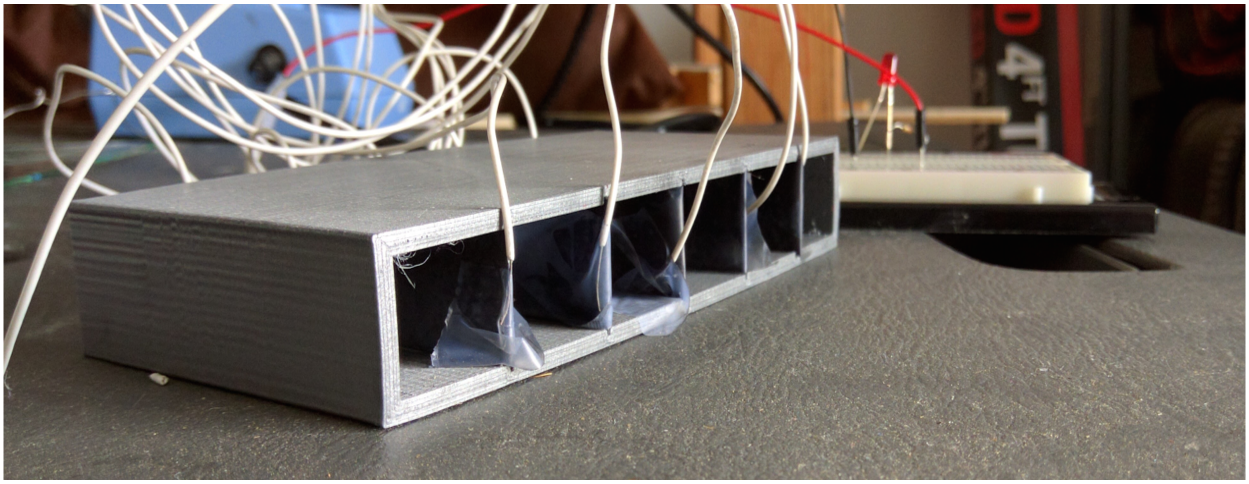

Multilayer Graphene Based Energy Harvester

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Table Of Contents

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There is a lack of sustainable energy technologies which are efficient, and more importantly, cheap. In order to solve this problem, the unique topological and electrical properties of graphene were used. First, a cheap method of synthesizing graphene was investigated, and the most efficient process involved the sonication of graphite flake powder in a water-heptane interface. Next, a structure to hold the graphene was designed and 3D-printed using the four design requirements: scalability, power output, shape, and cost. Finally, real world simulations in a saltwater tank were conducted, and results were measured using a LED bulb and a multimeter. Multiple test configurations were run: electrodes covered, electrodes uncovered, and various speeds in both conditions. After recording the data from the tests, it was clear that the voltage outputted was linearly proportional to the velocity of the fluid over the graphene plates. Also, the five graphene plates were able to provide enough voltage to power a 3 volt LED bulb. The structure proved to be scalable with a reasonable cost of $14, fulfilling all four design requirements. In the tests with the electrodes covered, a miniscule amount of voltage was detected compared to the amount of voltage detected in the tests with the electrodes uncovered. Thus, the graphene sheets are load bearers and it is impossible to transmit the load into the wires if they are covered because of the weak connection between the wires and the plate. The project proved that the science worked and the structure can be scaled.

BACKGROUND RESEARCH

Our goal is to create a cheap, alternative energy harvester using graphene, an extremely thin allotrope of carbon. When graphene is exposed to an ionic solution, the electrons in the ionic solution move quickly through the graphene, generating electric current. As the coal reserves of the world will be consumed by 2088, according to Ecotricity, it is vital that a new form of electricity generation is created that can be produced without any CO_2 emissions, or any other harmful emanations. While alternative energy sources can help alleviate the problem, historically, they have not made any impact on the existing infrastructure. Traditionally, solar, wind, and nuclear plants are extremely expensive in terms of money, land, and resources. According to the Energy Information Administration, the overnight costs to run alternative energy plants is twice as much as tradition coal and natural gas plants. This research will transform the way that people will create electricity in the future. Scientifically, it is very important to create a structure that can harness electricity passively using graphene in a cost-effective manner. Societally, this technology will transform every industry, as coal will be replaced in all uses with electricity. Instead of using coal to produce electricity, every power plant in the world will be replaced with a graphene-based energy harvester. Smog free environments will finally be a possibility. Global warming will be drastically reduced as coal is phased out of power plants and factories.

We have three major engineering goals. The first is to successfully synthesize a graphene sheet on a glass substrate and have the graphene sheet stick to the glass without any damage or tear. If possible, the graphene layers should be one to four layers thin without any surface damage to increase electron mobility to the maximum limit. Our second engineering goal is to design a structure that is capable of prolonged underwater exposure without erosion, deterioration, or damage to the graphene sheets or the electronics inside. This is because the structure will harvest energy by being submerged in an ionic solution, which will result in the passive generation of electricity. Our third and final goal is to test the structure for electricity generation in a medium of salt water similar to that found in the ocean, which will include a mixture of salts and other ionic substances. Depending on test results, we will make modifications until the design is producing its maximum electricity output. After this we will take it to the San Francisco Bay to perform a real world test. We expect that our design will generate a reasonable amount of electricity, which when scaled up, will be enough to power a small town. Over time, after scaling, this will cause a huge societal impact by transforming the way we produce electricity.

MATERIALS

1. Graphite Flake Powder 325 millimeter mesh
2. 97% pure n-Heptane
3. Bath Sonicator
4. 15ml Water
5. 3D printed structure
6. Wires
7. Soldering Iron
8. Soldering Metal

PROCEDURE

1. **Preparation of Graphene Sheets**
    a. We will add 15 milligrams of fine graphite silica powder to a small glass jar. We will then use a sonicator to bath sonicate the powder in order to break up any of the larger graphite chunks into a fine grain. The sonicator essentially uses sound energy, through vibrations, to agitate the particles present in the powder or even in a solution.
    b. For this step, heptane is needed. 30 milliliters of the heptane inside Bestine, a commercial plastic cement thinner, should be added to the sonicated graphite powder. We will then sonicate this mixture again for 15 minutes at the highest vibration level.
    c. We will add 30 milliliters of distilled water to the mixture. Note that it is important that the heptane to distilled water ratio remains 1:1. Also, the heptane, which has a lower density than water, will settle at the top of the mixture, while the distilled water, which has a higher density than heptane, will settle at the bottom. The graphite powder will remain in the center of both solutions. We will then bath sonicate the mixture again for 30 minutes.
    d. After the 30 minutes have elapsed, the graphene will have formed and will be resting on the top layer of the mixture (the heptane). Then, we will take a hydrophilic glass slide and insert it into the glass jar to extract the graphene from the mixture. Because of the nature of the heptane-water interaction, the graphene will climb up both sides of the hydrophilic glass slide and stick to the surface of the glass.
2. **Building the Structure**
    e. We will make a 3D model of the structure, which is essentially a rectangular prism with a hollowed inside and grooves that are spaced out evenly. After the CAD is completed, we will then 3D print out the structure at our school as an initial prototype for testing.
    f. We will also add electrical wiring and other components into a compartment beneath the actual harvester itself.
    g. After thorough computerized structural analysis to find any weak points in the design, we will print the model out of plastic using a commercial 3D printing service as our final prototype.
    h. Next, we will prepare our graphene slides by adding a strip of copper to each side of the slide. In addition, the grooves on the structure will be lined with a thin copper strip to harness the electricity being generated.

i. After extensive testing in simulated real world environments and real world tests, we will reevaluate the original design and make any corrections needed to improve the structural integrity of the design.
j. If after repeated trials using the 3D printed structure fail. We will replace all plastic components with metal bars and components and retest in real world and simulated conditions.

Risk and Safety:

Because graphite silica is an extremely fine powder, it is dangerous to inhale as it may lung inflammation. Therefore, we will wear gas masks to prevent accidental inhalation. We will also wear safety goggles to prevent any liquid vapor from entering our eyes. Because heptane can cause minor burns, we will wear latex gloves which prevents skin contact. Additionally, we will have a trained scientist supervising us at all times.

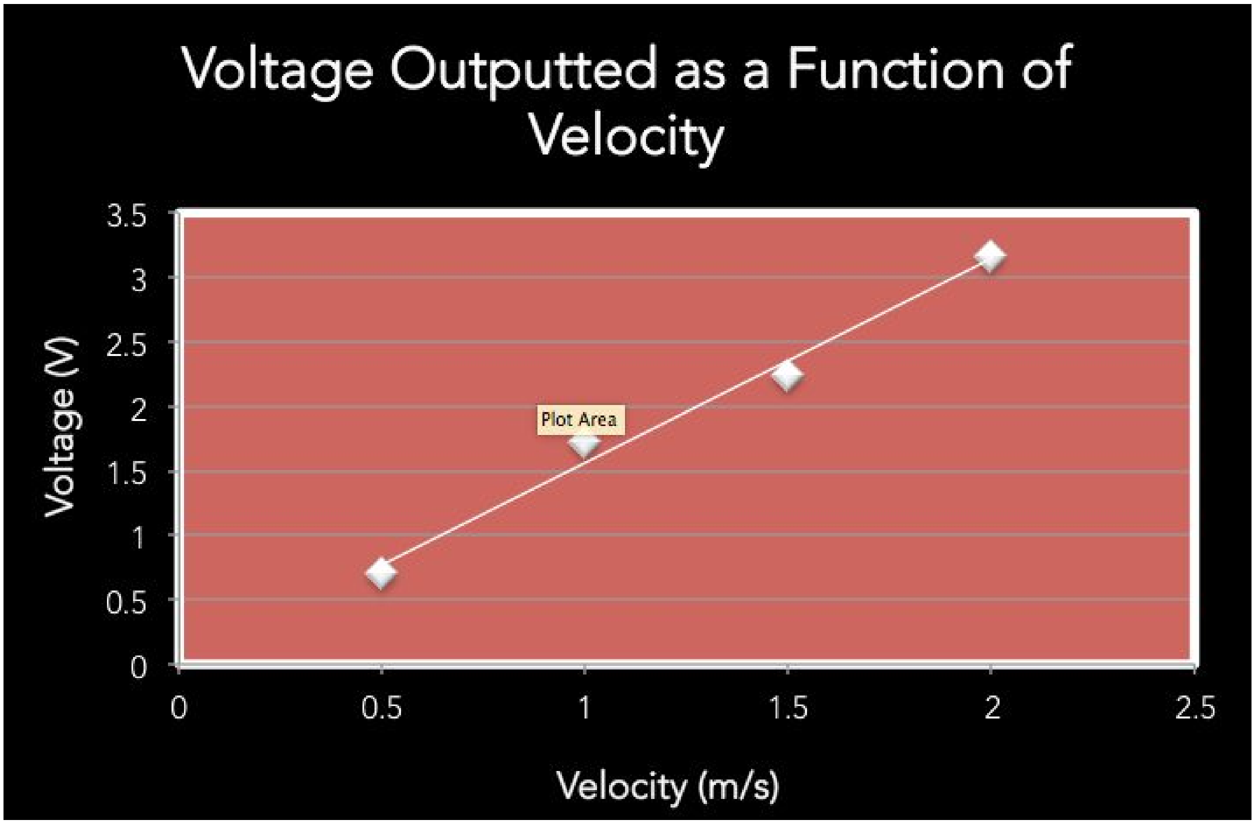
DATA ANALYSIS

Our data analysis includes recording the amount of energy the harvester produces based on three variables: size of the harvester, time, and number of graphene slides. Based on the electricity produced, we will determine if there are any structural improvements we can make to increase our electricity output by testing those variables. Also, we will calculate the amount of energy required to power a 40W light bulb by scaling up the energy produced based on the number of graphene sheets in the structure.

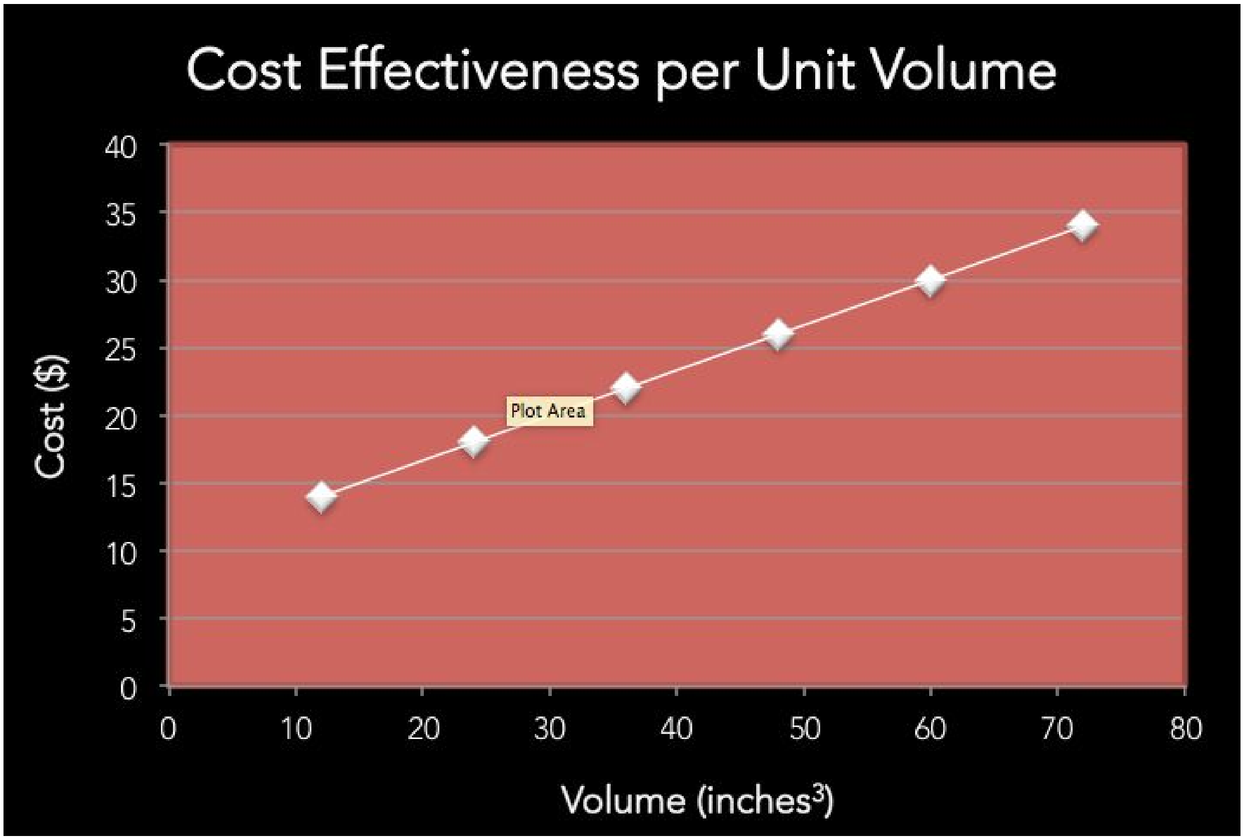
As per the research paper (by Steven Woltornist) that originally discussed the possibility of generating electricity from graphene sheets, we found that graphene does, in fact, generate a small voltage when it is passed through an ionic fluid (in this case, a solution of normal table salt and water) at fast speeds. The data presented in the paper showed a strong linear correlation value of .93. As the velocity of the structure in the solution increased, there was an increase in the amount of voltage generated, with a strong linear correlation, indicating that velocity of the moving water has a directly proportional relationship to the voltage outputted. The data showed us that the linear correlation would most likely be present in our data as well, shown by the graphical interpretation. In order to make sure that the voltage that we found through our testing was in fact coming from the saltwater and not any external sources, we compared our results to those found in the paper and we got a nearly exact match.

In the paper, the authors discussed how it would be very difficult to scale up the process to any reasonably manufacturable product because of the high cost and difficulty of producing high cost graphene. In our project, we found a way to produce lower cost, higher yield graphene without reducing the purity of the graphene. However our biggest insight in the project was realizing that the electrodes should not be covered. While testing the project multiple times, we kept getting, nearly exactly, two-fifths of the current which we were expecting. Upon very carefully examination of the prototype, we realized that the electrodes were covered for three out of the five plates and the tape had come off slightly for the other two. After trying again without covering the electrodes, we came to the conclusion that covering the electrodes would nullify the effect of the graphene electricity generation. The conclusion that we came to after this, is the graphene acts as a load bearer. The electricity generated by the salt water puts a load on the graphene and the load is passed into the wires. If the wires are covered, it would be impossible for the graphene to transmit the load into the wire, making the system useless.

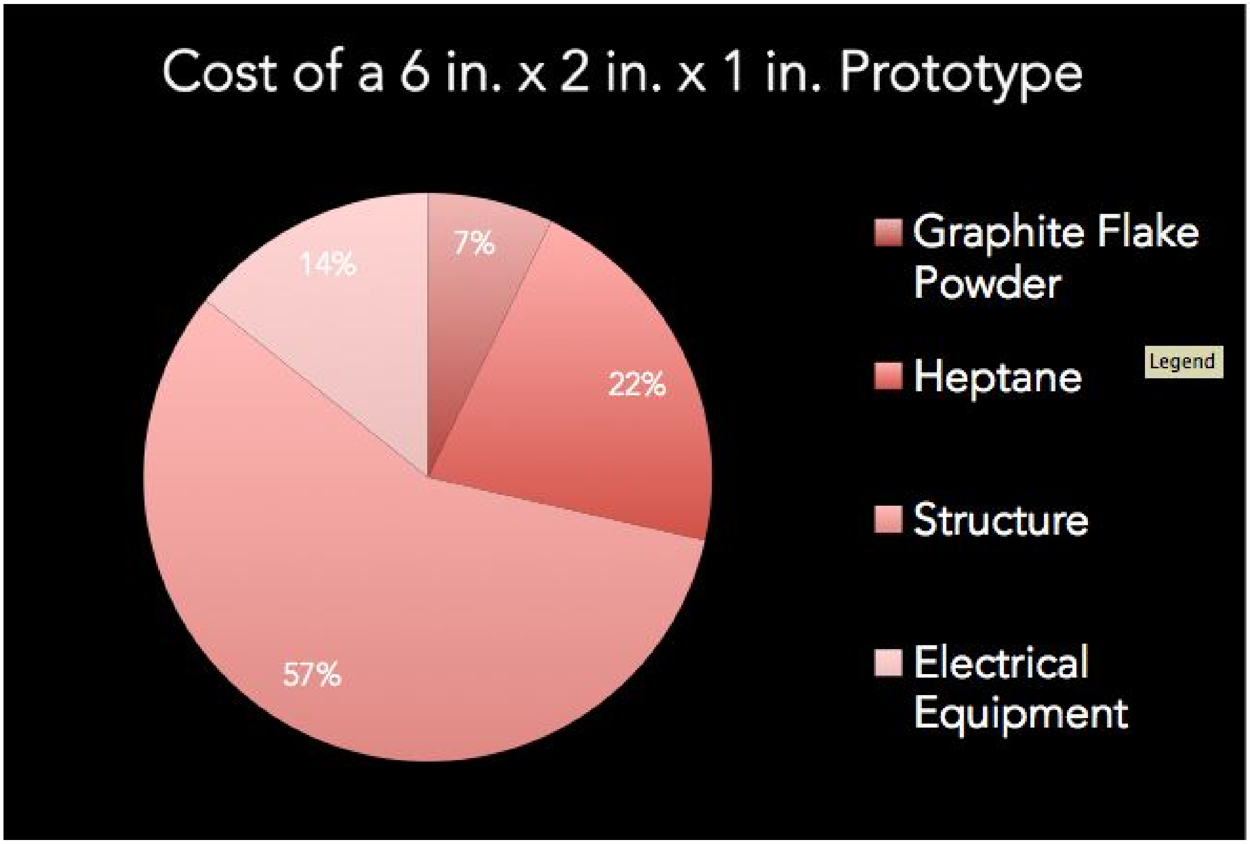
Graphs



Description: This is a graphical interpretation of data we recorded in which we manipulated the velocity at which the structure moved through the ionic fluid. As can be seen by the strong linear correlation, an increase in velocity increases the voltage outputted.



Description: Using our original dimensions for the prototype, we were able to estimate the costs of structures with larger volumes. We made these estimates based on the assumption that the larger 3D printed prototypes will have the same costs within a certain range, and that the consumable materials (refer to pie chart) increases proportionally to the volume.



Description: The 6 in. x 2 in. x 1 in. prototype has 4 components that contribute to its price. 3D printing the structure itself costs $8. The heptane costs $3. The electrical equipment (wiring, circuit board, etc.) costs $2, and the graphite flake powder costs $1.

CONCLUSION

The goal of our structure is to provide a cheap, alternative way of harnessing the electrical energy produced by graphene when exposed to an ionic fluid. Scalability was one of our biggest design requirements, which had to be addressed while researching this problem. We have designed the structure such that it is able to hold multiple slides of graphene that are equally exposed to the same amount of ionic fluid, and additionally, more slides can be added to the structure by reducing the space between two slides. Furthermore, the structure can be placed in stacks when scaled to a bigger size. The power output design requirement was addressed by the increase in velocity of the fluid. As the ionic fluid's velocity increases, the power output will increase, thus adding to the relative energy mass. The structure was also designed so that it wouldn't hinder the flow of the ionic fluid, and therefore exposure to the graphene. Finally, the structure and the graphene slides took around $14 to make for a 6 in. x 2 in. x 1in. prototype. Scaling this prototype to a large model, **as shown by our graph**, would increase the amount of average voltage produced.

FUTURE

There is a major need for a device that does not use any fuel, land, and is very cheap. The graphene salt water generator does not use any fuel unlike a nuclear reactor, nor does it produce any waste like fossil fuels do. It does not use any land, unlike wind energy, and therefore won't have any public backlash against it taking up public land. It barely costs anything to make by hand, and in a factory setting, the structure will be extremely cheap to scale to bigger dimensions. This technology can provide a clean future for the world. But first, there needs to be major improvements in undersea engineering. It would be difficult, but not impossible, to make a large underwater electrical substation that could control many generators. Second, we would need to negotiate many agreements with local and federal governments because of the novelty of the product. Third, it must integrate into the current power grid. If all of these steps are carefully followed, we can use this structure that uses the unique properties of graphene to successfully provide a clean and cheap alternative to harvest energy.

BIBLIOGRAPHY

"Conductive Thin Films of Pristine Graphene by Solvent Interface Trapping."*ResearchGate*. N.p., n.d. Web. 11 Jan. 2016.

"Polymer/Pristine Graphene Based Composites: From Emulsions to Strong, Electrically Conducting Foams." *ResearchGate*. N.p., n.d. Web. 11 Jan. 2016.

"The End Of Fossil Fuels." - *Our Green Energy*. N.p., n.d. Web. 13 Feb. 2016.

Badr, Magdy, and Richard Benjamin. "Staff Draft Report. Comparative Cost of California Central Station Electricity Generation Technologies." (2003): n. pag. Web. 13Feb. 2016.

"Graphene Basics." *4 Great Methods to Make Graphene At Home, along with Graphene Basics*. N.p., n.d. Web. 13 Feb. 2016.

"Andrey V Dobrynin." *ResearchGate*. N.p., n.d. Web. 24 Feb. 2016.

"Graphene - What Is It?" *Graphenea*. N.p., n.d. Web. 24 Feb. 2016.

"Team Finds Electricity Can Be Generated by Dragging Saltwater over Graphene." *Team Finds Electricity Can Be Generated by Dragging Saltwater over Graphene*. N.p., n.d. Web. 25 Feb. 2016.

"Pouring Saltwater Over Graphene Generates Electricity." *Gizmodo*. N.p., n.d. Web. 25 Feb. 2016.

"Nanotechnology Primer: Graphene - Properties, Uses and Applications." *Nanotechnology Primer: Graphene - Properties, Uses and Applications*. N.p., n.d. Web. 26 Jan. 2016.

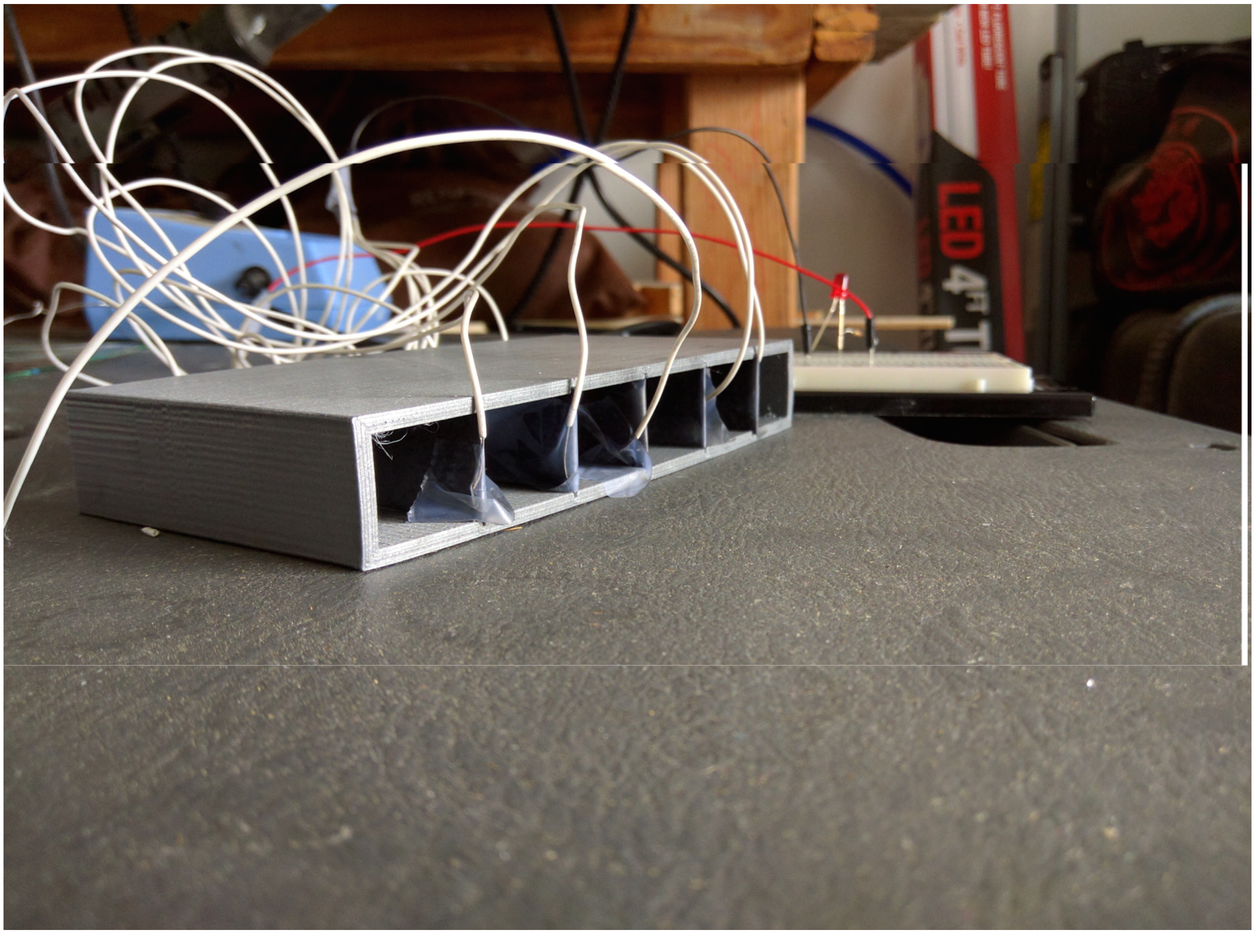
PICTURES

View of the Sonicator: This picture shows the sonicator providing energy to the interface in order to exfoliate the graphene layer.

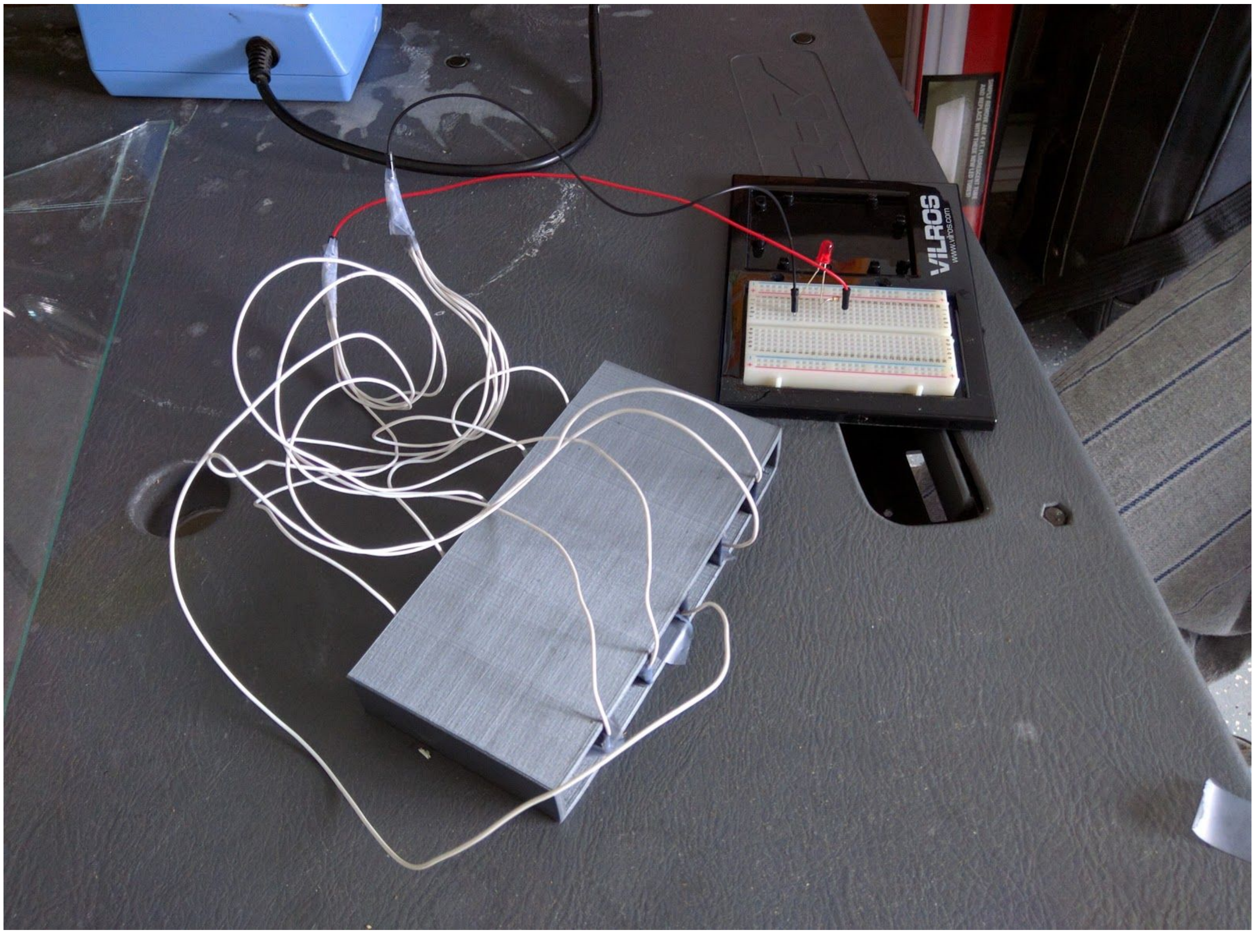
View of the individual graphene slide: This picture is a view of the harvesting plates themselves with the graphene on them.

View of the Glass Harvesting Jar: This picture shows the glass jar in which we synthesized the graphene using the sonicator. You can see the water-heptane interface with the graphene layer beneath it.

View of the Structure: This picture shows the 3D printed prototype without wiring or harvesting plates.

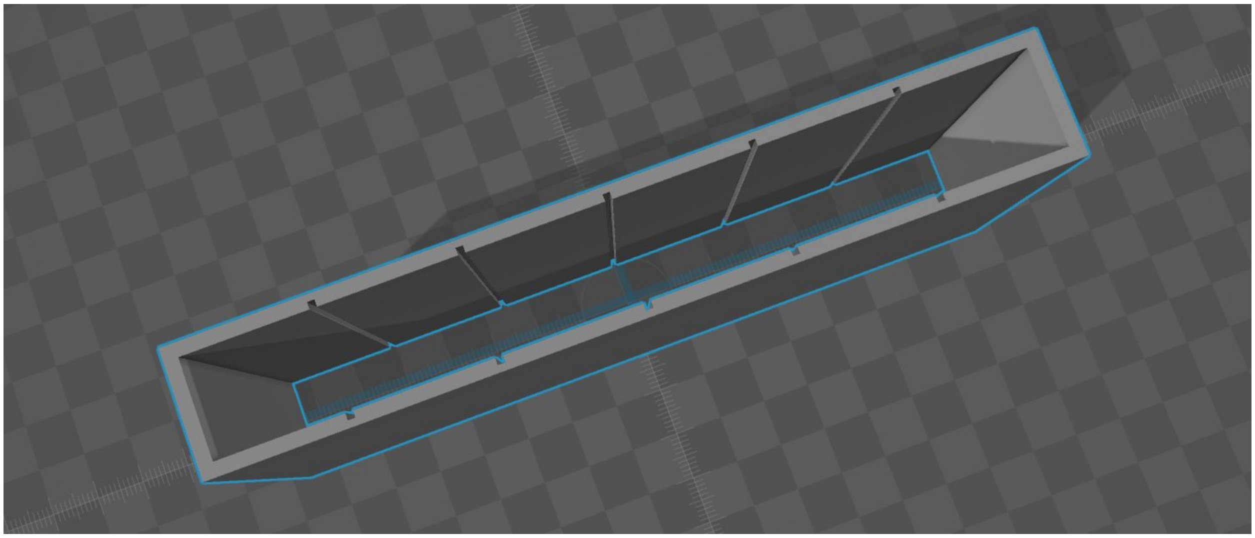


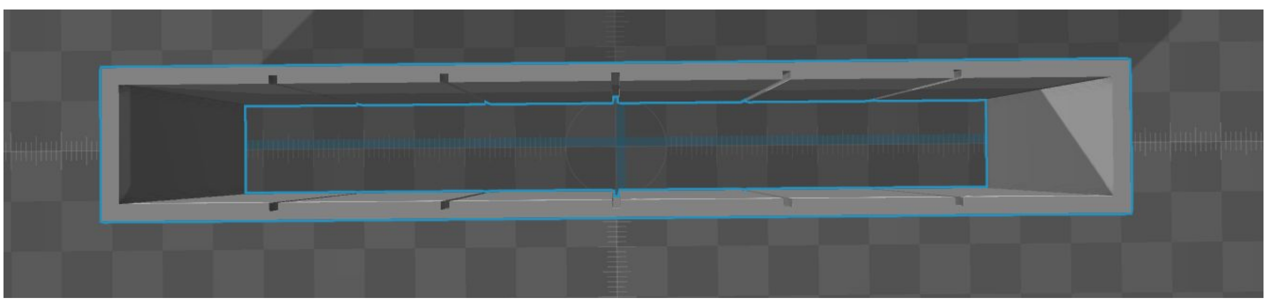
Side view of the harvester: This picture shows the positive wires on the harvester with the semi-exposed electrodes.



Top view of the harvester: These pictures show the entire harvester along with the test setup of the LED and the breadboard.

Pictures of CAD Model





Various Pictures:

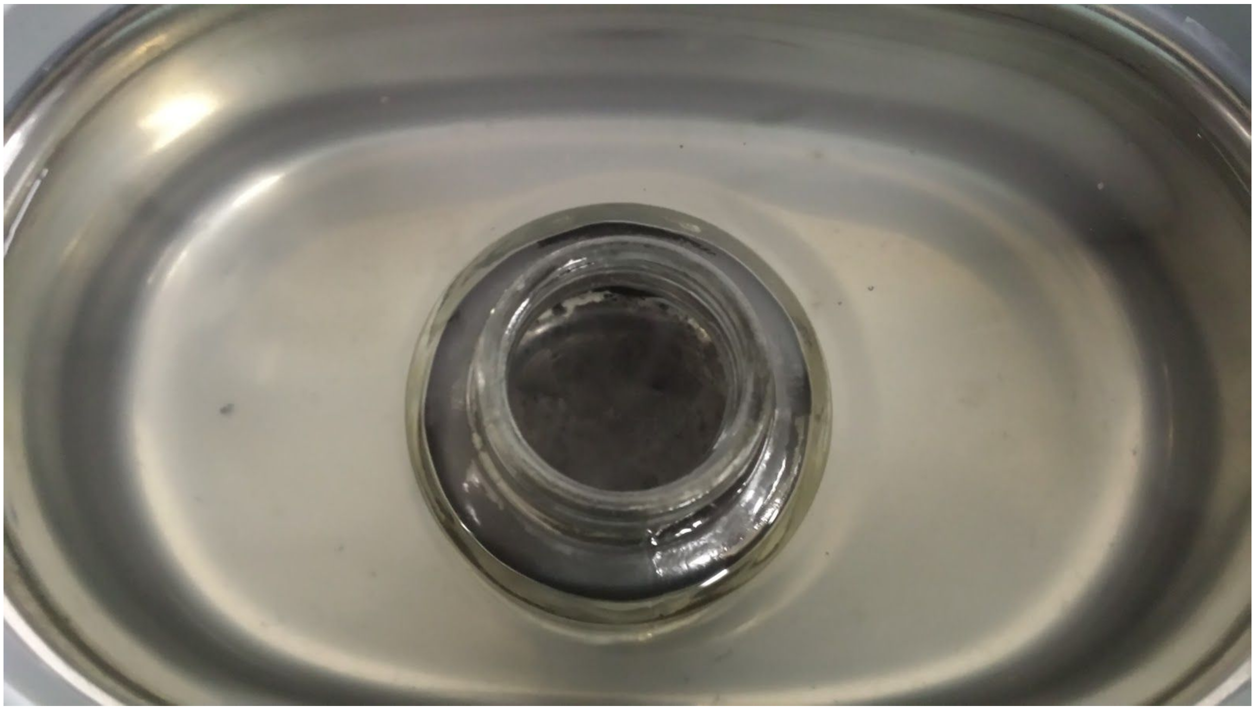
Description: Vial used in project.

Description: Vial with graphene layer.

Description: Vial with some graphene in it.

Description: Vial with graphene layer.

Description: Side view of the graphene on the side of the walls.



Description: Vial in sonicator

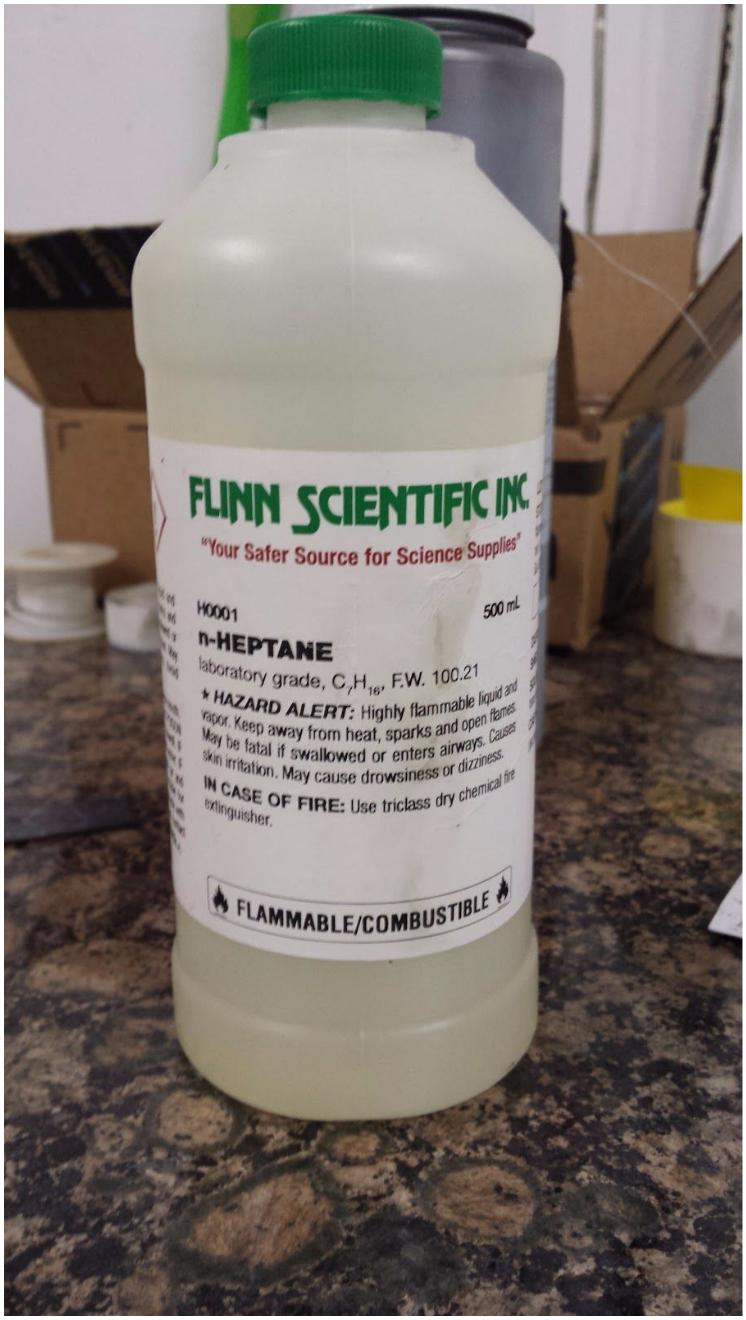
Description: Vial in sonicator

Description: Vial in sonicator.

Description: Smaller vial which we placed in the sonicator

Material Pictures

Description: Graphite Flake Powder which was exfoliated into graphene.



Description: 97% pure n-Heptane used with adult supervision to create the water-heptane interface.