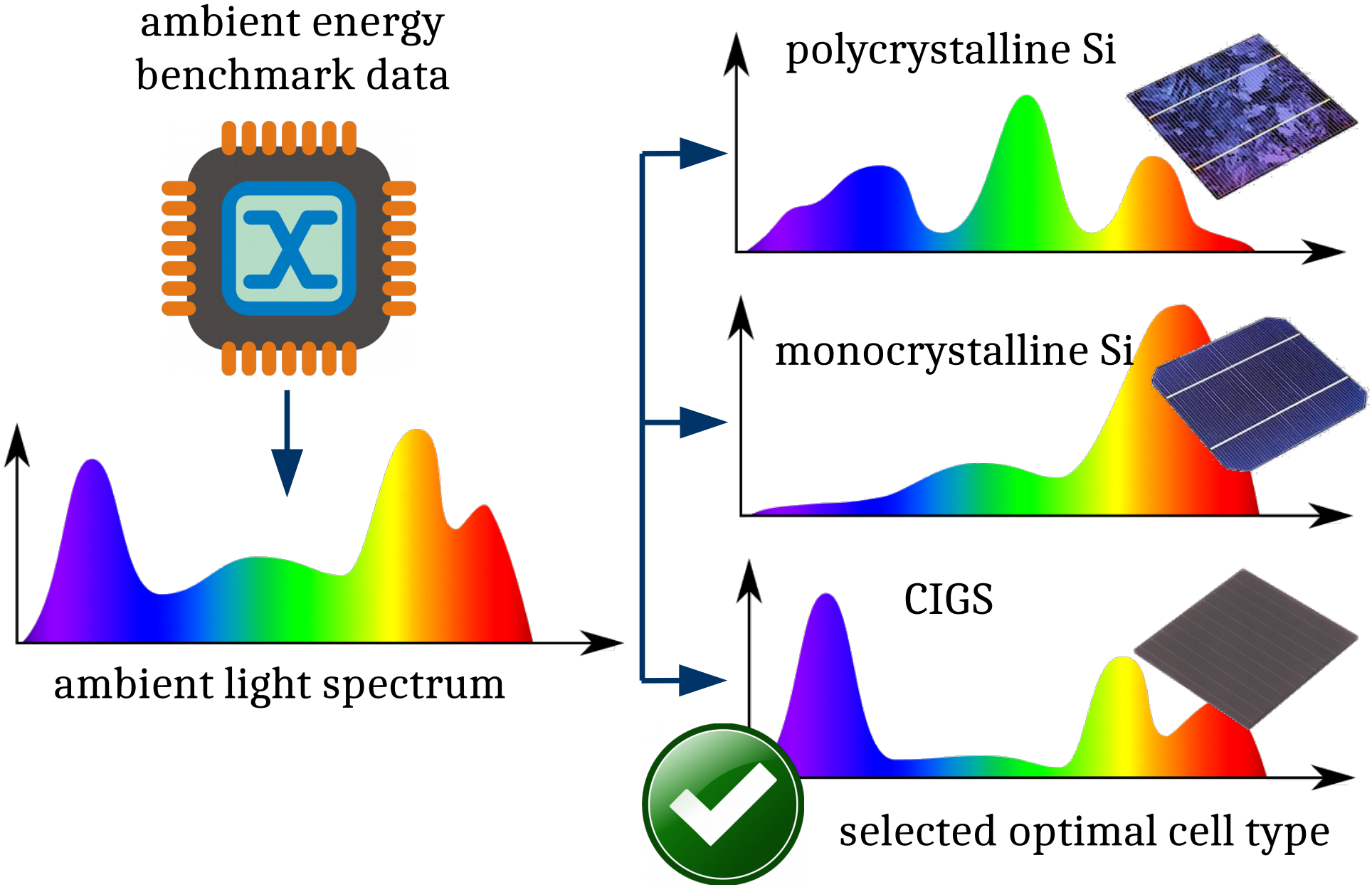
OpenObservatory: environmental monitoring



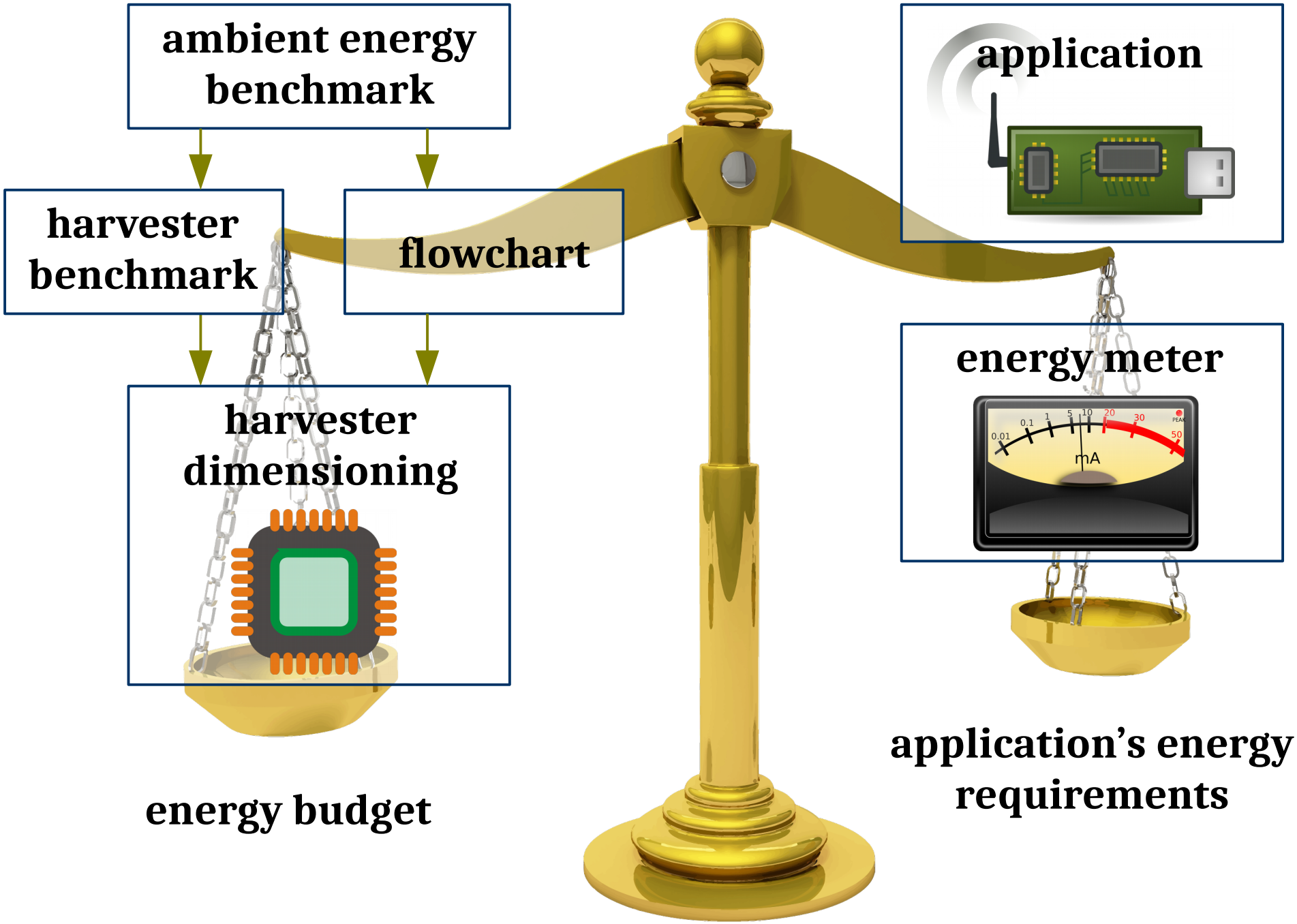
AEM: Ambient Energy Monitor



Correlating ambient energy with harvesters

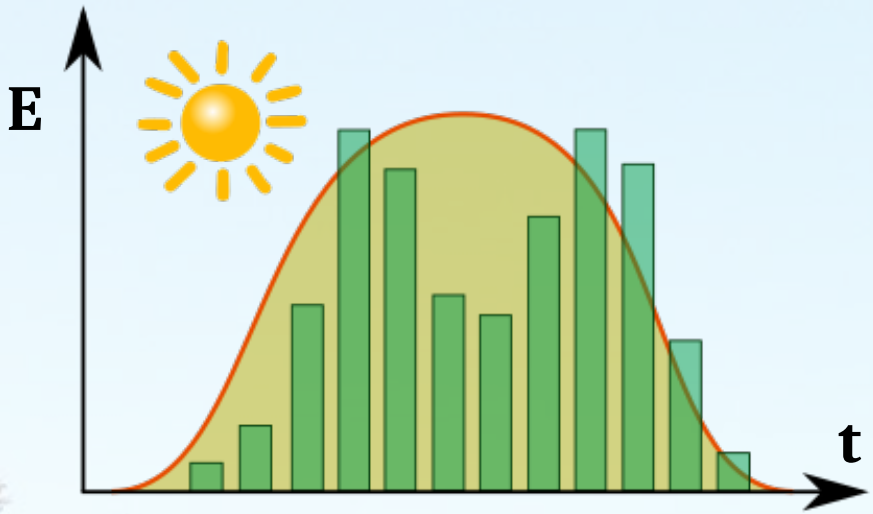


Energy balance



Pattern Matching

– correlating energy harvesting with application needs



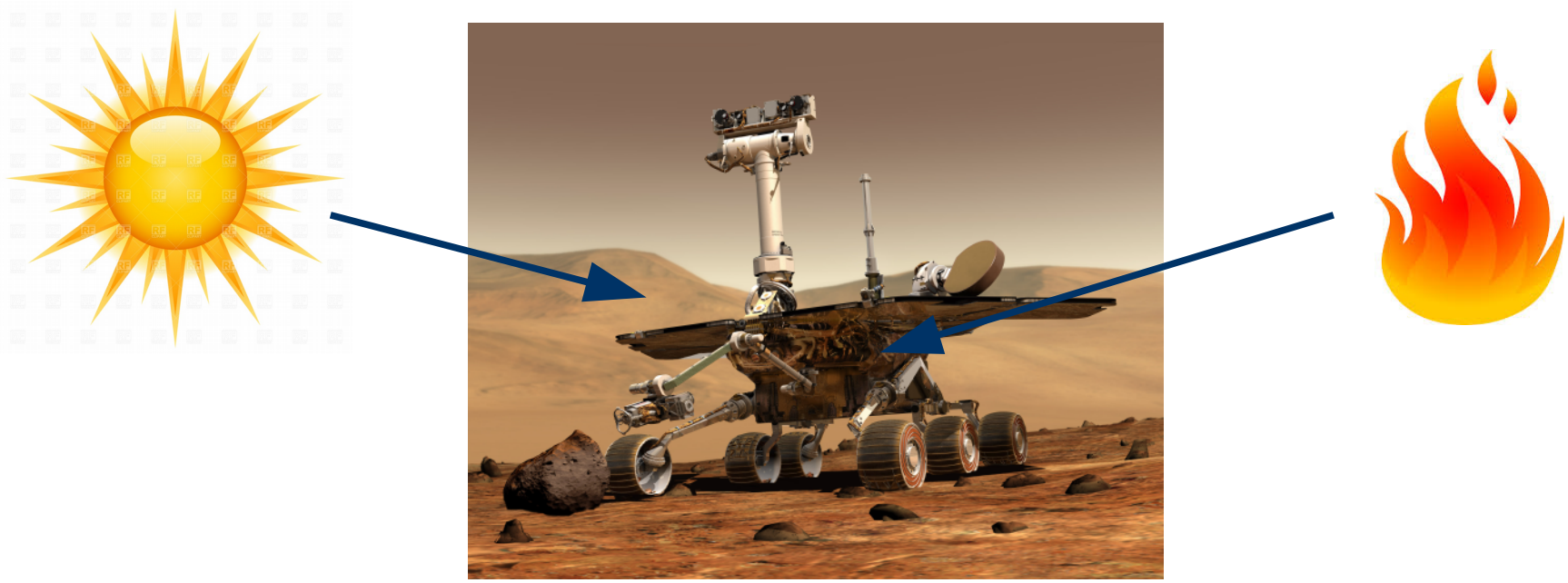
– minimizing local storage

- secondary chemical cells
- MLCC
- EDLC

harvester

wireless autonomous application

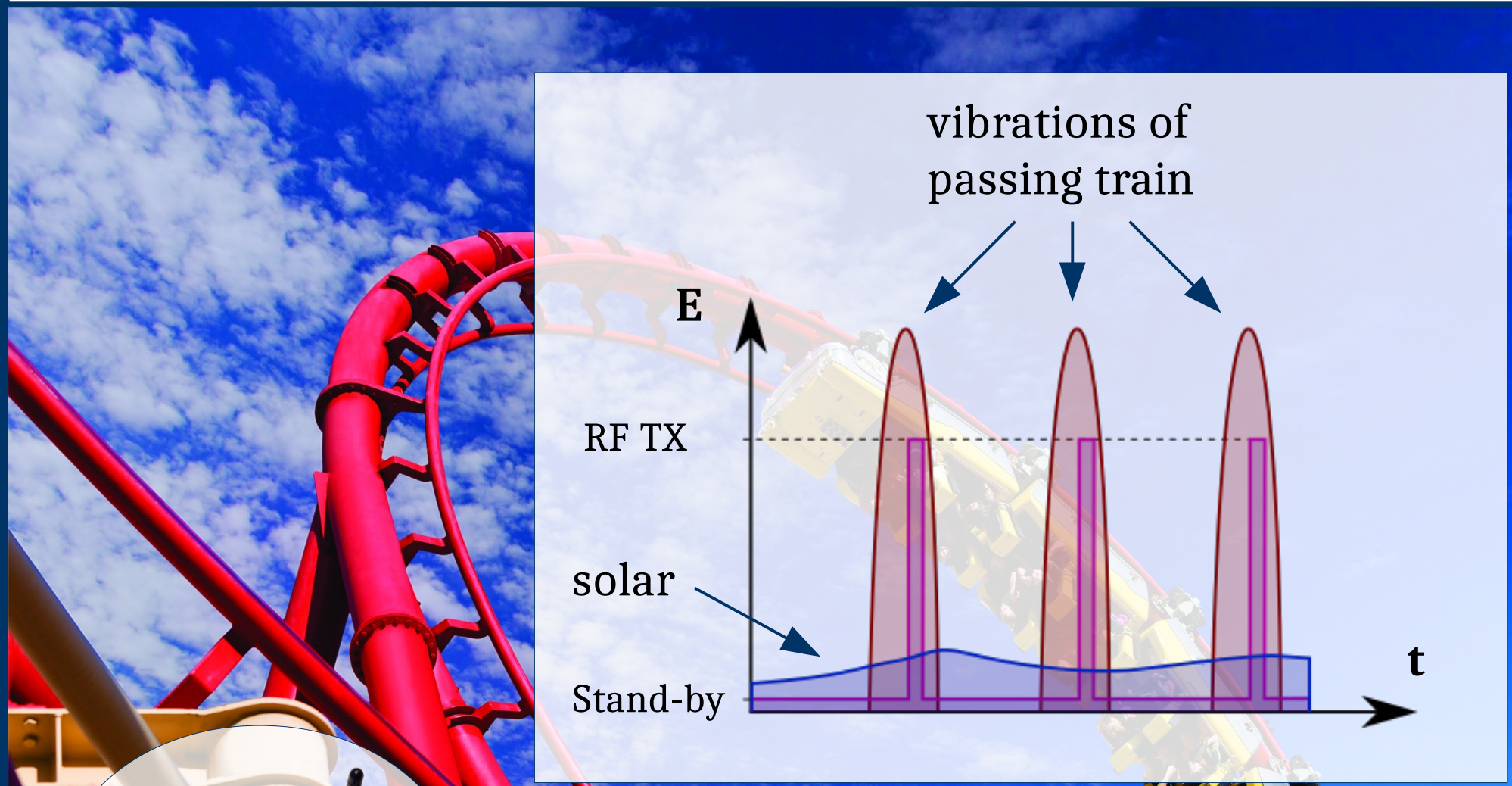
Complementary balanced energy harvesting

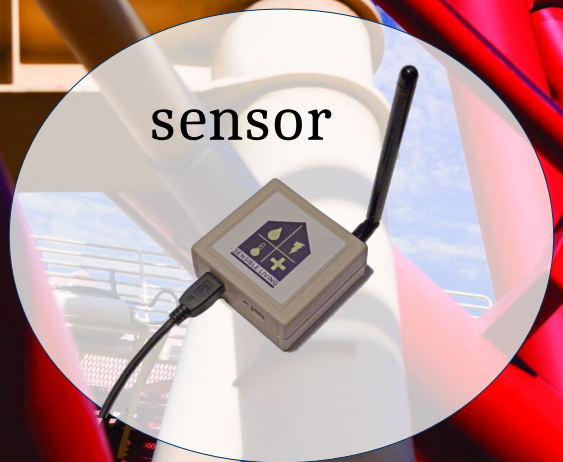


Combining **multiple energy sources** offers

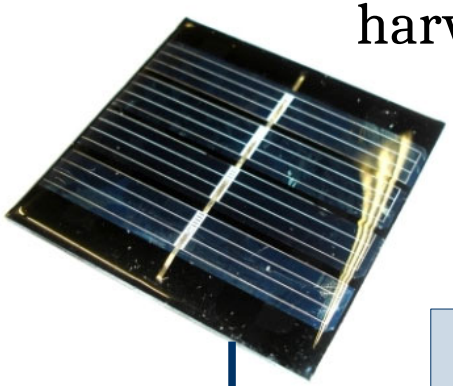
- increased reliability
- decreased combined harvester size
- lower production costs

Complementary balanced energy harvesting





Power path design



harvester

capacitor

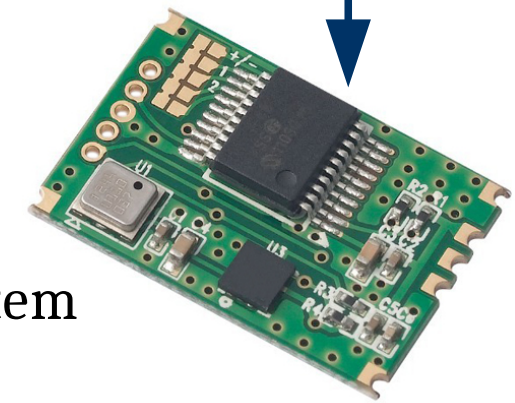
secondary power regulator

DC/DC

DC/DC

solid state battery

primary power regulator + MPPT



embedded system

Commercial initiatives

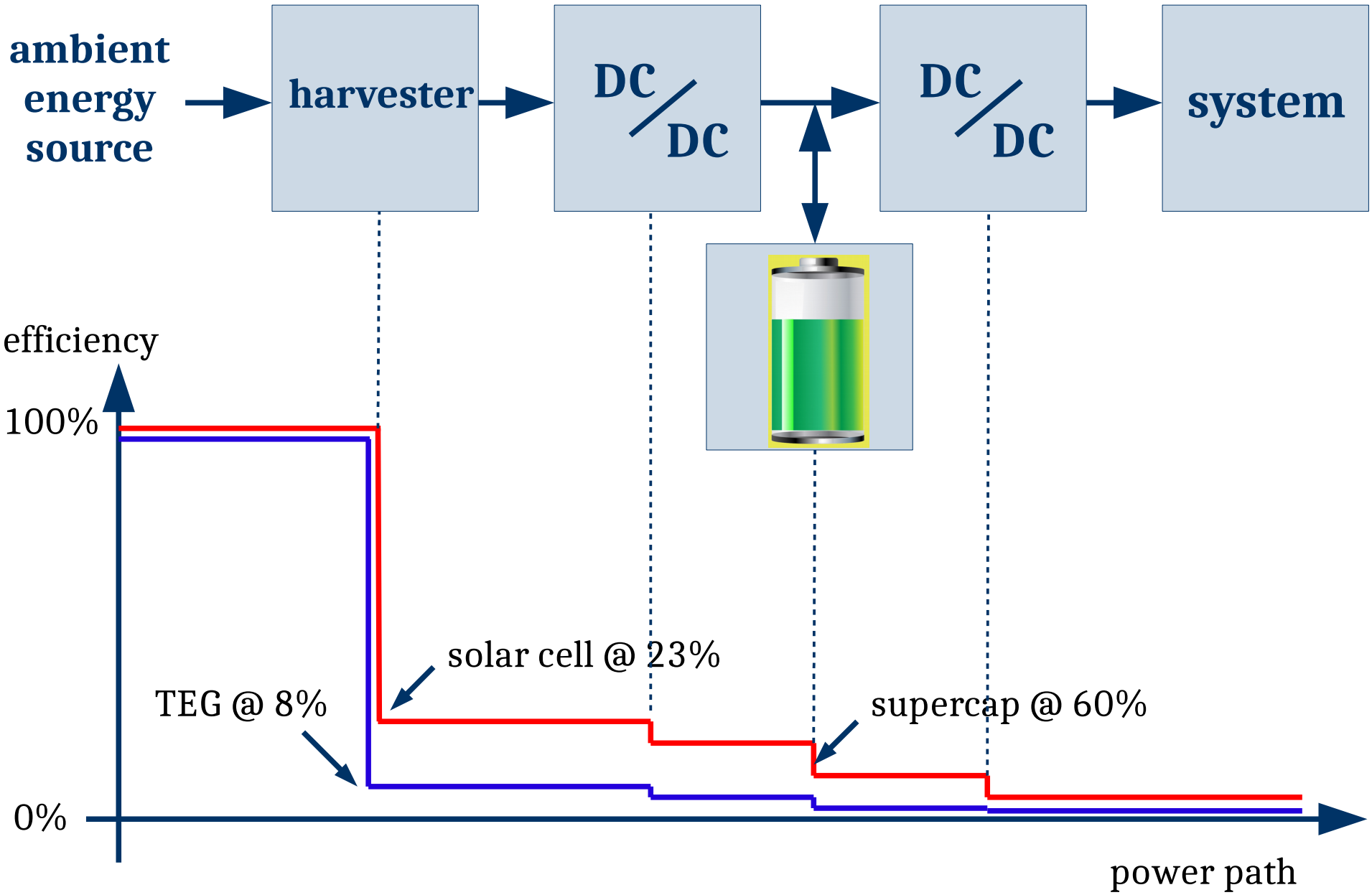
Integrators

modules and ready
to use applications

Manufacturers

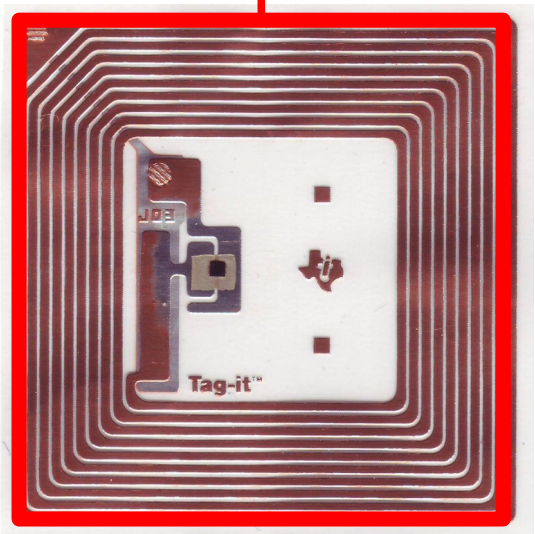
- separate harvesters
- development kits

Efficiency


ambient energy source
harvester
DC/DC
DC/DC
system
efficiency
100%
0%
solar cell @ 23%
TEG @ 8%
supercap @ 60%
power path

Harvester coverage

harvester coverage



EH powered application

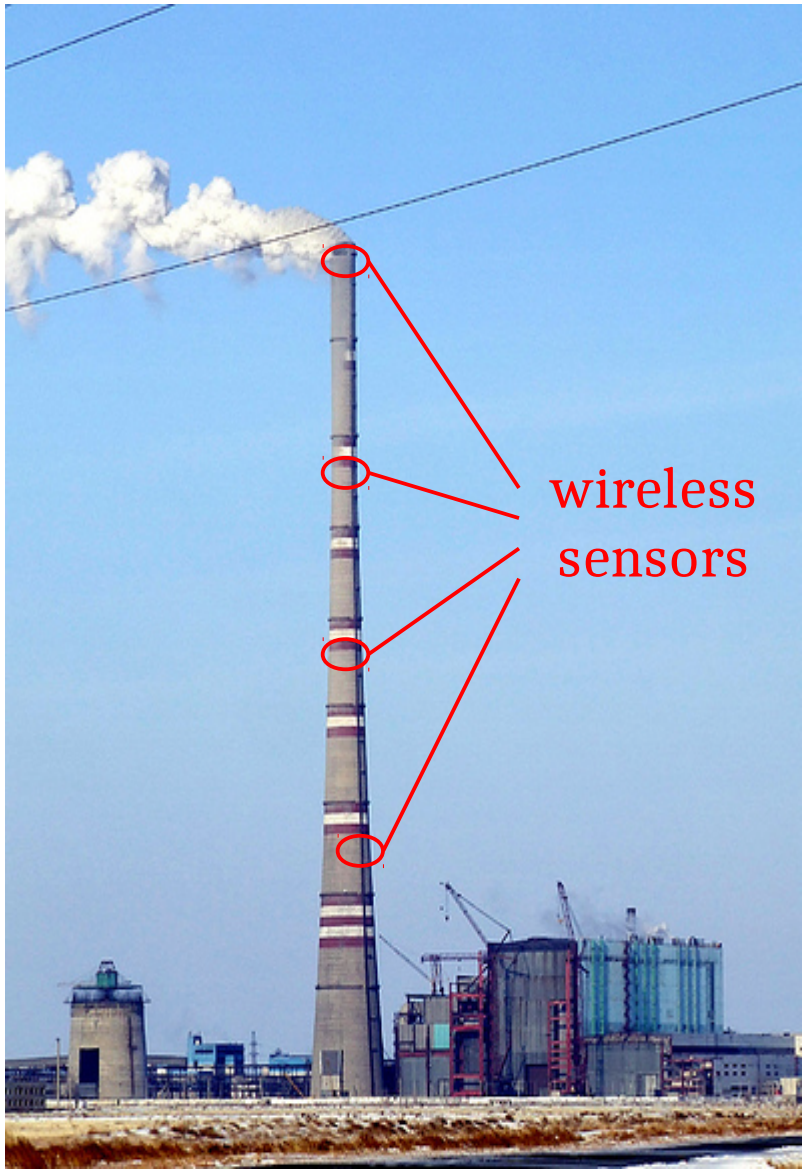
power path management
energy conversion and storage

system
energy consumer

Harvester output limited by

- physical harvester **size**
- ambient energy **flux density**

Durability



Robustness

- solid state vs. moving parts
- corrosion resistance
- mechanical durability

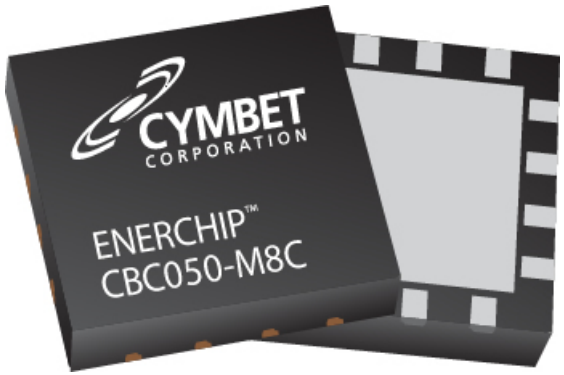
Autonomy

- longer life time
- less maintenance required
- lower operation costs

Storage

Secondary chemical cell

EDLC

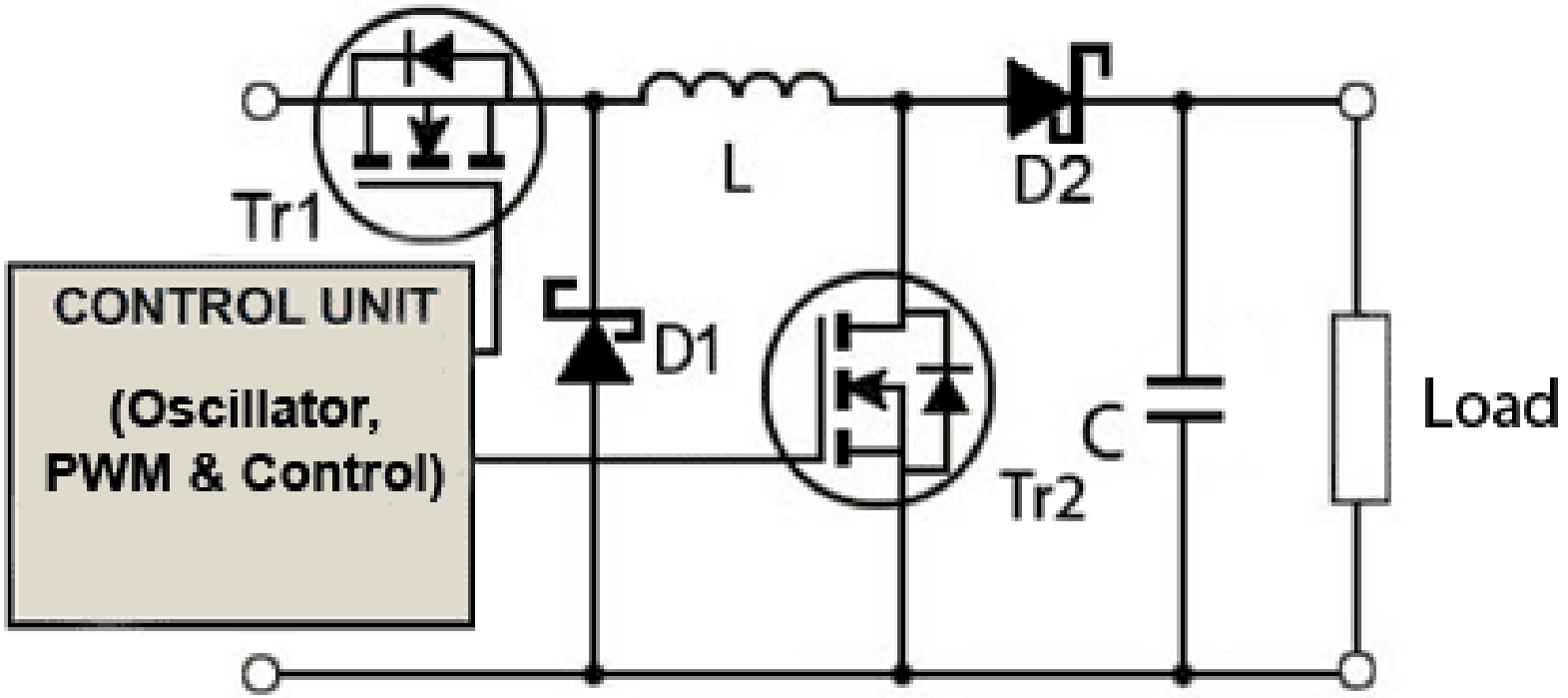


Secondary solid state cell

storage capacity ⟷ life time

Storage media also have different nonlinear **leakage currents**

Power conversion: DC/DC buck/boost



Myths

Solar Roadways

Story | Updates 129 | Comments 3,365 | Funders 48,472 | Gallery 28

241k Share | 21K Tweet | 5.9k +1 | Email | Embed | Link | Follow

$2,200,341 USD
RAISED OF $1,000,000 GOAL

220% | 0 time left

This campaign started on Apr 21 and closed on June 20, 2014 (11:59pm PT).

Flexible Funding

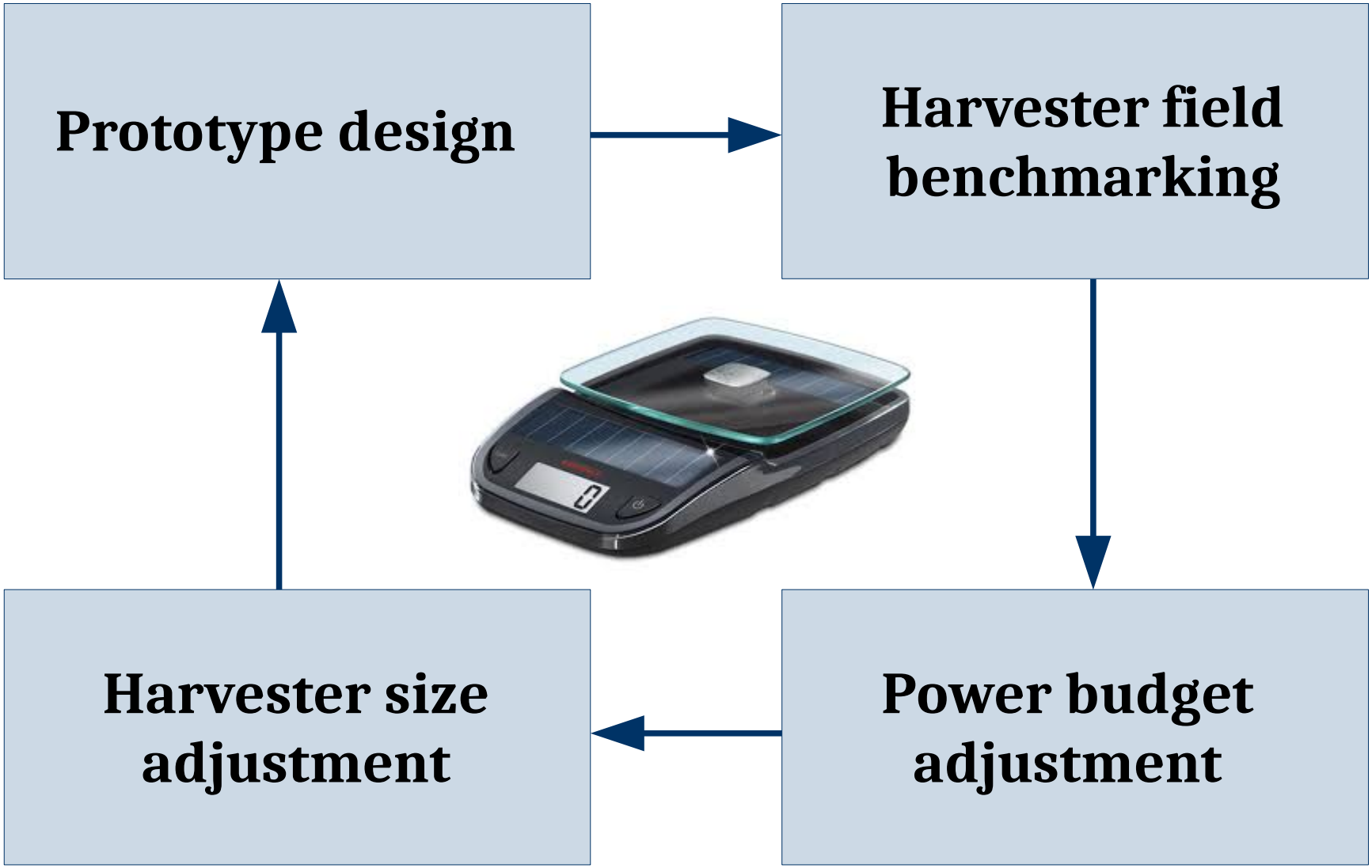
CAMPAIGN CLOSED
This campaign ended on June 20, 2014

SELECT A PERK

Opportunities

- **Retrofitting** existing applications
  - **Removing cables**, thus increasing reliability
  - Turning them **green** by removing primary chemical batteries
- **Improving harvesters** allow **new applications**
  - Combinations with other progressing fields (i.e. LED's)
  - Miniaturization through increased harvester efficiency

Development Cycle



State Awareness

Time

- Energy budget estimation
- Active duty cycle regulation
- Autonomous operations

State of Charge
(SoC)

- Energy budget estimation
- Active duty cycle regulation
- Task scheduling

State of Health
(SoH)

- Energy budget estimation
- Lifetime estimation
- Preventive maintenance

Environmental Awareness

Snow height logger

- low sample frequency
- local storage
- low reliability demands

INES event detector

- continuous sampling
- wireless communication
- high reliability required

Summary

Energy harvesting can offer...

- Nearly unlimited life time without batteries
- Power scalability for any application
- Low cost deployment without cables or wires
- Intelligent environment aware user interaction

Q&A

Join the AEM Project Today!

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