Snythesizing Biomorphic Batteries using Porous Plant Stems using Zinc (Zn) and Copper (Cu) Electroplating Technique

How do Biomorphic Batteries compare to Chemical-based Batteries in terms of energy efficacy and environmental impact?

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ABSTRACT

Chemical-based batteries such as lithium or any conventional battery fall under the label of a chemical battery. Biomorphic batteries are a new prospecting alternative battery that utilizes biological matter to assist with energy conductivity and capacity for future batteries and is reported to be 72 times greater in energy capacity than conventional batteries in the market. Currently, the research of biomorphic batteries is limited, and the basic designs are scattered. This begged whether biomorphic batteries could produce 72 times more energy than conventional batteries and be environmentally friendly, unlike current chemical-based batteries, disregarding other new alternative chemical-based batteries that are also competing for the role. This research aims to recreate a biomorphic battery using the basic structure of a battery, the voltaic (galvanic) cell, and porous plant stems, such as squash, corn cob, pumpkin, and sunflower stems as the biological component of the battery. The most stable biomorphic battery is the squash stem since the battery is durable in energy production compared to the other biomorphic batteries but is considerably dwarfed by the conventional lithium battery used as a comparison. This demonstrated that biomorphic batteries could outrank a chemical battery but will need more resources and studies done. This paper did not investigate these biomorphic batteries' energy capacity and density. Still, it will be a consideration in future battery improvements, and ultimately, the batteries will stem towards a more typical battery structure.

1. INTRODUCTION

Chemical-based batteries are the standard in the market and studies. With the growing demand for electronic devices, electric vehicles, smart grids, and robotics, there is a need for energy storage that can produce massive amounts of energy and have a longer life span, including eco-friendly and cost efficiency. Current chemical batteries out in the market are lithium-based batteries as the most common. Still, Lithium on earth is low in abundance compared to other metals used in studies or in the market, such as sodium (Na), potassium (K), and zinc (Zn). Lithium (Li) is shown to be very dangerous to humans and ecosystems, with Lithium only being 0.0017% in the earth's crust; this is not enough to keep up with demands for batteries (Gao). Many different studies explore potassium, sodium, and zinc ion batteries, and even zinc-air battery type, but there is one type of battery that can surpass chemical batteries.

Biomorphic Batteries have been a recent phenomenon in the research to find environmental and energy-efficient energy storage over the past few years. These batteries come in different forms, but the most common method and materials among all biomorphic battery studies are batteries that are a mixture of biological matter and chemical components to enhance electrochemical reactions; currently, there are no comparable batteries with the equivalent level of energy density. Biomorphic batteries can be composed of plant or animal biomass, and the batteries can possibly replicate fats like in mammals for electronics and robotics. Essentially, biomass are plant or animal material that are converted to be used as fuel to produce electricity or heat. These batteries produced large amounts of energy, and the reusability is sufficient than regular chemical batteries. This type of battery has the potential to replace conventional batteries that are on the market. In theory, the biomorphic batteries are environmentally friendly, since it is made from biological materials that are produced and extracted from biological organisms, and the chemical components are from abundant metals in the earth's crust. Researchers reported that biomorphic batteries are more efficient than the current advanced lithium-based batteries.

<u>*Research Question:*</u>

How does Biomorphic Batteries compare to Chemical-based Batteries in terms of energy efficiency and environmental impact?

Batteries essentially are electrochemical energy storages that are used to hold energy for recycled uses. The most common batteries that are in the mainstream market are chemical-based batteries such as Lithium or Lithium-ion batteries (LIBs). Biomorphic batteries come in all different sizes and structures. Most are similar conventional chemical-based batteries. Biomorphic batteries are made from a combination of biomass and chemical components from metals found in the earth's crust. Biomass is the use of plant and animal matter that is converted to generate heat or electricity. The use of biomass is not new, since it has been around for years, until it began to be implemented into batteries. It is unclear when the research of biomorphic batteries began but the reason why biomorphic batteries started to gain traction in the battery development fields is mostly due to the high demands of batteries, especially with the low abundance of Lithium. Currently, Lithium only has 0.0017% abundance in the earth's crust (Gao). Lithium also is a dangerous substance when being extracted from the earth's crust and it is unstable when it comes to heat or damages. The element itself poses danger to the surrounding environment and to humans if it is not disposed properly. Another reason is the large quantities of bio-waste disposed globally and that waste can pose a danger to the environment as well. Implementing biomass into batteries can help reduce bio-waste and produce high levels of energy. In most studies, such as in Xiangwei Lao et. al., studies theorized their version of the biomorphic battery is low in cost and is also stated in other studies as well with the low cost of the battery itself. Biomorphic batteries use abundant metals such as sodium (Na), phosphorus (P), potassium (K), potassium-ion batteries (KIBs), phosphorus-ion batteries (PIBs), sodium-ion batteries (NIBs), and zinc manganate ($ZnMn_2O_4$). The examples of biomass used are corn husks, walnut septum, black tea, cotton, and cartilage or non-biomass, such as microtubes or bio-mimic aramid nanofibers. The main areas where biomorphic batteries hope to revolutionize are in robotics, portable electronics, electric vehicles, drones, prosthetics, and large-scale energy systems. All those examples stated previously all have chemical-batteries in their functions. Throughout all the studies done, the most common question of the reliability of the biomorphic batteries is whether it is environmentally friendly and energy efficient compared to regular conventional chemical-based batteries that are currently in the market. Including new chemical-based batteries that are becoming more energy efficient and environmentally friendly.

This brings to question, can replicating a similar battery in a simple high school lab feasible? In many research papers done on biomorphic batteries all vary in materials and chemicals used to trigger electrochemical reactions. This investigation aims to replicate similar experimentations done but with local biomass materials in the San Juan Country region. Having looked at all available experimental papers that directly deal with biomorphic batteries or are similar in technology, this experimentation will be looking into porous plant stems and using said material for a small biomorphic battery, with experimental references to an already done experimentation.

This investigation aims to replicate a biomorphic battery by using sunflower, squash, corn cob and pumpkin stems, along with the comparison of Lithium batteries that are found in the stores. The experimentation aims to prove that biomorphic batteries, more specify, porous stem-based biomorphic batteries can do more energy production compared to the regular batteries.

The results from the experimentation should demonstrate the possibility of biomorphic batteries in general, the capabilities of replacing lithium batteries altogether. With the information from previous studies should give the rough prediction of the experiment that will be conducted.

Hypothesis:

If using porpus stem-based biomass to create a biomorphic battery and comparing to store bought Lithium batteries, then the energy produced will be greater than store bought Lithium batteries.

Variables:

Table 1: Independent Variables	
Variable	*How will it change*
Type of porous stem plant	This will be the type of plant stems that are porous to allow for electrical conduction of Zinc and Copper electroplating solutions.

Table 2: Dependent Variables	
Variable	*How the change will be measured*
Energy Production (Volts)	When the battery is operating, there will be a measurement of electrical current after a certain number of minutes.
Amount of reuse per trial	How many times the battery was reused over one trial run.

Table 3: Controlled Variables		
Variable	*Effect on experiment*	*How it will be controlled*
Store bought Lithium Batteries	It will be the standard comparison to the porous stem biomorphic batteries in the volt production, energy density, and the amount recycle use per trial.	It will have the same experimentation as the fiber batteries, but it will only be measured without the creation of lithium battery.

2. MATERIALS AND METHODS

In this investigation, using fiber-based biomorphic batteries in theory should produce a substantial amount of energy and have a long recycle of use compared to store bought lithium batteries. That is, if the conversion of fibers to be able to conduct electrochemical reactions goes according to the experimental procedure and produces energy when measured.

The first step in this investigation is to determine what type of biomorphic battery method that will be used for this experimentation. By investigating into previous research studies. In this experiment, the studies used as a reference will be the Mesoporous $ZnMn_2O_4$ Microtubules by Xiangwei Luo et.al and the Biomorphic carbon derived from corn husk research paper by Qing Wang et.al. This is where to begin gathering porous stems that will be used in this study. The selection is narrowed down to local stems found in the local area in San Juan County, such as squash.

Material List:

Materials for this research include: 30g Pumpkin stem strips, 30g Squash stem strips, 30g Sunflower stem strips, 30g Corn cob strips, 1– 12V Duracell battery, 250 ml Acid Copper Electroplating 8 oz, 250 ml Acid Zinc Electroplating Solution 8 oz, Oven, 2 Copper metal strips, 2 Zinc metal strips, Arduino Uno microcomputer, Voltmeter.

Methods for experiment 1:

Test experimentation of stems

Before beginning the main experimentation with the comparison of the store-bought lithium battery. Check if the stem materials will work together with the given chemicals under the guidance of the reference papers and experimental procedures. This will help with perfecting the biomorphic battery model before the actual experimentation.

1) 250 ml of Acid Copper Plating solutions and 250 ml of Acid Zinc plating solutions in separate containers to make a voltaic cell.
2) Add 1 zinc and copper metals into each respective acid plating solutions. (Zn(s) – Zn(aq) and Cu(s)-Cu(aq)).
3) Take 0.5 g of experimental stems then immerse one side of the stems into the zinc and copper solutions.
4) Place the stems once dried, wired to the zinc and copper solids with the red and black allegator clips for both the zinc and copper containers.
5) Then connect the Arduino Uno and the voltmeter with the stem batteries
6) If the small sample is successful, then prepare for the actual stem battery experimentation.

Methods for experiment 2:

Finalized version of experimental batch

The methods for the finalized version of the fibers will be repeated from the first method.

1) Repeat process from method.
2) Once completed, measure the energy production and the number of minutes it takes for the batteries to produce energy by the recycling use from the small motor.
3) Calculate the energy density from the three different stems.

Methods for experiment 3:

Test the 12 V Duracell battery for energy comparison

For this method, it will be like the previous methods but will skip the production of the battery instead. This section will focus on the energy production per recycle and the number to minutes for it to lose energy. Then calculate the energy density.

3. RESULTS

Table 4: **Experiment 1: Test Experimentation of Porous Plant Stems**			
Porous plant type	Mass (g)	recycle use	Volts(V)
Pumpkin stem	0.5	3	2
Squash stem	0.5	3	1
Sunflower stem	0.5	3	1
Corn cob	0.5	3	2

Table 5: Experiment 2: Final results for Three Trials on Experimental Stems									
Plant Type	Mass	Trial 1		Trial 2		Trial 3		Average Voltage	Standard Deviation
Porous plant type	(g)	Recycle use	Volts	Recycle use	Volts	Recycle use	Volts	Volts	Volts
Pumpkin stem	0.5g	3	0V	3	1V	3	1.77V	0.92 V	0.88V
Squash stem	0.5g	3	1V	3	1V	3	1.1V	1.03 V	0.05V
Sunflower stem	0.5g	3	0V	3	1V	3	1.5V	0.83 V	0.76V
Corn cob	0.5g	3	2V	3	1V	3	1.55V	1.52 V	0.05V

Table 6: **Experiment 3: Test the 12 V Duracell battery for energy comparison**								
Chemical-Based battery	Mass	Trial 1		Trail 2		Trial 3		Average Voltage
	(g)	Recycle Use	Volts	Recycle Use	Volts	Recycle Use	Volts	Volts
Duracell Battery(Lithium)	7.4g	3	12V	3	12V	3	12V	12V

4. DATA ANALYSIS

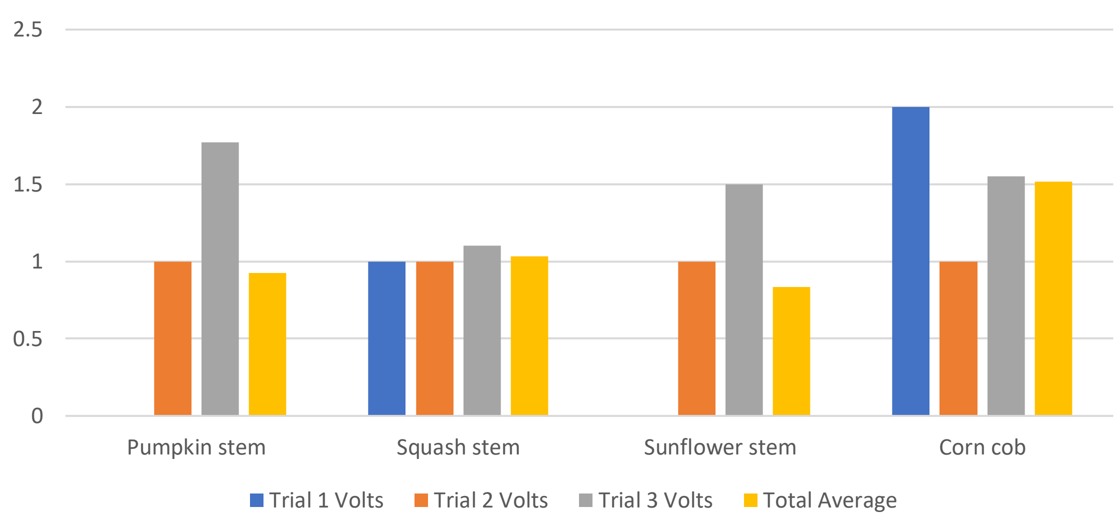
To determine the overall energy density and production from the experimentations, there need to be an overall comparison to the 12V Duracell battery as well. By doing this, the samples should have a clearer depiction which battery type is more efficient in energy production. By doing this there will be a table and graph to demonstrate what the experimental results entail to the idea that biomorphic batteries have better energy density and production compared to store bought lithium batteries.

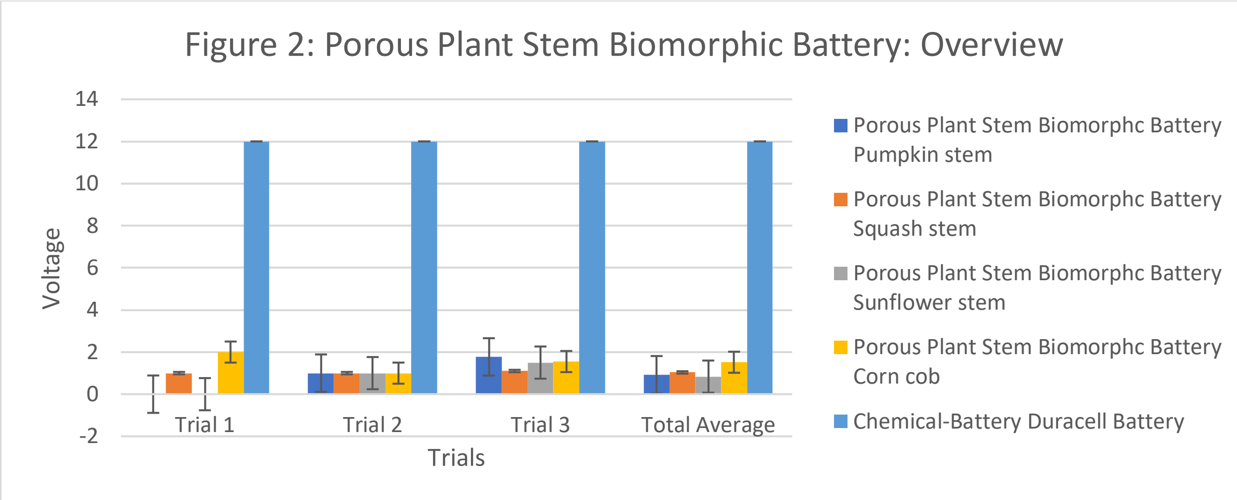
Table 4 shows a pre-test of the different porous based stem plants in order to check if there is energy in the form of voltage generated. When the test came out positive, further testing and experimentation was done. In order to compare the production of energy of the different porous based stem plants to the chemical-based battery (Duracell), standard deviated was calculated.

Table 5 and Figure 1, shows the voltage from the replicated biomorphic batteries using porous plant stems were not energy sufficient. The average voltage from the four porous plant stems is dwarfed by the chemical-based battery, lithium 12V battery. Hence the data argues that even though biomorphic batteries have a promising energy production, that energy is not enough to power a small motor or a light bulb. The standard deviation of the four biomorphic batteries varies for each battery type. The pumpkin battery's standard deviation is 0.88V and throughout the data, it shows the battery itself shows variable results in terms of voltage of energy production in the three trials, showing the battery is unstable. For the squash battery, the standard deviation is 0.05V and the battery in all trials including the average demonstrates that the battery is stable without wide energy production variation in the deviation. The sunflower stem battery's standard deviation is 0.76V. Table 5 and Figure 2, shows that for each trial, the sunflower battery has the second largest deviation next to the pumpkin battery, the battery is also unstable with energy production. The final biomorphic battery is the corn cob variation, and its standard deviation is 0.5V. Which is the second smallest deviation, but it is still large in variation compared to the squash battery. The interesting observation in Table 5 and Figure 1 is, the corn cob battery has the largest average compared to all the other biomorphic batteries in voltage production, but it is still dwarfed by other biomorphic battery studies. Out of the batteries recreated for this study, the biomorphic battery that has the best record is the squash battery since it has the smallest deviation and it is the most stable with energy production but compared with the lithium battery, the energy is too small, even though it is stable. Regardless, the squash biomorphic battery is having a better chance but needs to increase its energy production.

With the small energy production, there could have been an influence in data due to the small weight size and the size of the biomorphic battery compared to the lithium battery, which weighs 7.4 grams. There may have been more energy production if the biomorphic battery were larger or equal to the weight and size of a store-bought lithium battery.

Figure 1: Porous Plant Stem: Voltage





Even with the positive outlook on the biomorphic batteries was mentioned numerous times, there are indeed problems with the biomorphic battery that are not suitable for mass marketing compared to conventional chemical-based batteries and new prospecting chemical batteries. In a few studies have evaluated the use of different chemical combinations in biomorphic batteries that have shown to be difficult to develop efficiently, it all depends on the chemical combinations used, such as potassium-ion batteries (KIBs) for an example. In Chenglin Gao et. al. study proclaimed that "anode materials for KIBs are difficult to develop because of large size potassium (K) ion" (Gao 166). In other words, developing anode materials for KIBs pose an issue due to potassium having large atomic structure. KIBs need to use carbon materials for it to be stable to generate energy. This chemical combination, KIBs, need to have carbon to stabilize it for any electrochemical reactions, this can be difficult to develop in biomorphic batteries. In other biomorphic battery studies, some of the batteries have various designs and structures that are not all the same, leaving future researchers to figure out other methods with what is presented or mentioned in other studies. This can be seen in Mingqiang Wang et. al. study mentioning the lack of "sufficient mechanical, chemical, and transport properties…methods for their structural design" (Wang 1). This refers to biomorphic batteries having no solid battery design or materials to use as the primary functions. Wang mentions that all previous studies regarding biomorphic batteries in general do not have a basic design to go off. Biomorphic batteries have different battery designs from various research done, and all are not the same in structure. Wang and their team had to develop their own version of what a biomorphic battery could be and referencing to other studies to assist in designing their biomorphic battery.

With difficulties with finding a common design, there is the issue of chemical combinations that corrode after several reuse cycles done during experimentations. In Yuqing Gao et. al. research pointed out that "alkali metal ion batteries suffer from inferior power density and insufficient cyclic performance" (Y. Gao 1). Which means that even if the chemical combinations used along with infusing with biomass to boost electrochemical reaction, the chemicals used will have low energy density and poor cycle performances regardless of biological enhancements. Gao also mentions with the use of phosphorous ion batteries (PIBs) in some biomorphic batteries have poor cycle performances and energy density compared to other biomorphic batteries and chemical batteries. The energy efficiency will be impacted by what type of chemicals are used along with the type of biomass used. Other studies, have also dealt with the cycle performance issue in zinc-air cells and in zinc manganate ($ZnMn_2O_4$). Regardless, the energy efficiency in most of all studies on biomorphic batteries have demonstrated outstanding energy levels but those energy levels are temporary after several recycle uses, which at times, can be must less than that of conventional chemical batteries. Mingqiang Wang et. al. mentioned that "reductions in energy density…especially under strain" (Wang 1) can impact the energy performance of biomorphic batteries. The batteries "often suffer from severe performance fade" (Wang 1). In other words, Biomorphic batteries suffer from energy density reductions and cycle performance fades over time and can happen when the battery is under stress. It is like chemical batteries but for biomorphic batteries it is a lot of worst, certain biomorphic batteries can just lose its powerful energy density after one cycle of use. With the issues of performances and energy density in biomorphic batteries lowers its possibility to be marketed due to it being unstable compared to conventional chemical-based batteries.

Interestingly, most studies done with biomorphic batteries all have porous or fiber-based biomass used for conduction and energy storage. Such as Yuqing Gao, Qing Wang, and Xiangwei Luo's research, all have fiber or porous plant stems or leaves. With the exception of Mingqian Wang's 'Biomorphic structural batteries or robotics' paper. There is a limitation to the use of biomass in these Biomorphic batteries and not just any type of biological matter can be used. Utilizing such materials maybe cost friendly and ecologically friendly but post such energy density troubles unlike a regular chemical battery.

In the replicated biomorphic batteries in section 4, exhibit the possibilities of the biomorphic batteries' positive outcomes but the energy production from the most stable plant battery is still dwarfed by the lithium battery. This goes with the argument that biomorphic batteries are not capable to outpace the common chemical batteries both the new variations and the current market batteries. Even with the promising 75 times energy production that outranks the chemical battery, it shows that in an economical setting, the biomorphic battery cannot produce those 75 times projectile prediction from Mingqiang Wang's own biomorphic battery.

4. CONCLUSION

Even though the limitations of materials and the biomass limitation, Biomorphic batteries do have the possibilities of becoming the new environmentally friendly variation of a chemical battery. Not only will it be a contender to replacing the current marketplace batteries, but it might be in the future. There are other batteries that also fall in the chemical-based batteries but are the environmentally friendly versions as well that also have the prospecting future. Regardless, biomorphic batteries do carry the capacity but ultimately is very difficult to replicate with common materials in a non-lab environment. Even with the replication of a biomorphic battery, in order for battery to surpass the lithium battery, there needs to be a large size of porous plants along with the weight. With regards the previous researches with other variations of the biomorphic battery, all the papers detail with the addition of a larger or a more energy producing plant type or chemical reaction to trigger a more powerful electrical production.

Biomorphic batteries are an interesting form of alternative batteries that could one day remove humanity from using environmentally dangerous or human hazardous chemical components found with in current market place batteries. Current understanding of biomorphic batteries still have a long way of improvement in order to meet our energy consumption needs that regular chemical batteries can do with ease. With many other research and experimentation of other types of biomorphic batteries, all only have temporary burst of energy and a rapid decay of battery capacity. Which is a big problem with biomorphic batteries in general. Regardless, from this investigation, biomorphic batteries are a good alternative to regular batteries in the environmental impact, human energy consumption, and energy production, along with the battery capacity. Even though both the energy production and the capacity varies in amount from research to research and including with the replicated biomorphic battery previously mentioned, there is hope in using biomorphic batteries. Biomorphic batteries just need more research and extensive long term investigation of the environmental impact, along with finding more effective methods of retaining longer energy capacity and energy production greater or similar to chemical batteries.

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Wang, Qing, Chenglin Gao, Wanxing Zhang, Shaohua Luo, Meng Zhou, Yanguo Liu, Ronghui Liu, Yahui Zhang, Zhiyuan Wang, and Aimin Hao. *Biomorphic Carbon Derived from Corn Husk as a Promising Anode Materials for Potassium Ion Battery*. Amsterdam: Elsevier, 2019. PDF.

Appendix:

This some of the images from the experimentation of the biomorphic battery.

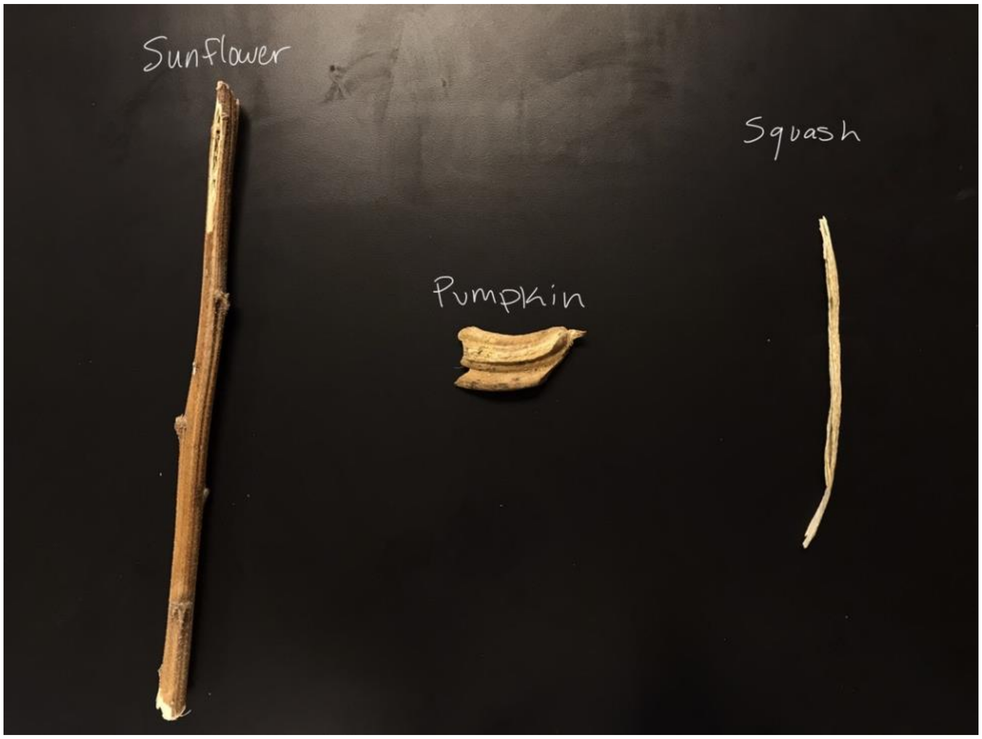


Fig 1: Porous Plant in original form.


Fig 2: Porous Plants in cut form and baked.

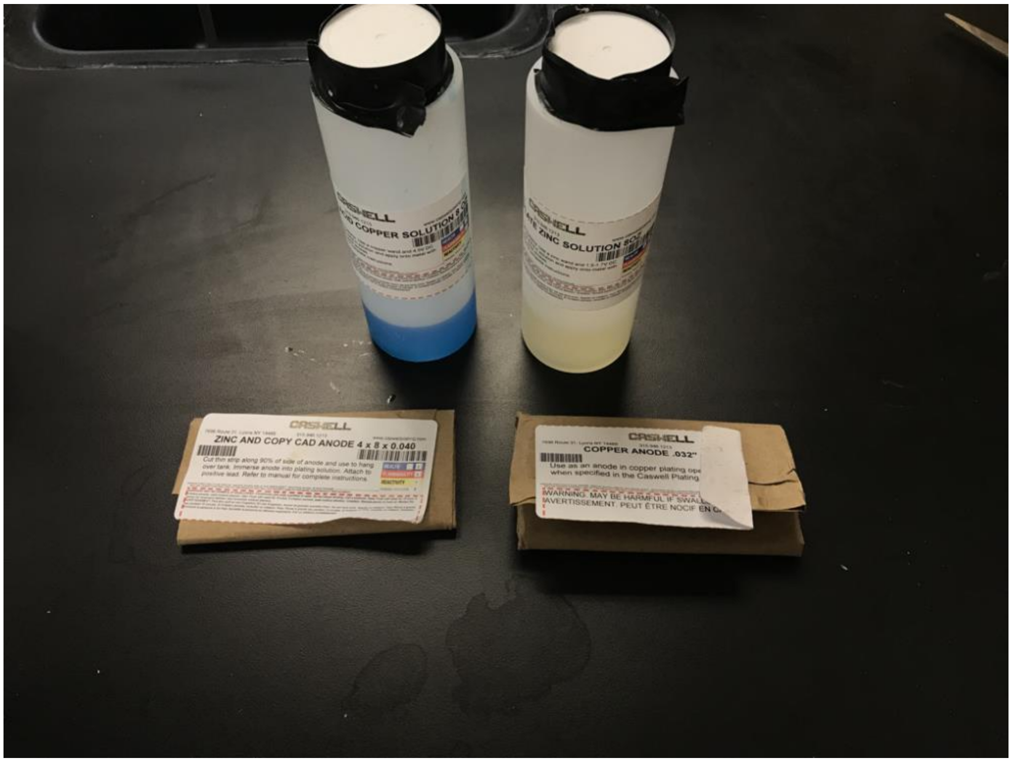


Fig 3: Zinc and Copper solutions with their respective metals.

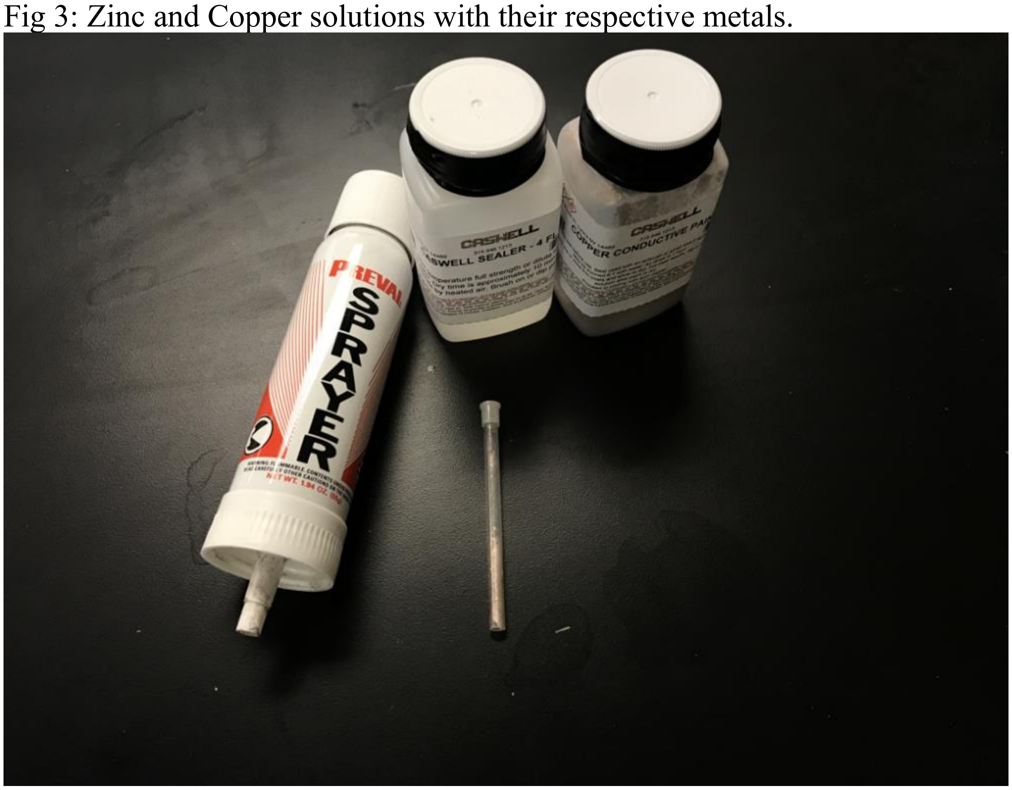


Fig 4: The copper conductive paint for the stems to be covered in.

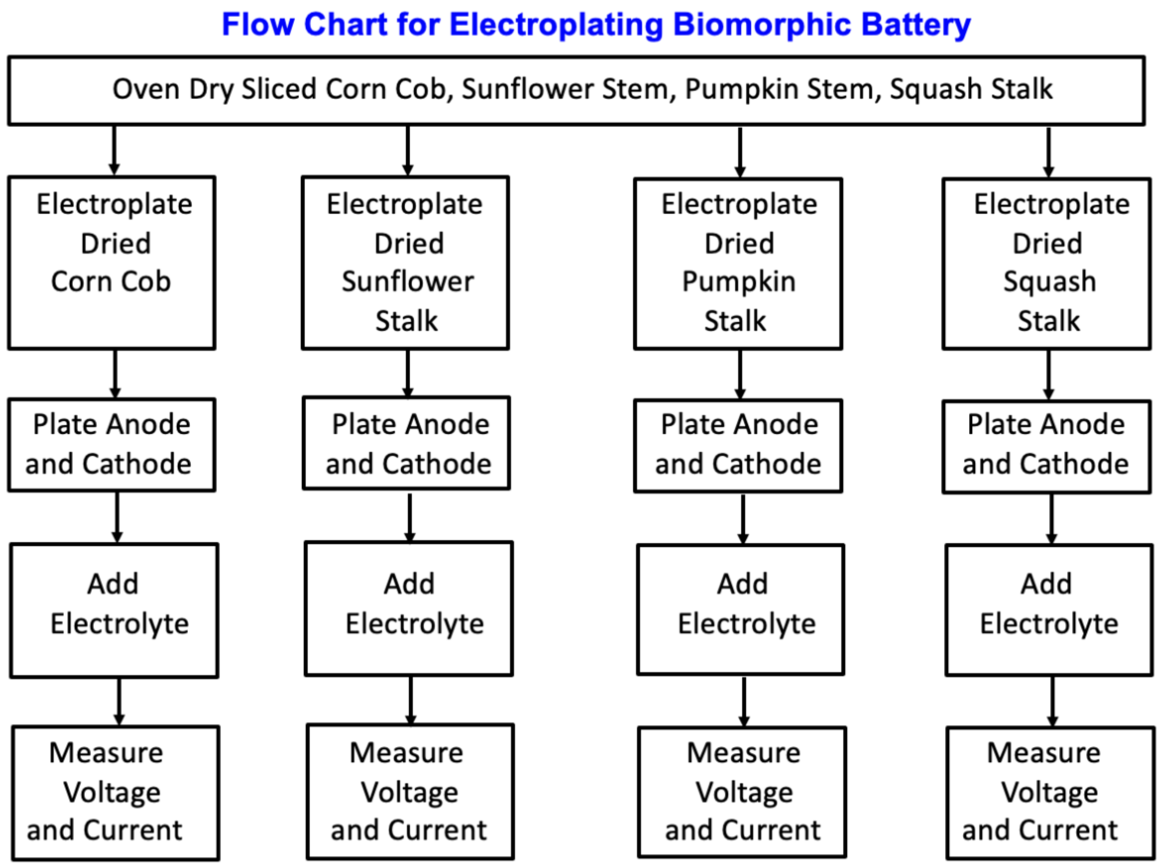


Fig 5: Flow chart for electroplating the Biomorphic Battery

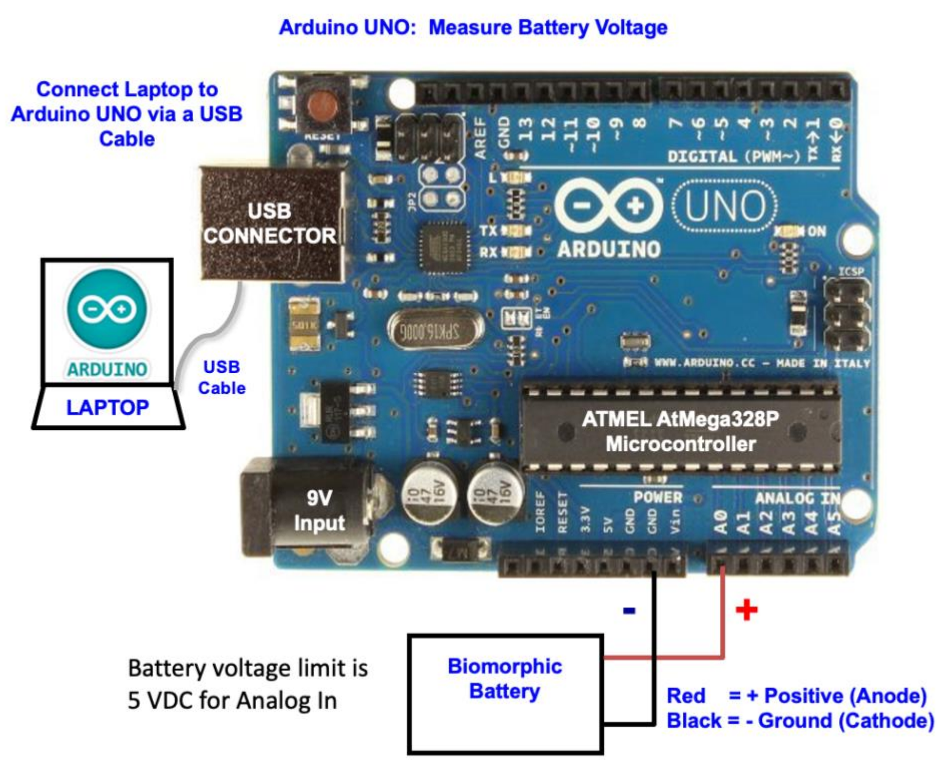


Fig 6: The Arduino to measure the battery voltage.

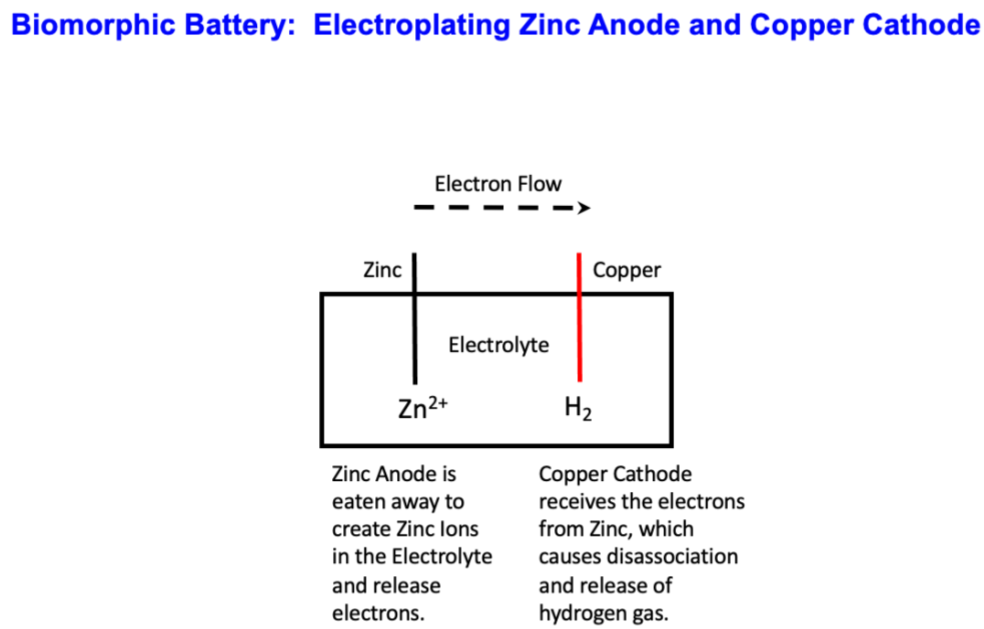
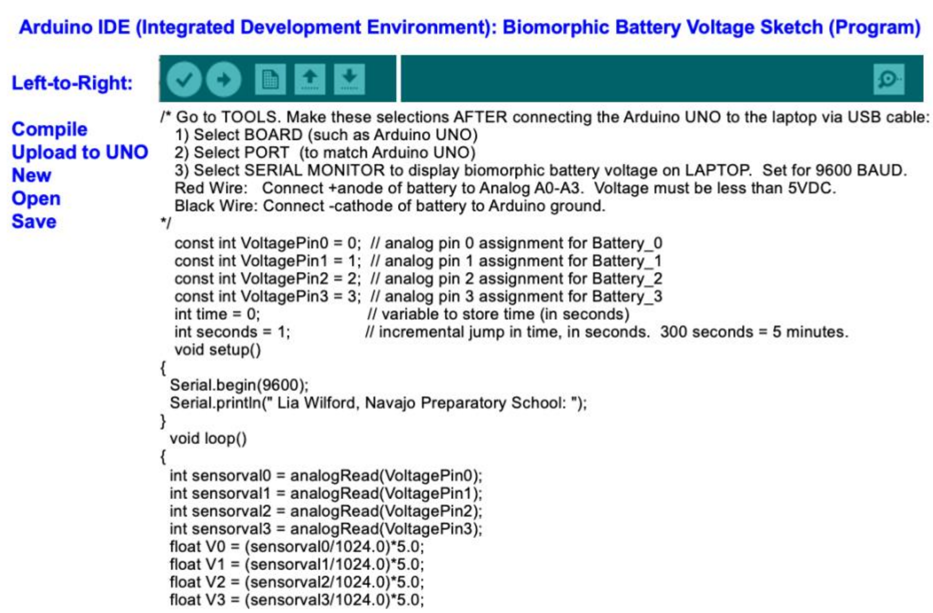


Fig 7: The electroplating Zinc Anode and Copper Cathode.




```
/* Go to TOOLS. Make these selections AFTER connecting the Arduino UNO to the laptop via USB cable:
  1) Select BOARD (such as Arduino UNO)
  2) Select PORT  (to match Arduino UNO)
  3) Select SERIAL MONITOR to display biomorphic battery voltage on LAPTOP.  Set for 9600 BAUD.
  Red Wire:   Connect +anode of battery to Analog A0-A3.  Voltage must be less than 5VDC.
  Black Wire: Connect -cathode of battery to Arduino ground.
*/
  const int VoltagePin0 = 0;  // analog pin 0 assignment for Battery_0
  const int VoltagePin1 = 1;  // analog pin 1 assignment for Battery_1
  const int VoltagePin2 = 2;  // analog pin 2 assignment for Battery_2
  const int VoltagePin3 = 3;  // analog pin 3 assignment for Battery_3
  int time = 0;                // variable to store time (in seconds)
  int seconds = 1;             // incremental jump in time, in seconds.  300 seconds = 5 minutes.
  void setup()
{
 Serial.begin(9600);
 Serial.println(" Lia Wilford, Navajo Preparatory School: ");
}
 void loop()
{
 int sensorval0 = analogRead(VoltagePin0);
 int sensorval1 = analogRead(VoltagePin1);
 int sensorval2 = analogRead(VoltagePin2);
 int sensorval3 = analogRead(VoltagePin3);
 float V0 = (sensorval0/1024.0)*5.0;
 float V1 = (sensorval1/1024.0)*5.0;
 float V2 = (sensorval2/1024.0)*5.0;
 float V3 = (sensorval3/1024.0)*5.0;
```

Fig 8: The code for the Arduino UNO.

These are extra tables from the replication experiment of the biomorphic battery from this investigation.

Table 7 - Total Average of Volts without Recycle Use

		Trial 1	Trial 2	Trial 3	Total Average
Porous plant type	Grams	Volts	Volts	Volts	Volts
Pumpkin stem	0.5g	0V	1V	1.77V	0.92V
Squash stem	0.5g	1V	1V	1.1V	1.0V
Sunflower stem	0.5g	0V	1V	1.5V	0.83V
Corn cob	0.5g	2V	1V	1.55V	1.51V
Duracell Battery	7.4g	12V	12V	12V	12V

Table 8 - Table with the voltage and the recycle use

		Trial 1		**Trial 2**		**Trial 3**		**Average**	
Porous plant type	**Grams**	**Recycle use**	**Volts**	**Recycle use**	**Volts**	**Recycle use**	**Volts**	**Recycle use**	**Volts**
Pumpkin stem	0.5g	3	0V	3	1V	3	1.77V	3	2.77V
Squash stem	0.5g	3	1V	3	1V	3	1.1V	3	3.1V
Sunflower stem	0.5g	3	0V	3	1V	3	1.5V	3	2.5V
Corn cob	0.5g	3	2V	3	1V	3	1.55V	3	4.55V
Chemical-battery type	**Grams**	**Recycle Use**	**Volts**	**Recycle Use**	**Volts**	**Recycle Use**	**Volts**	**Recycle Use**	**Volts**
Duracell Battery	7.4g	3	12V	3	12V	3	12V	3	36V