PEMANENAN ENERGI

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2024

Kontrak Kuliah

- Materi diunggah ke EMAS.
- Kuliah kombinasi *offline* dan *online*.
- Nilai:
  - ❑Homework 4x: 30%
  - ❑Project 2x: 30%
  - ❑Midterm Exam: 20%
  - ❑Final Exam:20%
- Izin kuliah diperbolehkan untuk alasan berikut: sakit, kedukaan dan perjalanan dinas/tugas kantor.
- Plagiarisme akan diberikan sanksi sesuai peraturan yang berlaku.

Outline

- Definition
- Conversion Process
- Categories
- Relative Motion
- Temperature Gradient
- Light

Definition

"Energy harvesting is one of the key emerging technologies of the twenty-first century. It refers to the collection of energy from the environment; energy that would otherwise be lost to heat. In order to distinguish from renewable energy sources more generally, energy harvesting can be defined as the collection of local naturally available energy for local use."

Pemanenan → mikro

(Kiziroglou & Yeatman, 2012)

Conversion Process

The generation of electrical energy involves an energy-to-energy conversion process such as:

- mechanical-to-electrical (ME)
- chemical-to-electrical (CE)
- solar-to-electrical (SE)
- radio frequency-to-electrical (RFE), and
- thermal-to-electrical (TE).

(Kiziroglou & Yeatman, 2012)

Conversion Process

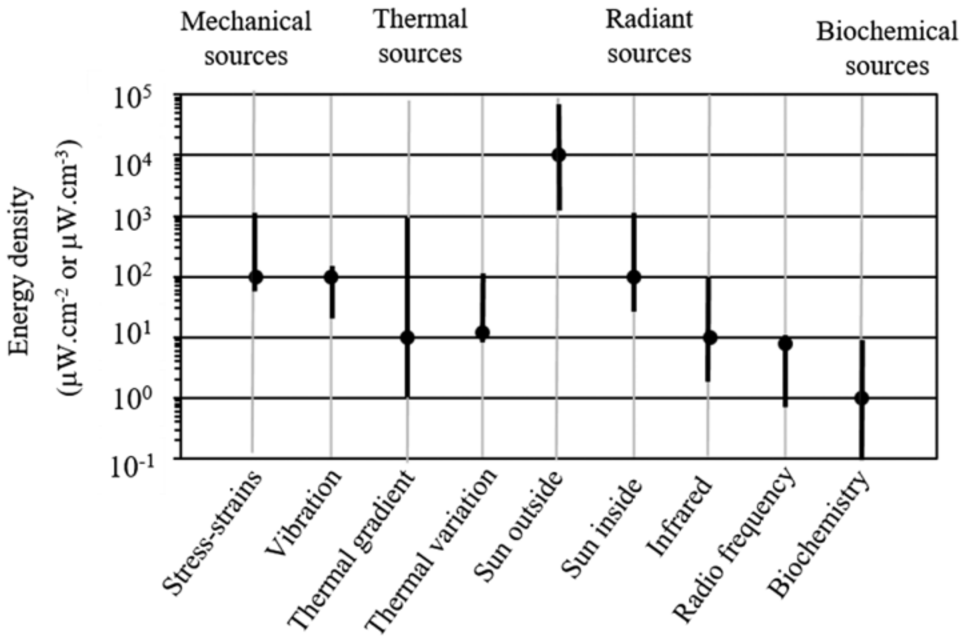
- ME conversion is used in hydroelectric and wind turbines for large-scale power generation.
- CE conversion is used in batteries to provide portable electrical energy.
- TE conversion is used in thermoelectric generator.
- SE conversion uses solar energy to generate electricity. Solar farms provide electrical generation on a large industrial scale as well as residentials.
- RFE converts electromagnetic energy in the millimeter (mm)-to-micron-wavelength range of the electromagnetic spectrum to electrical energy.

(Kiziroglou & Yeatman, 2012)

Conversion Process

(based on process/method)

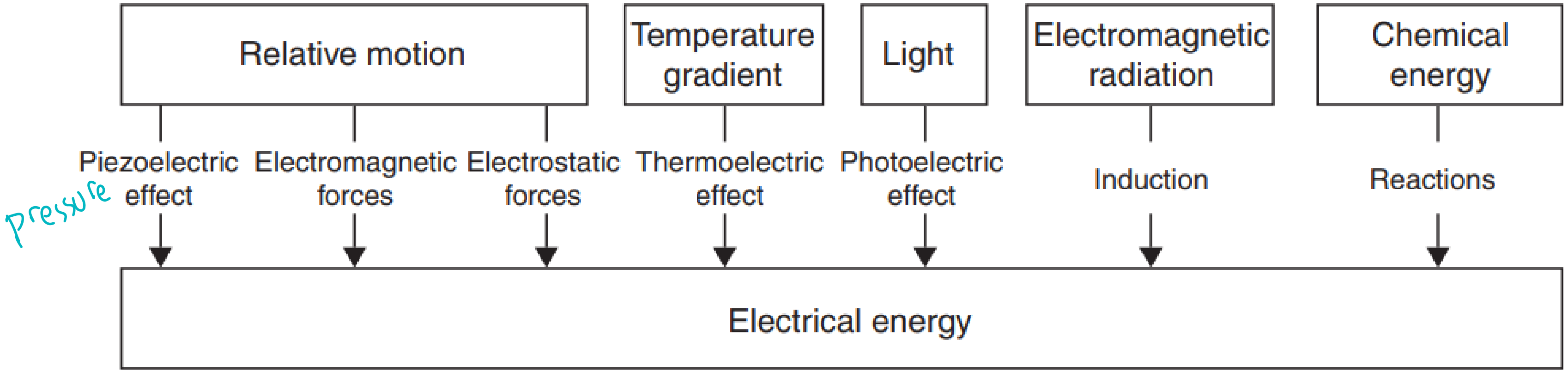
- The choice of a particular energy source is determined by the operational environment, available energy density, and the required energy level to power the intended device.



https://spie.org/samples/TT108.pdf

Categories (based on E source)

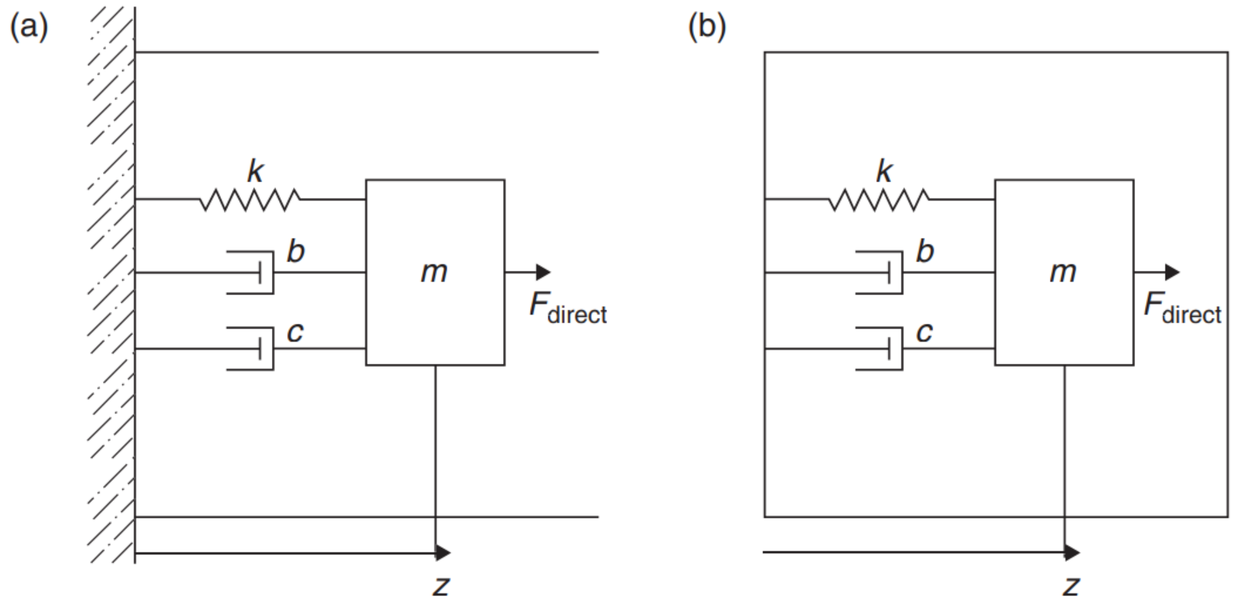
Motion, temperature gradients, light, electromagnetic radiation and chemical energy can all be used as sources for energy harvesting. For motion, three different transduction mechanisms are available, namely electromagnetic, electrostatic and piezoelectric transduction. Thermal harvesters use the thermoelectric effect (also known as the Seebeck effect) and light harvesters the photoelectric effect, while electromagnetic harvesters use induction. Chemical harvesters can employ a variety of chemical reactions on the surface of electrodes.



(Kiziroglou & Yeatman, 2012)

Relative Motion

- Motion energy-harvesting devices typically use a proof mass that moves relative to the device frame.
- Energy is harvested either by directly applying force to the proof mass, causing it to accelerate and generate electrical energy, or by applying force to the frame, creating an inertial force on the proof mass.
- This inertial force performs work, which is converted into electrical energy.



(a) Direct force harvester & (b) inertial force harvester.

langsung kasih force ke sistem (phys contact)

kita yg goyangin (indirect)

(Kiziroglou & Yeatman, 2012)

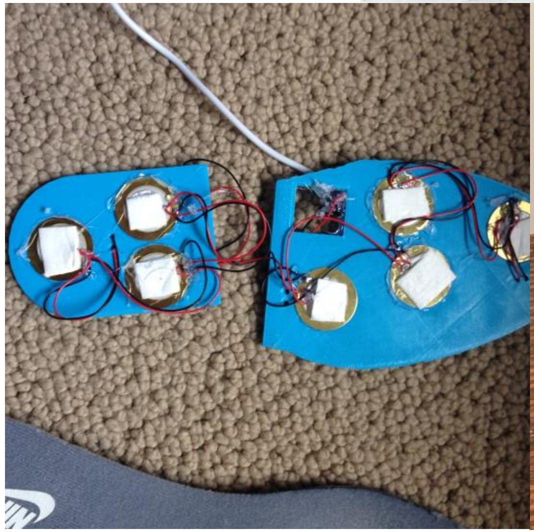
Relative Motion

- Direct force harvester
  - A **direct force harvester** directly converts applied forces into electrical energy.
  - Direct force harvesters usually exploit mechanisms like piezoelectric, electromagnetic, or electrostatic transduction and require a direct physical connection to the force source.
- Inertial force harvester
  - An **inertial force harvester** generates energy from the relative motion between a mass and its base (or frame), caused by external vibrations, accelerations, or other dynamic forces.
  - Inertial force harvesters often include a spring-mass-damper mechanism and rely on the movement of an inertial mass.

(Kiziroglou & Yeatman, 2012)

Relative Motion

- Examples of direct force harvesters
  - ❑ Piezoelectric Shoe Inserts
  - ❑ Electromagnetic Linear Generator
  - ❑ Wave Energy Converters (Direct Drive)



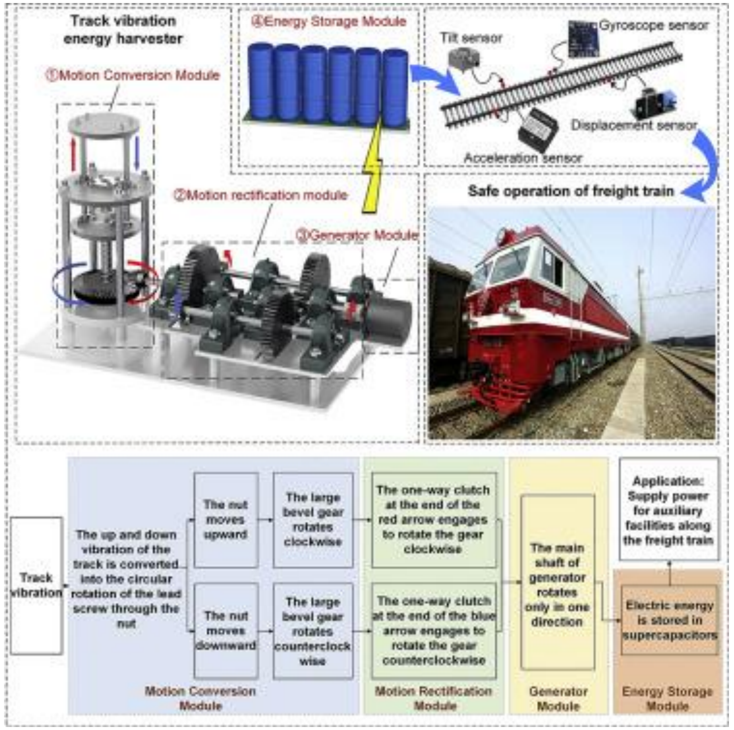
https://www.instructables.com/Piezoelectric-Shoes-Charge-Your-Mobile-Device-by-W/

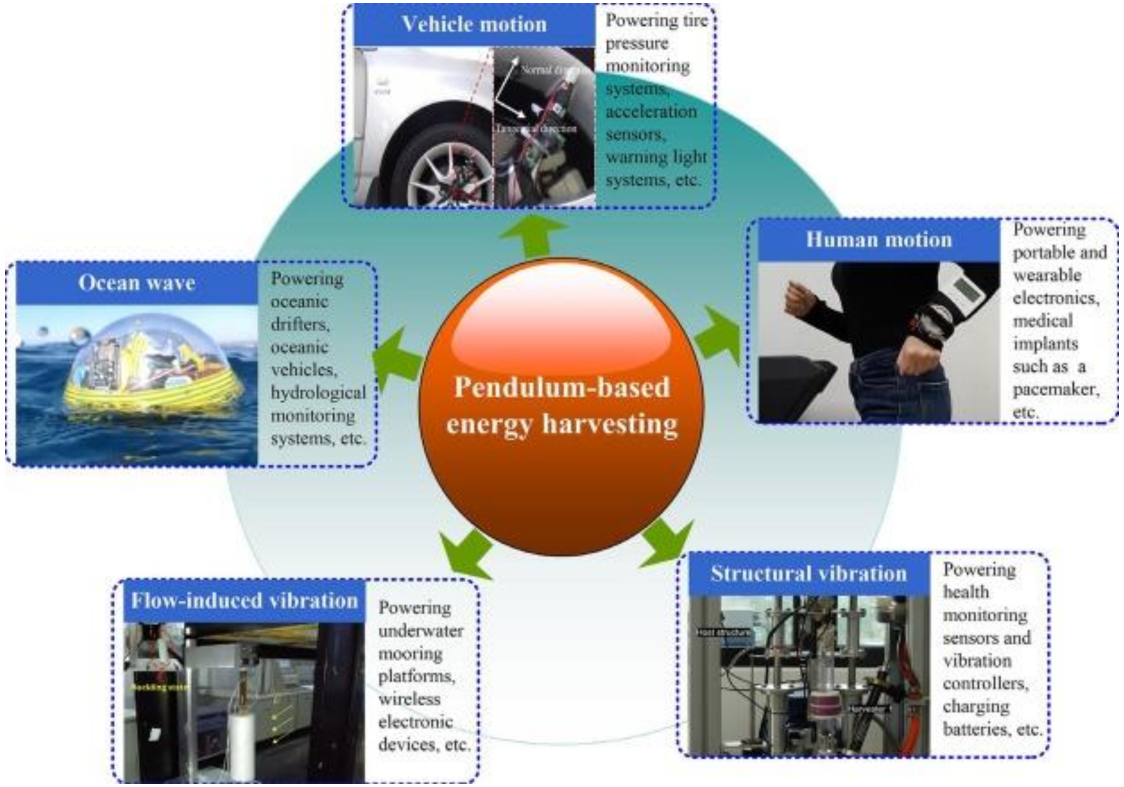
https://www.instructables.com/OpenErg-Based-Erg-Rower-Generator/

https://www.nacleanenergy.com/energy-efficiency/eco-wave-power-s-innovative-wave-energy-pilot-is-on-its-way-to-altasea-at-the-port-of-los-angeles

Relative Motion

- Examples of direct force harvesters
  - ❑ Vibration-Based Energy Harvesters
  - ❑ Pendulum-Based Energy Harvesters
  - ❑ Railroad Vibration Energy Harvesters





(Wang, 2023)
(Liu et al., 2022)

Temperature Gradient

Seebeck effect: Heat → e⁻s
peltier — " — : e⁻s → heat

- The thermoelectric effect is used to convert temperature difference into voltage. An implementation of the effect in a loop constructed of two dissimilar conductors generates an electromotive force V_{emf} when a constant temperature gradient exists between the two common points.
- The generated voltage is given by

$$V_{emf} = (\alpha_1 - \alpha_2)\Delta T$$

(in K)

- where α_1 and α_2 are the Seebeck coefficients for the two dissimilar conductors. The value of a may range from 100 μV/K to 1000 μV/K for common conductors.
- Very large temperature differences are needed to produce useful operating voltages compatible with electronic integrated circuits. In order to make a useful generator, conductors are typically replaced by n- and p-type semiconductors

https://spie.org/samples/TT108.pdf

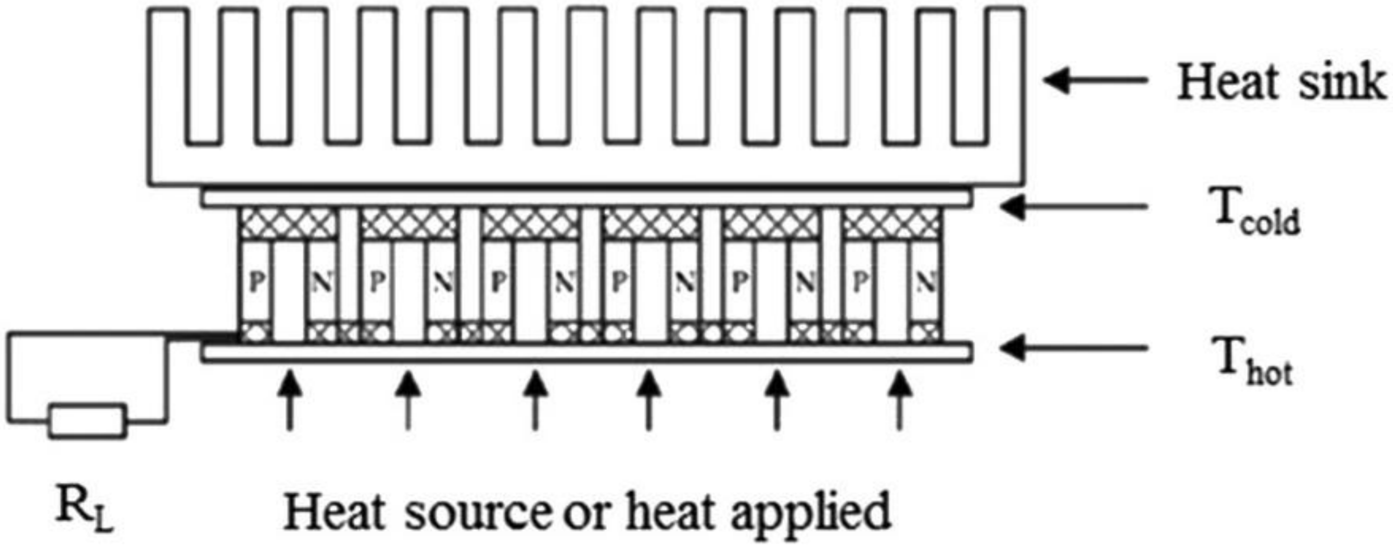
usually use diff conduc/or / semi-cond. → cobalt, led, . . .

heat diff → e^- flow → e^s
N ↔ P

↳ thermoelectric properties
↳ temp drop/gradient x boleh terlalu jauh

Temperature Gradient

The power output of an n-p-based thermoelectric generator is proportional to the square of the temperature difference between the hot and cold surfaces and is proportional to the physical cross-sectional area of the n-p legs. For example, the generated power density at a temperature difference of 200 °C is on the order of 100 mW/cm^2.



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Light (

- Solar Energy as a Source: Solar energy, the dominant source of radiated electromagnetic energy, provides about 1 kW/m² to the Earth's surface.
- Harvesting Methods: Solar energy can be harvested both indoors and outdoors using photovoltaic devices.
- Constraints: Solar energy is preferred if it meets device/system requirements, such as access to direct sunlight and uninterrupted power without storage limitations.
- Photovoltaic Technology: Targets the visible-to-near-infrared spectrum and generates electron-hole pairs by photon absorption in a p-n junction's depletion region.
- Device Model: Photovoltaic cells are modeled as a current source in parallel with an ideal p-n junction diode.

(Kiziroglou & Yeatman, 2012)

Electromagnetic

- Transduction Mechanism: Electromagnetic energy harvesting uses induction per Faraday's law, where relative motion between a magnet and coil induces an electromotive force (EMF).
- Energy Conversion: Motion is damped, and the resulting energy is converted into electricity.
- Large-Scale Usage: Induction is dominant in large-scale power generation, especially for rotational motion.
- Energy Harvesting: In smaller-scale applications, motion is often non-rotational, such as vibrations or irregular movements (e.g., human body motion).
- Innovations: New electromagnetic generator designs are being developed to adapt to non-rotational motion in energy harvesting.

https://spie.org/samples/TT108.pdf

Electromagnetic

- Device Classification: Electromagnetic energy harvesters are categorized as resonant, non-resonant, or hybrid.
- Resonant Devices: Best suited for vibration energy sources at specific frequencies.
- Non-Resonant Devices: Typically rely on rotational motion for energy harvesting.
- Hybrid Devices: Designed to handle a wider range of vibration frequencies or irregular motions, e.g., imbalanced rotor designs.
- Objective: The primary goal is to efficiently convert source motion into productive motion within the device.

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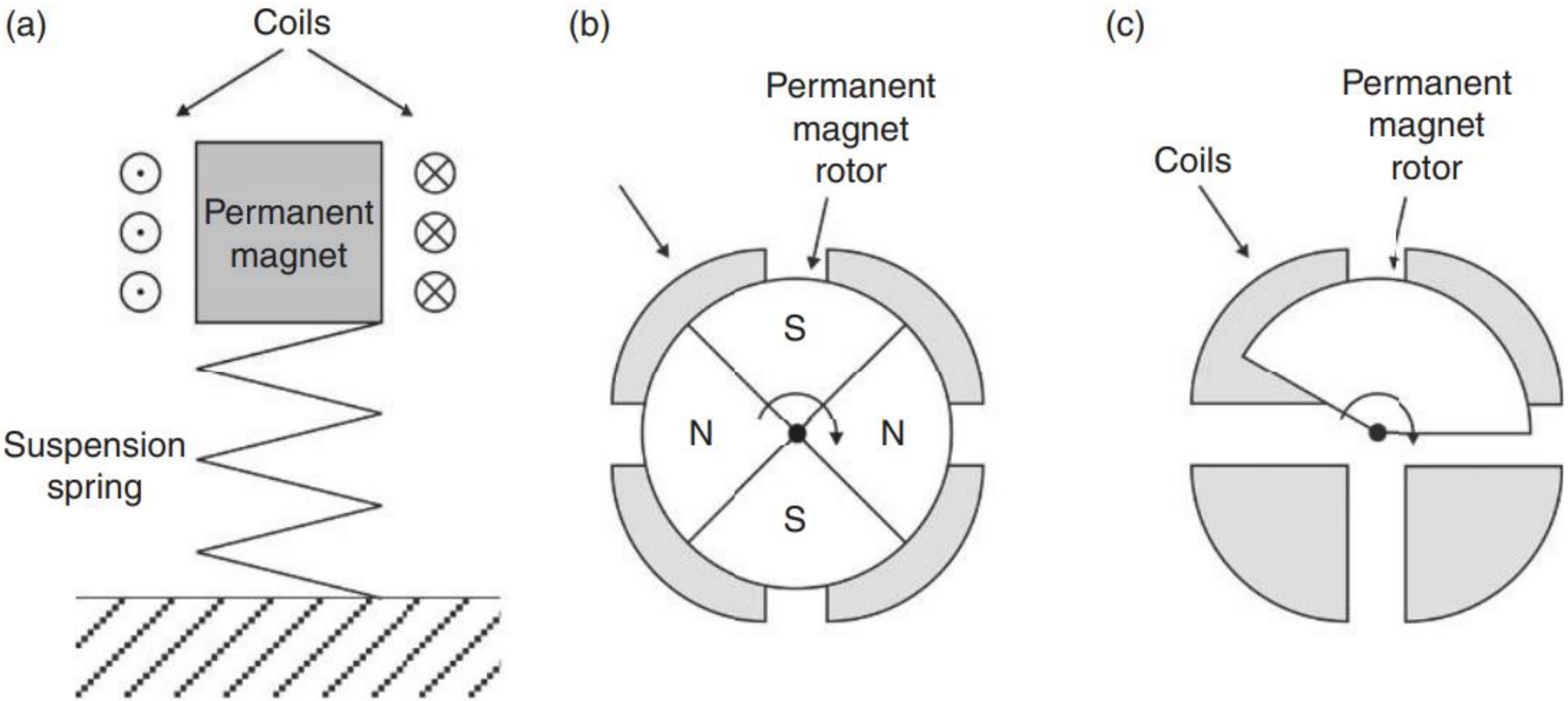
Electromagnetic



(a) Resonant, (b) non-resonant and (c) hybrid electromagnetic energy harvesting devices

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Chemical Energy

- Energy from chemical reactions is transformed into useful electrical energy through a process known as chemical energy harvesting. This process occurs primarily through electrochemical reactions.
- Electrochemical processes, which entail the transfer of electrons between chemical species, are the main mechanism by which this process happens. The predominant energy harvesting technologies utilizing chemical reactions are batteries and fuel cells.
- The advantage of chemical energy compared to other sources like solar or wind, chemical energy harvesting can provide continuous power generation.

Mechanical-to-Electrical-based Energy Harvesting

- The process of converting mechanical energy to electrical energy may be described in three distinct phases.
  - ❑**Phase 1**: An interfacing mechanism transfers mechanical energy to the transducer.
  - ❑**Phase 2**: The transducer converts mechanical energy into electrical energy.
  - ❑**Phase 3**: Electrical energy is collected and conditioned for storage (e.g., battery or capacitor) or direct use by the load.
- There are three primary types of transducers typically used for converting mechanical energy to electrical energy, that is, piezoelectric, electromagnetic, and electrostatic transducers. (relative motion)

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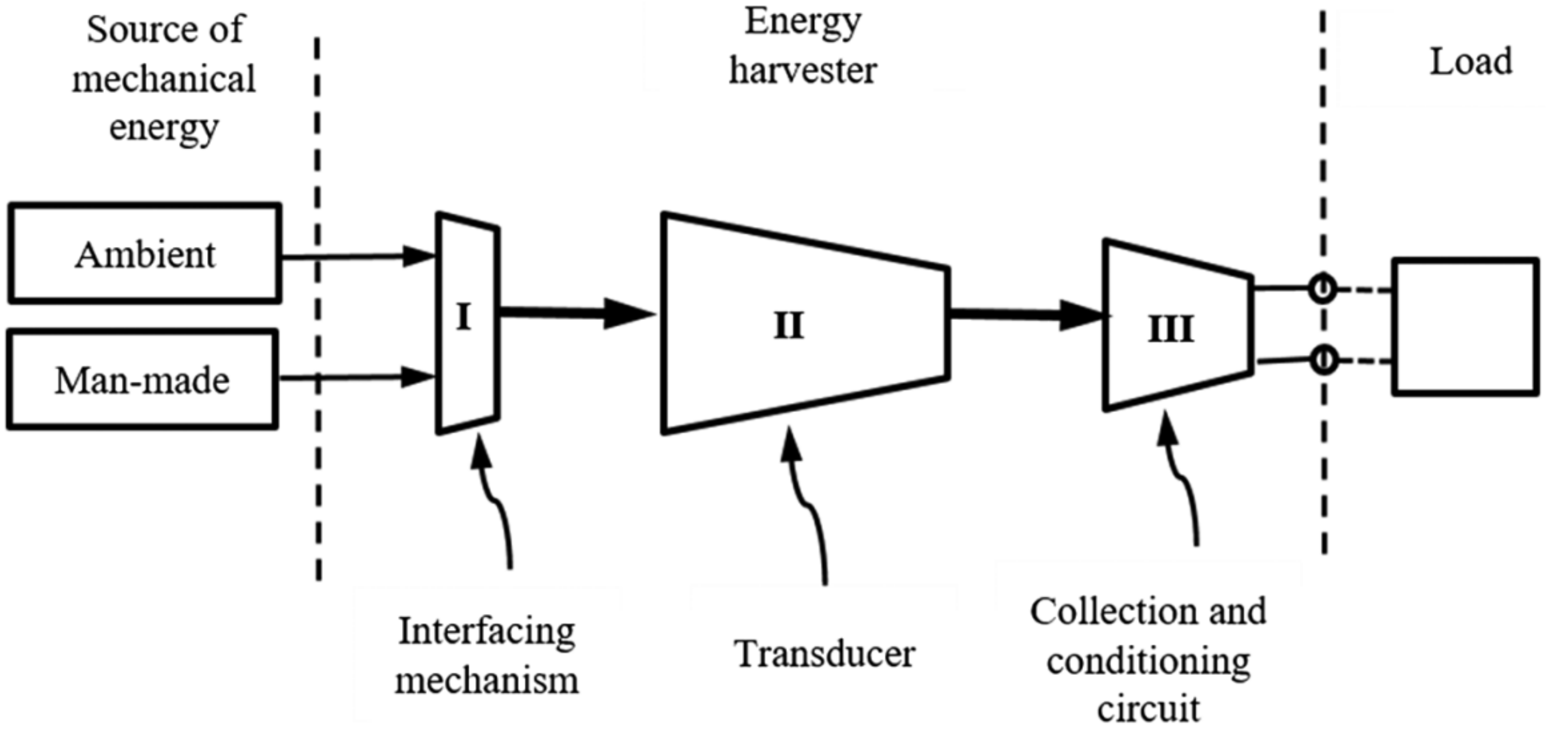
Mechanical-to-Electrical-based Energy Harvesting



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Chemical-to-Electrical Energy Conversion

Battery, fuel cell,

- Chemical-to-electrical energy conversion is the process of transforming chemical energy held in substances into electrical energy.
- This process normally occurs through electrochemical reactions, which involve the transfer of electrons between chemical entities. The most frequent devices utilized for this conversion are batteries and fuel cells.
- Batteries store chemical energy and turn it into electrical energy through redox (reduction-oxidation) reactions.

A battery consists of:

- ❑ Anode (Negative Electrode): Where oxidation occurs (loss of electrons).
- ❑ Cathode (Positive Electrode): Where reduction happens (gain of electrons).
- ❑ Electrolyte: A medium that enables the passage of ions but prohibits the direct transport of electrons.

Chemical-to-Electrical Energy Conversion

- Example: Lithium-ion Battery
- Anode: Graphite (stores lithium ions)
- Cathode: Lithium metal oxide (e.g., $LiCoO_2$)
- Electrolyte: Lithium salt dissolved in an organic solvent
- Working Mechanism: While electrons flow across an external circuit producing power, lithium ions move from the anode to the cathode across the electrolyte during discharge.

TMI
* Battery in Gt no longer use Ni
* Posible alt util → pengganti Pt utk fuel cell

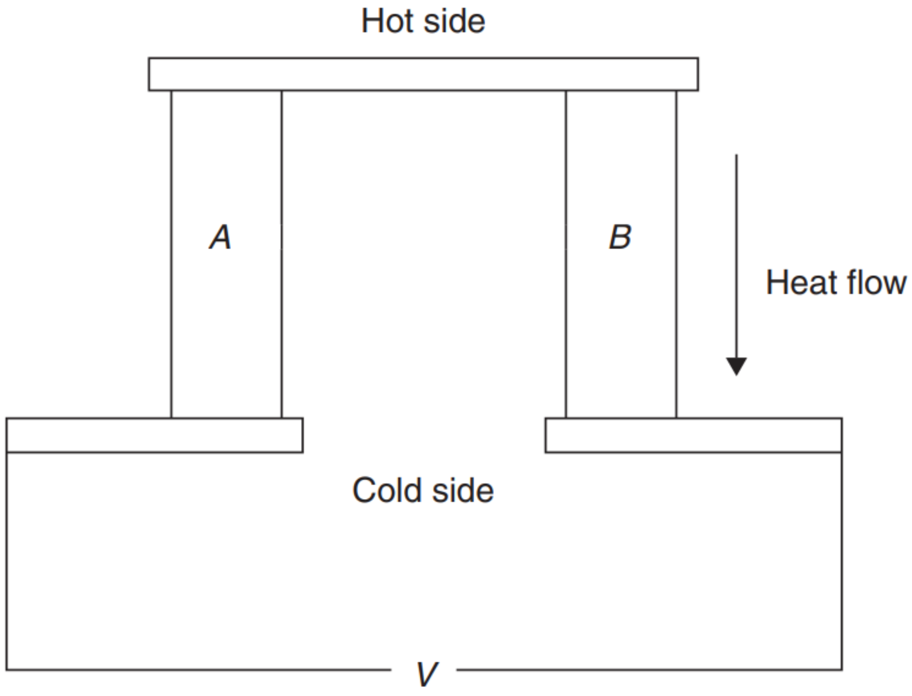
Chemical-to-Electrical Energy Conversion

- Fuel cells use an oxidizing chemical and an ongoing supply of fuel to create electricity. They do not need recharging as long as the fuel is readily available unlike batteries.
- The anode reaction of a hydrogen fuel cell is $H_2 \rightarrow 2H^+ + 2e^-$
- Protons and electrons separate out from hydrogen gas.
- Cathode Reaction: $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$
- Protons and electrons combine oxygen to create water.
- Generating electricity, electrons move over an external circuit.

https://www.sciencedirect.com/topics/engineering/fuel-cell-reaction

Thermoelectric Harvesting

- Two materials, A and B, are positioned with one side at a low temperature *T1* and the other at a high temperature *T2*.
- They are electrically connected at the hot side, and the voltage is monitored at the cold side. The temperature difference drives heat flow via free-moving particles (electrons and holes) and lattice vibrations (phonons).
- The motion of charged particles generates space charges at the material contacts, creating an opposing electric field until equilibrium is reached.
- If the materials are identical ($A=B$), the voltages cancel out. For different materials, a non-zero voltage V results.



(Kiziroglou & Yeatman, 2012)

Solar-to-Electrical Energy Conversion

- Conversion of solar-to-electrical energy is the process of turning sunlight into electrical power. Typically found in solar panels, photovoltaic (PV) cells help to do this.
- Photovoltaic Effect: The photovoltaic effect is the process that converts sunlight into electricity. When light hits certain materials, it causes them to produce electric current.
- The photovoltaic effect is the basic process that converts sunlight into solar energy. It includes:
  - ❑ Photon Absorption: Sunlight (photons) hits a semiconductor material, which is usually silicon.
  - ❑ When energy is absorbed, it raises electrons from the valence band to the conduction band, making pairs of electrons and holes.
  - ❑ The electric field in the semiconductor helps split electrons and holes, which makes electrons move through an outside circuit and produces electricity.

Solar-to-Electrical Energy Conversion

Structure of a Solar Cell Semiconductor Material:

- Typically, silicon comes in three forms: single crystal (monocrystalline), multiple crystals (polycrystalline), or a non-crystal structure (amorphous).
- p-n Junction: This is where p-type and n-type semiconductors come together, forming an electric field.
- Anti-Reflective Coating: Helps absorb more light.
- Metal contacts gather and move electrons.
  - Frame

Radio-Frequency-to-Electrical-based Energy Harvesting uses "Rectena"

- Frequency Range: Radio-Frequency Energy (RFE) technology harvests electromagnetic energy in the megahertz to microwave range.
- Mechanism: A tuned receiving antenna converts RF energy into electrical energy.
- Power Output: RFE harvesters generate very low power unless the receiver is close to the source or is large.
- Usage: These devices often utilize ambient electromagnetic energy from nearby sources, commonly in autonomous sensor nodes.
- Limitations: RFE harvesters cannot function inside conductive enclosures.
- Rectenna Technology: Directed RF emissions are collected by matched receiving antennas (rectennas), as used in active and passive RFID systems.

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Sources of Energy from Human Activity

Human Activity	Power (W)	Application	Power (W)	Possible human activity
Pushing a button	0.3	TV remote	0.1	Finger movement
Shaking	0.4	Portable radio	0.72	Finger movement/Hand crank
Squeezing a handle	3.6	Mp3 player	0.16	Hand crank
Twisting	12.6	Cell phone	2	Hand crank
Bending	20	Laptop	2	Hand crank
Pushing	20	Flash light	4	Hand crank
Turning a handle	21	Video & camcorder	6	Hand crank
Pulling	23	Notebook	10	Hand crank
Swinging	25	Television	75	Pedaling

power available from human activity

power needs of some typical applications

Sources of Energy from Human Activity

- There is considerable interest in attaching self-powered health-monitoring sensors directly to organs, such as the heart.
- The sensors may also assist the organ's function by providing electrical stimulus, as is the case with heart pacemakers.
- Things to consider:
  - ✓Hidden cost of attaching an energy-harvesting device to human's organ
  - ✓Attaching an external device, no matter how small, may produce a reactive chain of events. The long-term effects are difficult to predict and will require the accumulation of clinical data over many years.

Reference

- Kiziroglou, M. E., & Yeatman, E. M. (2012). 17—Materials and techniques for energy harvesting. In J. A. Kilner, S. J. Skinner, S. J. C. Irvine, & P. P. Edwards (Eds.), *Functional Materials for Sustainable Energy Applications* (pp. 541–572). Woodhead Publishing. https://doi.org/10.1533/9780857096371.4.539
- https://spie.org/samples/TT108.pdf
- Liu, G., Fang, Z., Zhang, Z., Tan, X., Dai, C., Wu, X., Jin, Z., & Li, D. (2022). A vibration energy harvester for freight train track self-powered application. *iScience*, *25*(10). https://doi.org/10.1016/j.isci.2022.105155
- Wang, T. (2023). Pendulum-based vibration energy harvesting: Mechanisms, transducer integration, and applications. *Energy Conversion and Management*, *276*, 116469. https://doi.org/10.1016/j.enconman.2022.116469