From Waste to Wattage: Converting Wasted Mechanical Energy into Electricity Through Triboelectrification and Electrostatic Induction

BACKGROUND

In recent years, California has faced devastating wildfires, endangering lives and the environment. While predicting wildfires remains challenging, early detection is vital for timely intervention. There are many advanced disaster monitoring systems deployed to aid with this effort. Advanced monitoring systems require sustainable energy sources that don't need frequent recharging or replacement, ultimately enhancing reliability.

This realization motivated me to create a reliable, self-sufficient power source that is lightweight, cost-effective and eco-friendly. An energy source that is capable of powering low-voltage devices like sensors, as well as critical healthcare applications such as pacemakers, hearing aids, and more.

RESEARCH

- *Triboelectric effect* - A form of contact electrification in which a material becomes electrically charged after coming in contact with another material.
- *Electrostatic Induction* - A redistribution of electric charge in an object that is caused by the influence of nearby charges.
- *Triboelectric Nanogenerator (TENG)* - An energy harvesting device that converts mechanical energy into electricity through the combination of the triboelectric effect and electrostatic induction.

FOUR MODES OF TENGs

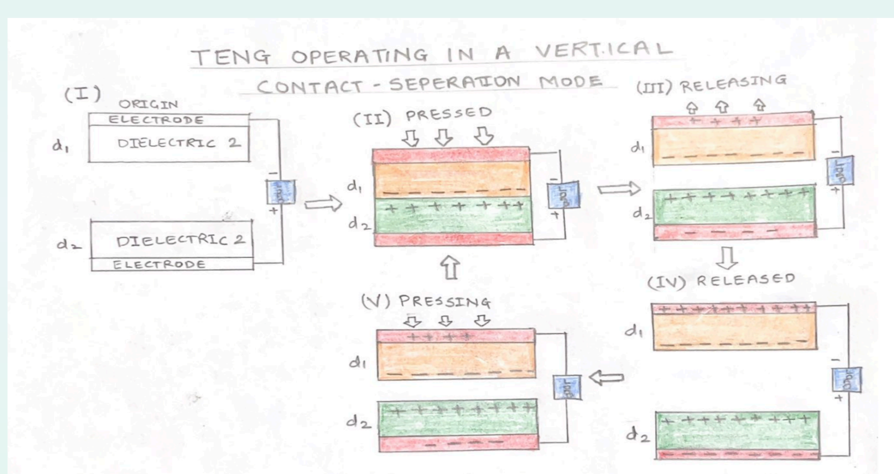


Image credit: self

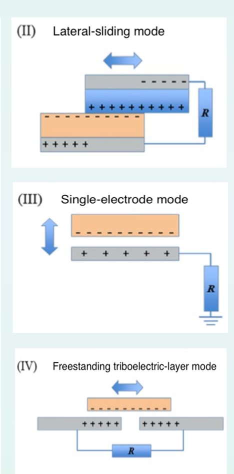


Image credit: semanticscholar.org

- ***Working Principle:*** *Contact-separation mode*
- When two different materials with attached electrodes come into contact with each other under the presence of external force, they produce a surface charge depending on their electron affinity.
- When the two charged surfaces start to separate, an electrical potential develops, which induces the opposite kind of charges on the surface of the electrodes. This induction of charges comes from the transfer of electrons from one electrode to the other.
- During compression, the potential difference tries to minimize and the direction of flow of the electrons becomes opposite to that of the separation, thereby producing alternate current at output.

HYPOTHESIS

It is predicated that:

- For the control group, lowest possible voltage would be produced from all trials.
- For the first experimental group, with independent variable as type of materials used, the farther apart the materials were on the triboelectric series, the more electricity would be produced.
- For the second experimental group, with independent variable as the material surface area, the larger the surface area, the more electricity would be produced.

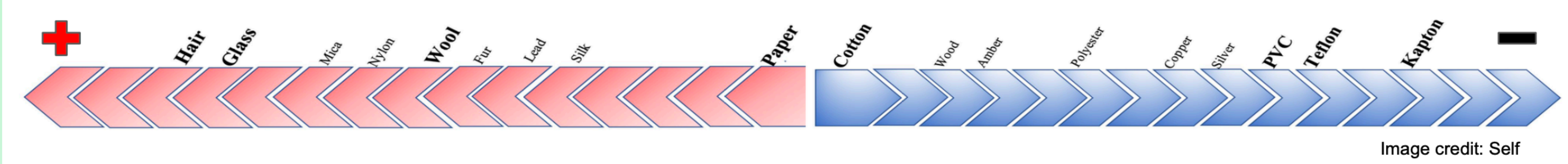


Image credit: Self

Materials: Expected Charge Affinity Positions

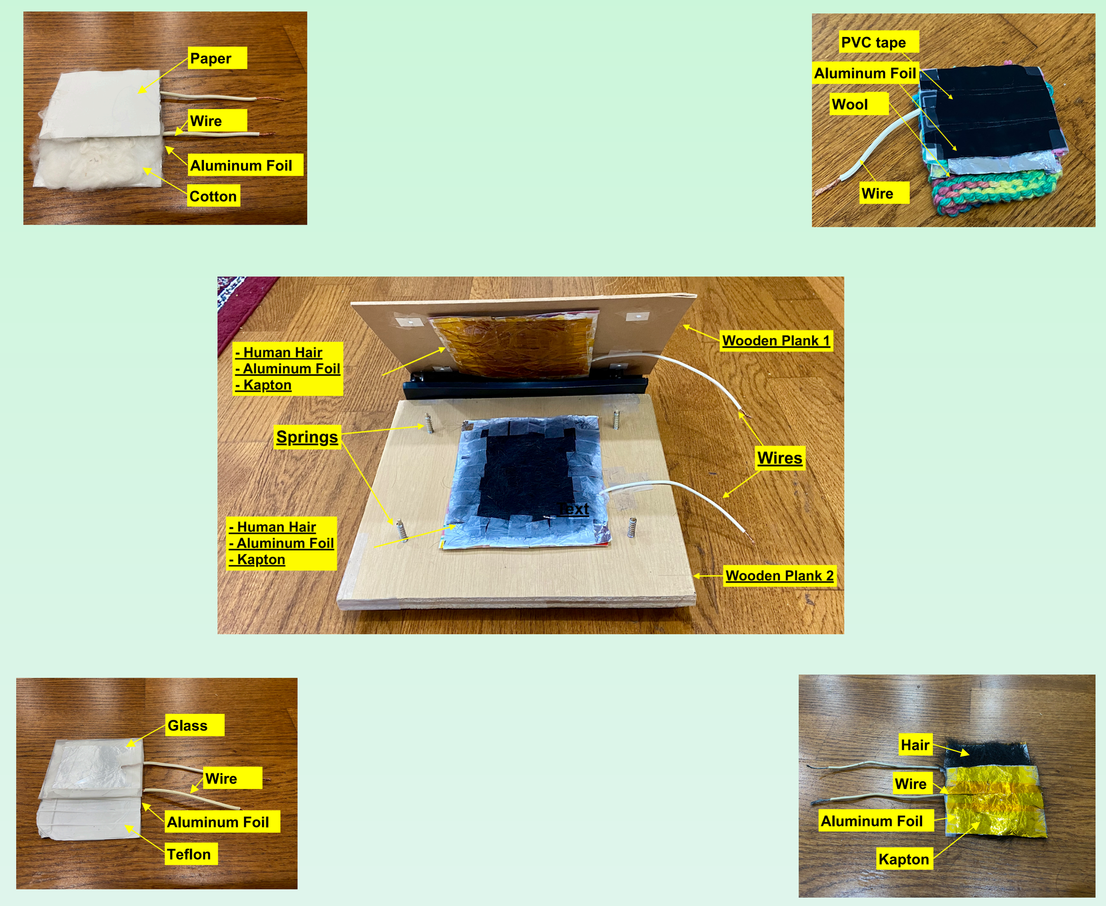


Image credit: self

- ***Control Group:*** *Paper & Cotton*
- ***Experimental Group:*** *Glass & Teflon, Kapton & Human hair, and Wool & PVC*

BUILD THE NANOGENERATOR

- Build a reusable structure with wooden planks and springs for contact-separation mode.
- The planks should be 1cm. apart in a relaxed state and should touch each other when pressed down.
- For each material pair (small, medium, and large sizes), construct dielectric layers with aluminum foil and wires as electrodes for current induction.
- Construct the TENG with reusable structures and material pairs, apply a constant force, and measure the voltage in millivolts (mV) using a multimeter.
- Repeat for 12 material pairs with 5 trials each resulting in total 60 trials. Calculate the average voltage for each TENG.

CAPTURE AND STORE ELECTRICITY

- Connect the TENG output to the AC input terminals of the full wave bridge rectifier.
- Connect the DC output terminals to a capacitor (100uF 50v) on the breadboard using alligator clips.
- Connect the LED in parallel to the capacitor using a switch.

- *Collected charge was used to light up the LED (1.79v).*

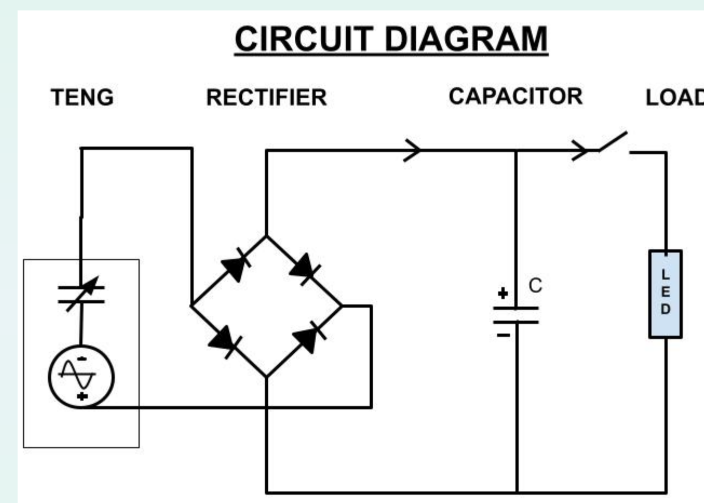


Image credit: self

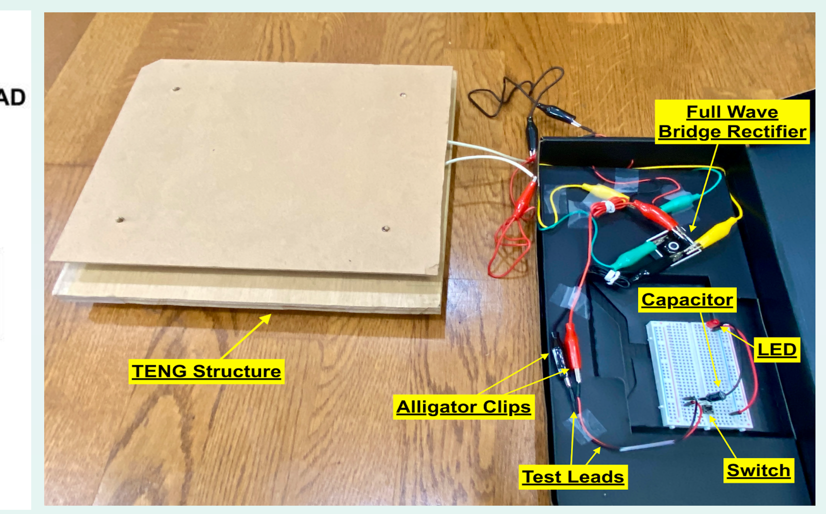


Image credit: self

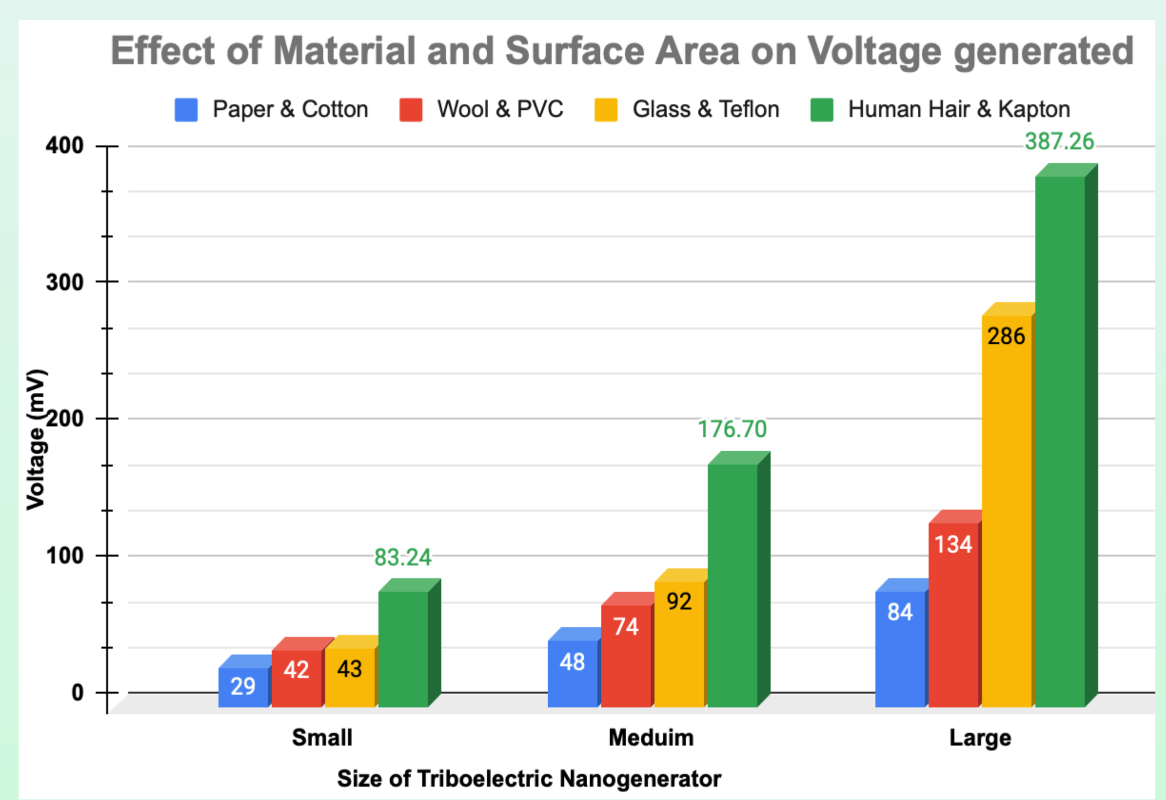
DATA AND CHARTS

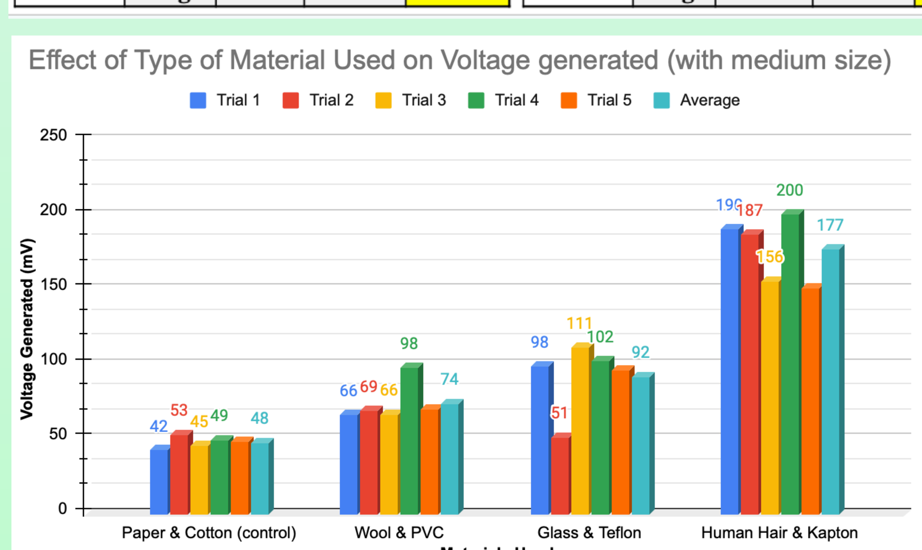
Control Group: Paper & Cotton				
Material	Trials	8x 6cm small	8 x 8cm medium	8 x 12cm large
Paper and Cotton	Trial 1	25.2	42.4	85.8
	Trial 2	29.6	53.0	79.8
	Trial 3	31.4	45.4	81.9
	Trial 4	25.2	49.3	84.2
	Trial 5	31.7	48.1	90.0
	Avg	**28.62**	**47.64**	**84.34**

Experimental Group 2: Glass & Teflon				
Material	Trials	8 x 6cm small	8 x 8cm medium	8 x 12cm large
Glass and Teflon	Trial 1	36.2	98.3	245.8
	Trial 2	38.4	51.3	302.5
	Trial 3	39.3	111.2	234.3
	Trial 4	52.5	102.1	295.5
	Trial 5	46.1	95.9	352.1
	Avg	**42.50**	**91.76**	**286.04**

Experimental Group 1: Wool & PVC				
Material	Trials	8 x 6cm small	8 x 8cm medium	8 x 12cm large
Wool and PVC	Trial 1	43.4	65.9	145.1
	Trial 2	35.5	68.6	149.0
	Trial 3	41.3	66.4	134.4
	Trial 4	41.8	97.6	112.8
	Trial 5	46.3	70.2	126.3
	Avg	**41.66**	**73.74**	**133.52**

Experimental Group 3: Kapton & Human Hair				
Material	Trials	8 x 6cm small	8 x 8cm medium	8 x 12cm large
Kapton and Human Hair	Trial 1	63.5	190.3	401.3
	Trial 2	71.4	186.9	402.5
	Trial 3	68.8	155.6	398.9
	Trial 4	95.3	200.1	321.1
	Trial 5	78.2	150.6	412.5
	Avg	**83.24**	**176.70**	**387.26**





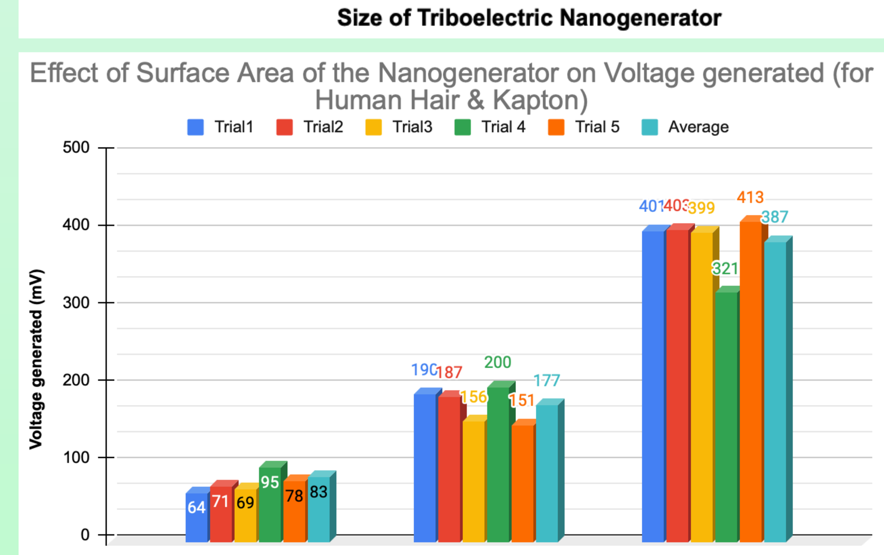


Image credit: self

RESULTS

The results reflected how different materials and surface areas affected the output voltage generated

- Charge-neutral cotton paired with paper in small size produced the least average output of 28.62mV.
- TENGs made of Kapton and Human hair were the most efficient, producing almost 60% more average voltage than that made of Glass and Teflon. This is because Kapton and Human hair have the highest electron affinity, thereby producing the highest voltage.
- Larger surface area TENGs produced the highest average voltage for every material, with 96cm^2 having the highest output and 48cm^2 having the least.
- The surface area increase from small to medium size yielded an average 93% voltage increase, and medium to large was about 33%.

- *Few Outliers observed: Glass & Teflon (2nd trial) and Wool & PVC (4th trial) for the medium size.*
- *Infrequencies observed: multimeter fluctuations were addressed by using cell phone in slow-motion mode to record the highest readings.*

CONCLUSION

My hypothesis was supported. The TENG with higher electron affinity materials and larger surface area produced the most voltage. This voltage was captured and converted from AC to DC to successfully power up a LED.

These results show that TENGs can be used as an ideal, real-time energy harvester to power low-voltage applications such as health and environment monitoring devices.

APPLICATIONS

- **Environmental Science:** The TENGs, deployed on trees, can capture branch movements to power monitoring sensors for wildfire detection. This self-sustaining system ensures continuous fire monitoring without the need for post-deployment maintenance.
- **Healthcare Applications:** TENGs can harvest energy from human motion to power implanted and wearable devices such as pacemakers and hearing aids.
- **Internet of Things:** TENGs when integrated with floor can sense the presence of people as they walk on it. The energy generated due to the walking motion could be harvested to power the connected IoT devices such as light bulbs.

- *Scientists at **NASA** are exploring the use of TENGs for Mars Exploration and High-Altitude Power Generation on Earth.*

FURTHER RESEARCH

- Try different methods of generating triboelectricity – sliding mode, single-electrode mode and free-standing mode.
- Measure the performance of different TENGs when connected in series and parallel, to analyze the output efficiency.
- Build an Amplifier circuit to amplify current to power on high-voltage devices.
- Test the effect of environmental factors (extreme temperatures, humidity, seasons etc.) on the efficiency of the triboelectric nanogenerators.