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Hydropower from Gutters: Generating Electricity from Rainwater

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Bala Maheswaran is currently a senior faculty in the College of Engineering, Northeastern University. He has contributed and authored over one hundred publications consisting of original research and education-related papers, and conference proceedings. He has over twenty years of experience in teaching at Northeastern University. He is the Chair of the Engineering Physics Division, ASEE, Chair and executive board member, ASEE NE Section; the co-chair of TASME Conference (Technological Advances in Science, Medicine and Engineering, Toronto, Canada), Academic Member and the Unit Head, Electrical Engineering, ATINER (Athens Institute for Education and Research, Athens, Greece). A charismatic educator, Dr. Maheswaran has received several awards including the Northeastern University first-year Engineering Outstanding Teaching Award twice, the ASEE-Northeast Section Outstanding Teaching Award, the ASEE Division Distinguished Educator and Service Award. He was also the nominee for the ASEE National Outstanding Teaching Medal and nominated to be the ASEE Fellow. Honoring his outstanding contribution, the TASME presented an award in his name at the 24th year award ceremony: “Dr. Bala Maheswaran Junior Faculty Award 2020 for Excellence in Science Education”, and awarded him the Life Time Achievement Award in 2021.

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Abstract
As Earth faces the dual issues of climate change, caused in large part by the generation of electricity through methods that use fossil fuels, and a growing energy crisis, the world is searching for ways to produce renewable energy utilizing existing infrastructure. The kinetic energy of rainwater falling through gutters is a widely available yet untapped source of energy that could be used to generate electricity. No widely produced devices exist to harness this energy and convert it to electricity or some other useful form of energy. Our team focused on this development gap to create a system capable of generating electricity from this falling water. We sought to create a device that uses a water turbine, similar in principle to a hydroelectric dam, to convert rainwater into electrical energy that could be used to charge a battery or power lights. Our goal was to make this device small, efficient, and easy to install in existing rain gutter systems.

Our design uses a slanted slide to divert the falling water into our turbine, which utilizes a pelton water wheel to ensure peak efficiency. The water wheel is attached to a motor, which is used to generate electricity, and is housed within a box-shaped case. The case connects to the gutter attachment, which is 3D printed in a shape to fit into existing gutter systems. Our device is thus able to convert potential energy from rainwater into electricity and demonstrates a possible application of small scale hydroelectric generators.

This design provides many applications in the realm of engineering education, as it provides an introductory-level design project and solution with a design process that can be taught and applied in a wide level of introductory engineering education. This project exposed us to the fundamentals of problem solving, research, design, and construction and serves as a basis for further engineering research and development.

Introduction/Background

Since their introduction and spread during the Industrial Revolution, fossil fuels such as coal and oil have accounted for the majority of society's power generation. Although concerns about the sustainability of oil, gas, and coal reserves have raised questions about their future reliability, much of the current technological advancement in the green energy sector has been a result of evidence implicating their use as a primary factor in the ever-growing climate crisis.

As such, there has been an unmatched investment in the future of alternative sources of energy, such as wind, solar, and hydropower. These have led to massive improvements in every aspect of these technologies, especially cost and efficiency [1]. For example, according to the Department of Energy's National Renewable Energy Laboratory, the cost of a 200kW solar array has declined from 5.57 to 1.72 dollars per watt, a 69% decrease [2].

However, there are still many drawbacks to these technologies. Perhaps the most notable of these is the area that large scale projects, such as solar or wind farms or hydroelectric dams, take up. For example, while wind farms are more effective in areas near the coast, where strong winds are consistently available, half of the population of the United States lives in coastal areas, which uses land and severely limits where these wind farms can be built [3]. This dilemma of both high energy consumption in major coastal population centers and a low availability of space has led to an increasing demand for smaller scale projects and products that harness ordinarily wasted energy and make it available for reuse. Small scale hydroelectric power generation bypasses many of the issues facing its larger-scale cousin as it is not tied down to a particular location, does not damage the environment, and has comparatively low startup costs [4].

Almost all modern forms of electricity generation use rotational energy, whether it is using steam, such as in coal or nuclear plants, or the wind via large turbines. This means that the technology used in converting rotational energy into electricity via changing magnetic flux is well understood and that the infrastructure required to do so is widely available.

We chose to explore hydropower because of the ease of testing and widespread availability of untapped sources, specifically rain gutters. In addition, we considered that this application could complement existing technologies, such as solar power, which is notoriously ineffective during the cloudy rainstorms that our use case would run on.

Some existing small-scale hydropower generation systems include Rainergy [5], Pluvia [6]-[7], and triboelectric generators [8]-[9]. Rainergy collects rainwater in a tank, with the option to increase the area the rain is being collected from with a funnelike attachment. This collects water from a significantly lower area than a gutter-attached system, which would draw from an entire roof. Pluvia requires an entire gutter system to be installed because it includes a number of features including filters and gardening beds, making it impractical for homes with already existing gutter systems. Additionally, the energy is generated by pumping water through a microgenerator, which produces less energy than the pump consumes. Roof-based triboelectric generation would likewise require a substantial investment in infrastructure, especially given the high cost of triboelectric generation. A gutter based system would also be compatible with triboelectric generators, allowing for more energy to be produced as the water runs off of the roof.

Water running off of a roof has a large amount of gravitational potential energy, which is converted to kinetic energy as it travels down the gutter. Our paper seeks to determine the viability of harnessing this energy using a turbine hooked up to a DC motor to harness this oft-wasted source of energy.

Design Approach and Methods

When considering how we wanted to design our solution, we first came up with a set of objectives by which we would be able to judge any potential design approaches. We then set up these objectives to perform a rank order comparison to determine their relative weights. The matrix we used is in Table 1 below.

Objectives	Low Cost	Maintenance	Efficiency	Aesthetic	Ease of Installation	Simplicity	Sum of Row	Weigh t

Low Cost	--	0	0	1	0	0	1	4
Maintenance	1	--	0	1	0	0.5	2.5	6
Efficiency	1	1	--	1	1	1	5	10
Aesthetic	0	0	0	--	0	0	0	2
Ease of Installation	1	1	0	1	--	0.5	3.5	8
Simplicity	1	0.5	0	1	0.5	--	3	7

Table 1: Rank order comparison for our chosen design objectives.

The objectives we decided on are described below, in order of weight:

1. **Efficiency**. Because our goal was to generate electricity from previously untapped sources of energy, efficiency in generating this electricity was the most important objective we considered. Without efficiency, all of the other objectives were unimportant, so we chose to maximize this objective above all others.
2. **Ease of Installation**. As we describe above, it was important for our product to be easy to install in houses by anyone, including those without any engineering experience. Without being easy to install, the total power output of the few units that could be installed by us or other skilled engineers would be very limited. As such, we needed to focus on making ease of installation a priority so that any person could easily install one or more of our systems in their residence.
3. **Simplicity**. Similar to ease of installation, we decided that our product should be relatively simple, which makes it easier to install, produce, and maintain. Rather than having extremely complex valves or funnels that could become clogged, broken, and difficult to repair, we wanted our product to be simple and in relatively few parts, which would allow it to be more widely used.
4. **Maintenance**. We also wanted to keep maintenance to a minimum for our devices, which should allow them to run for an extended period of time without constant monitoring. However, as gutters do naturally have debris and other potential challenges that could require repair, we wanted our system to be easy to maintain so that, if our system did become clogged or otherwise broken, it would be easy and quick to fix without requiring additional parts.
5. **Low Cost**. Cost was an important objective, as we wanted to ensure that our product can be widely produced and available for typical homeowners to use. However, especially with our proof of concept initial prototype, this was one of the lower priority objectives we had, as functionality and use were more important. The cost can be reduced through mass production or slight refining of methods in the future.
6. **Aesthetic**. While we did want our product to look good, this was the least important aspect of our design, as functionality, ease of use, and even cost were all more important than how it would look on a gutter. We also did not expect our different designs to vary widely in terms of aesthetics, so this was the least important objective we considered.

After deciding on our specific design objectives, we started brainstorming different designs we could use. We were able to separate our project into three distinct categories, which would each have various options we could consider separately from the rest of the design. The first category was the funnel, which is the method by which we direct the relatively large area of the gutter water flow into a smaller, more controlled stream that we could target to hit our turbine optimally. The second category was the turbine itself, which is the device that would be hit by water falling through the gutter, producing torque on the turbine and converting the linear kinetic energy of the falling water into rotational kinetic energy. This would spin an axle to our generator that would produce electricity. The third category is the method of attachment to the gutter, which would determine how we connect our product to the gutters it would be installed in. The various design options we came up with for these categories are described below:

- **Funnel**
    - **Slide Funnel.** This type of funnel would cover only one side of the gutter and simply divert the water flow onto the other side of the gutter, leaving all of the water in a more controlled, smaller area.
    - **V-Funnel.** This type of funnel would divert water from the edges of the gutter into the center, which would direct the water into a more controlled flow that could be targeted correctly onto our turbine.
    - **Timed Release Siphon.** We also considered creating a separate module that would sit in the gutter above the main device and would act as a siphon to ensure that water never trickled down, but instead was stored until there was enough water to guarantee the turbine to spin. This device would fill until enough water was present, and then drain all at once.
- **Turbine**
    - **Water Wheel.** This type of turbine would have the flow of water perpendicular to the axis of rotation, like a normal water wheel. Water would fall vertically onto horizontal turbine blades, which would convert the kinetic energy into rotational motion.
    - **Vertical Screw Turbine.** This type of turbine would have the flow of water parallel to the axis of rotation, which would be vertical like a screw. The water would hit the blades wrapped around the center cylindrical axis, causing rotation.
- **Attachment Mechanism**
    - **Nested Attachment of Non-Gutter Material.** This gutter attachment would fit inside the gutter on the top and bottom and would be made from 3D printed material or some other material that did not come from a gutter. The attachment would be designed to slot inside the gutter and hold it by friction.
    - **Nested Gutter Attachment.** This type of attachment would have a similar function to the nested attachment described above, but would simply be made out of a piece of gutter permanently attached to our design, which would then fit into the gutter itself.
    - **Clamping Attachment.** This type of attachment would involve clamps or screws that would fit onto the ends of the gutter and would physically attach the gutter to the device, either by putting holes into the gutter or providing a direct frictional force between the design and the gutter.

After we brainstormed all of these design ideas, we created a decision matrix (Table 2) to decide which ideas to use, considering our objectives we had determined previously.

	Objectives	Low Cost	Maintenance	Efficiency	Aesthetic	Ease of Installation	Simplicity	
	Weights	4	6	10	2	8	7	
	Designs							**Sum**
Funnel	Timed release water	2	3	8	2	1	2	132
	V funnel	8	5	6	8	7	5	229
	Slide funnel	**8**	**8**	**7**	**8**	**7**	**8**	**278**
Turbine	**Water Wheel**	**8**	**8**	**7**	**6**	**7**	**8**	**274**
	Vertical Screw	3	5	4	8	5	5	173
Attachment to gutter	Nested attachment	8	8	8	7	7	6	272
	Nested attachment of different material	**7**	**7**	**8**	**8**	**7**	**8**	**278**
	Clamping attachment	5	4	4	2	4	3	141

Table 2: Decision matrix for potential design choices.

From this decision matrix, we decided on the components of our final design based on what had the highest score on our objectives.

These matrices are powerful tools that allow engineers to weigh various factors quantitatively and make informed decisions. As such, they are often one of the first techniques taught to novice engineers. This project offered an excellent opportunity to weigh multiple factors to evaluate our priorities in the design and thus what options were most likely to be effective.

We decided to use a slide funnel because of its simplicity, ease of installation, and a greater efficiency, as we thought that it would be more effective to have the water flowing at a slight angle when hitting the turbine to maximize power generation. We also decided against using a timed release siphon because of the extreme difficulty of installing a separate module at the top of the gutter, which goes against ease of installation, cost, and maintenance.

We decided to use a water wheel because it allows us to maximize torque given by the water by increasing the radius between the point of contact and the center of rotation on the turbine. This distance is relatively easy to change for a water wheel, but would be very limited by a vertical screw. Additionally, we thought that it would be much easier to capture the rotation of an axle that was going perpendicular out of the gutter, rather than having to install our system at the end of the vertical axle, which would be in the middle of the gutter.

Finally, we decided to use a nested attachment of a different material as our attachment mechanism, due to its ease of installation, simplicity, and overall efficiency. It is much easier to install a slip-fit attachment to a gutter rather than having to drill holes or clamp attachments to the gutter during installation.

Based on these initial design decisions, we created a first model for our design, seen below in Figure 1.

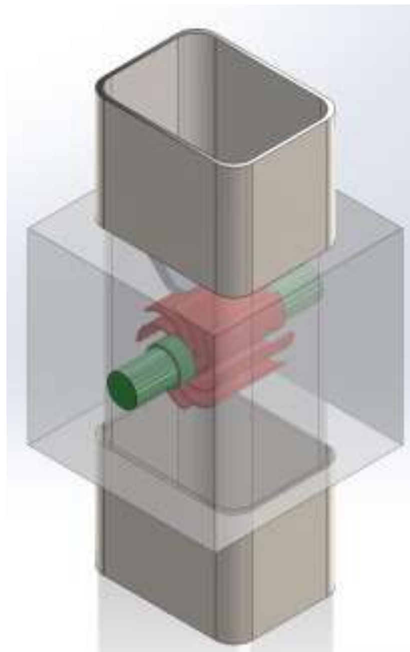


Figure 1: Our initial SolidWorks model for our design, based on our criteria and decision matrices.

Design Details

After determining what general components we wanted to have in our design, we started modeling the various components to determine exactly what we were going to make.

We did this using AutoCAD and SolidWorks, software suites we learned to use as part of Northeastern University's first year engineering curriculum. The powerful yet beginner-friendly and well-documented nature of these packages made it ideal for our design goals as novice engineering students. However, these are also software tools used by professional engineers, and as such our exposure to them during this project provides an excellent foundation for further exploration and learning.

We decided to make the top gutter attachment piece have a border around the edge sized to the outer size of a gutter, and then have a base that would hold the gutter in place. Since a typical gutter is 3in by 4in, we made our top attachment piece have the same interior dimensions in order for the gutter to slide into it. This piece was also made with an extended base around the bottom, which allows it to effectively fit into the top of the case. The 3D model for this piece is shown in Figure 2a. This section would also house the slide ramp, which would be attached using screws to hold it in place effectively. The slide ramp is 3.54 in. long (2.5 in. horizontally across) and is at a 45 degree angle. The slide is shown in Figure 2b.

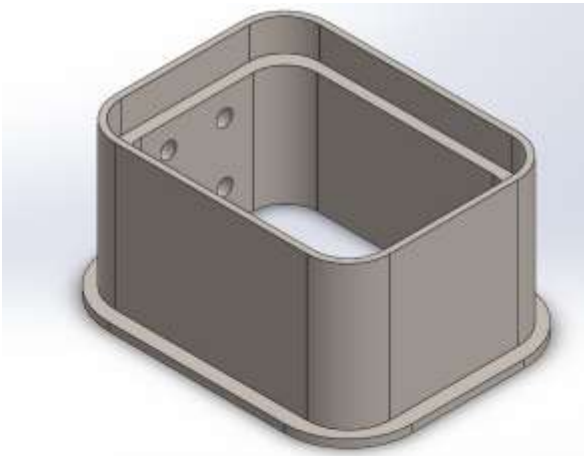


Figure 2a: The top gutter attachment.

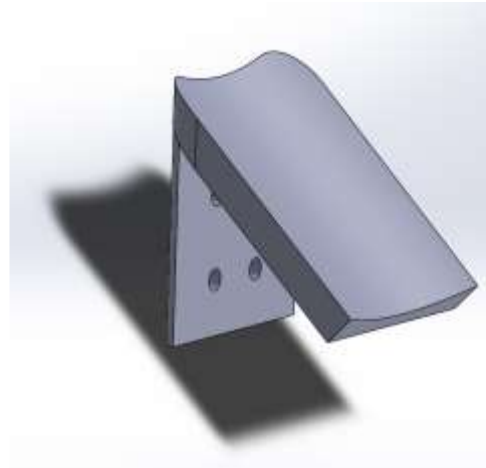


Figure 2b: The slide ramp.

For the bottom gutter attachment, we decided to use a much more simple insert that would simply slide inside the bottom gutter section, which would hold the product in place and hold it up through the strength of the gutter. This attachment is shown in Figure 3.

Figure 3: The bottom gutter attachment.

Figure 4: The axle.

For our axle, which connects our turbine to the gears that spin the motor, we decided to go with a D-shaped axle. This allows for us to use circular bearings rather than hex-shaped bearings, which are more easily available to us, and the flat section would still allow for the turbine hub to have a firm grip on the axle. The radius of the axle in Figure 4 is 0.25 in., which gives them the same interior diameter as the bearings, and it is 6in long. The flat edge, which makes it into a d-shape, is 0.20 in. from the center.

To hold the axle itself, we ordered bearings online, which would allow us to minimize friction while still having a structurally stable method of attaching the axle and turbine to the case. These bearings have an inner diameter of 0.5 in., an outer diameter of 1.125 in., and were 0.3125 in. thick. To hold these bearings in the case, we created inserts for both sides of the case. One insert had a hole in it, which would allow the axle to stick through that side and reach the gears and generator. The other insert was filled so it could hold the bearing in place. One of the bearings used is shown in Figure 5, and the two bearing-case attachments are shown in Figure 6a and 6b.

Figure 5: The bearing.

Figure 6a: The through-hole bearing attachment.

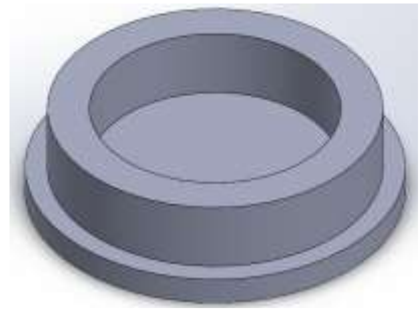


Figure 6b: The closed face bearing attachment.

For the case itself, we decided to make the six faces out of laser cut 0.125 in. thick acrylic sheets, which is easier and more efficient to make than 3D printed material. The overall dimensions of the completed case were 9 in. by 5 in. by 8 in. The top piece included a slot for the top gutter attachment, and the bottom piece included a smaller, but similar, hole for the bottom attachment and for the water to flow out. The two large side pieces had holes for the two bearing attachments described above. These six faces are shown in Figure 7 below.

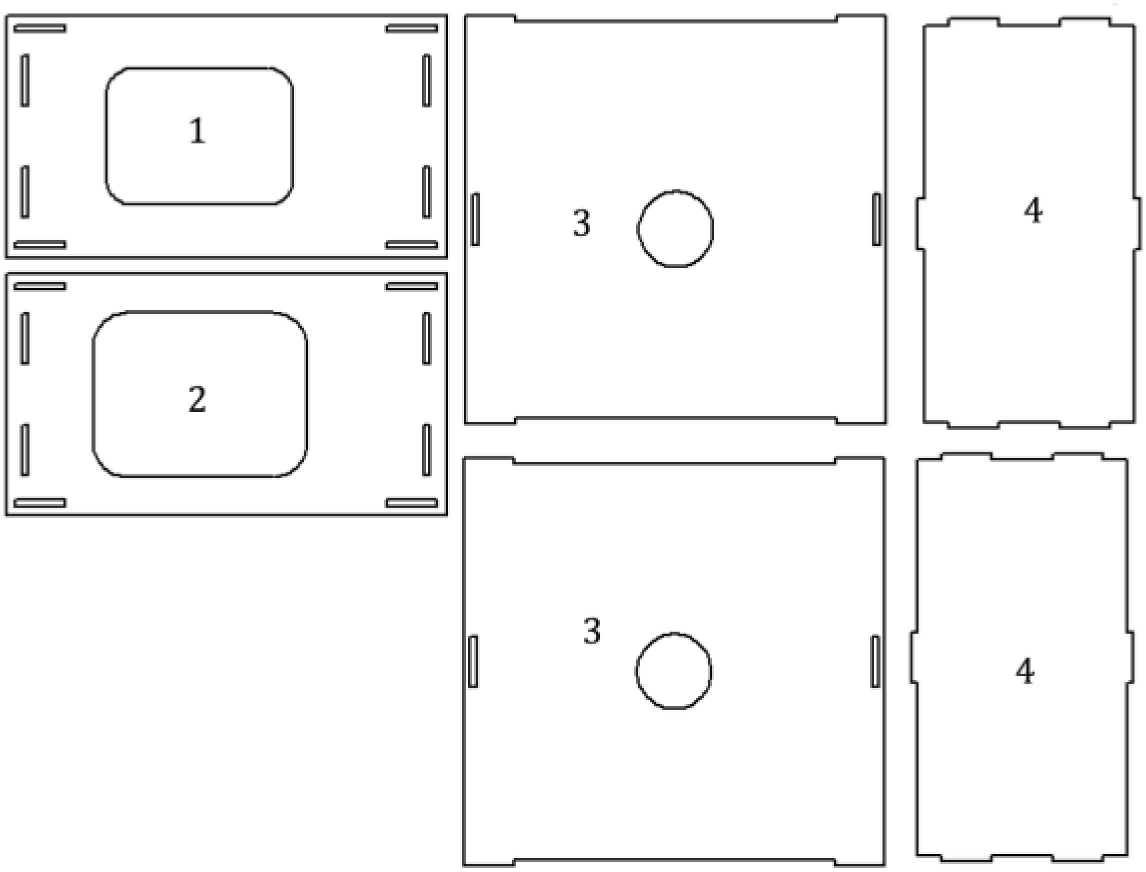


Figure 7: The laser-cut acrylic faces used to make our case. Piece 1 is the bottom, piece 2 is the top, pieces 3 are the two large side faces through which the bearings are attached and the axle goes through, and pieces 4 are the two small side faces.

For our turbine, we designed a pelton wheel to fit onto the axle and inside of the case, and we 3D printed six identical paddles to fit into corresponding slots in the hub piece that rests on the axle. A pelton wheel is an impulse turbine, one that generates energy from the impulse of water, rather than the mass of water, as in a waterwheel. It is among the most simple and efficient turbine designs, making it ideal for our use. The pelton buckets, which are shown in Figure 8a, are 2 in. by 3 in. at the top and have a height of 0.5 in. The rectangular extrusion from the buckets, which attaches them to the hub, is 0.4 in. by 1 in. and is 1.75 in. long. The hub piece, which is depicted in Figure 8b, is a hexagon with 6 sides of length 0.7 in. and a height of 1.50 in., and each of the six sides has a 0.4 in. by 1 in. opening that is about 0.25 in. deep. To fit on the axle, the hub has a hole with the same dimensions as that of the axle, that being an arc with a radius of 0.25 in. and a flat edge 0.2 in. from the center. The finished and assembled pelton wheel can be seen in Figure 8c.

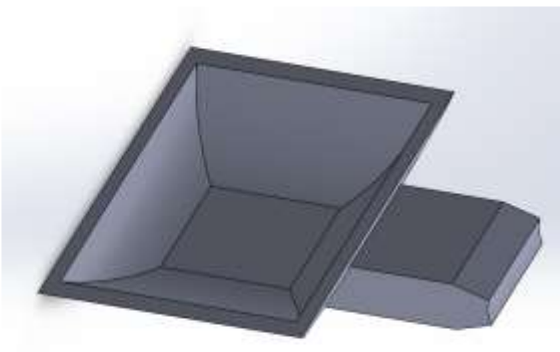


Figure 8a: One of the six identical pelton buckets.

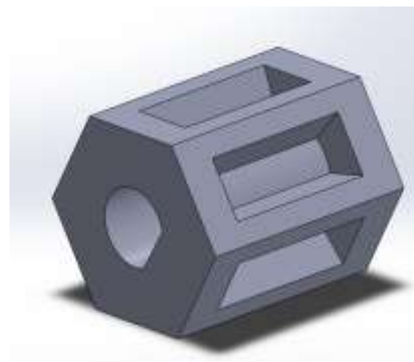


Figure 8b: The hub piece.

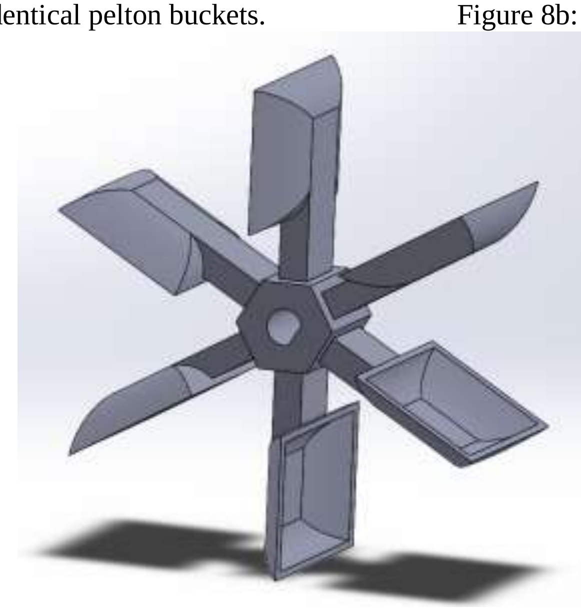


Figure 8c: The assembled pelton wheel.

For our gears, we decided to have our smaller gear fit on the axle, which is attached to the turbine, and our larger gear on the motor. This would allow us to have an overall gear ratio of 1:3 that would enable us to more easily spin the motor. The bigger gear, which attaches to the motor, is shown in Figure 9a. The smaller gear, which attaches at the end of the axle, is depicted in Figure 9b. We made the gears from the same acrylic sheets as we did the case.

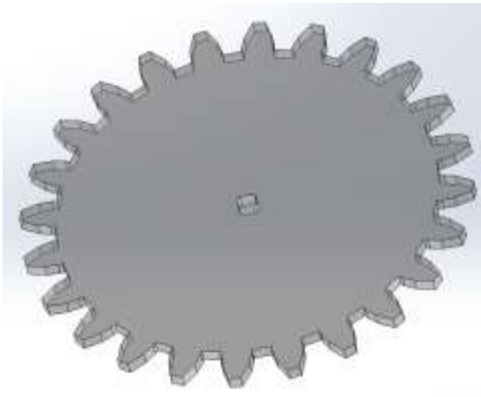


Figure 9a: The bigger gear.

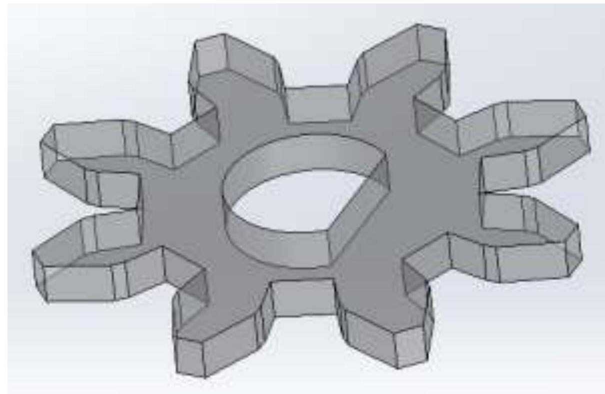


Figure 9b: The smaller gear.

For the electric motor/generator, we made use of a DAGU DG01D DC motor that we had in our SparkFun kits. While we could have purchased a different motor to use, this one was accessible to us and is widely produced.

We assembled all of these design components together in SolidWorks, as seen in Figure 10.

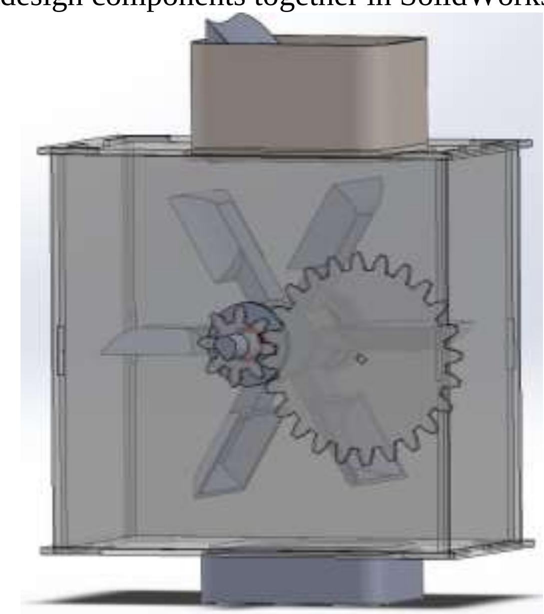


Figure 10: Completed SolidWorks assembly of our product.

To physically create all of these pieces, we used a combination of laser cut acrylic and 3D printed plastic. The case faces and gears were all laser cut from 0.125 in. thick acrylic sheets, while the gutter attachments, bearing attachments, turbine hub and blades, and axle were all 3D printed. We then attached all of the pieces together with hot glue, attached the motor to the edge of the case with the gears meshed, and inserted the axle into the bearings and bearing attachments. Our final assembled product is shown in Figure 11.

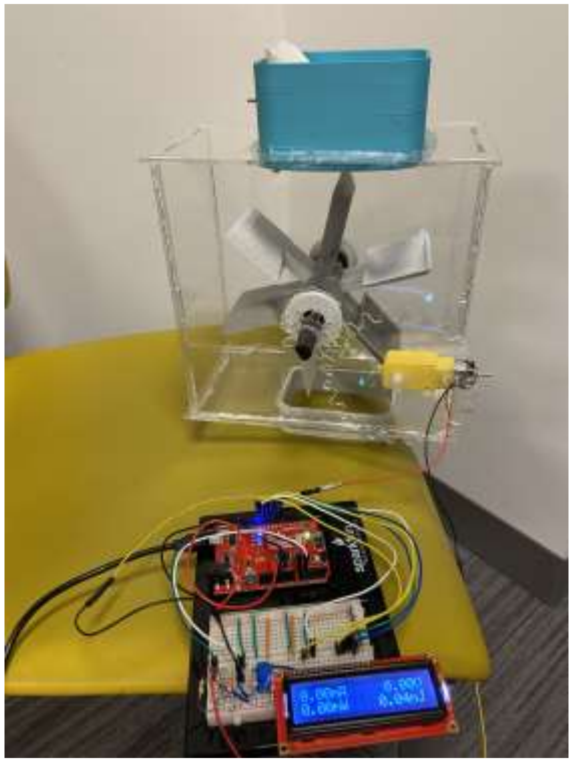


Figure 11: Final completed assembly and circuitry.

Data Collection Methods

To test our prototype, we initially would pour water into the opening at the top onto the slide, which gave us a sense of how our prototype worked and adjustments that could be made. Eventually, we began testing the prototype in a sink, which gave us a constant flow of water with consistent pressure that would flow to the same place. This allowed us to optimize the angle of the slide to ensure the most amount of rotation possible, which occurred when water would hit the very edge of the pelton buckets. The circuit we used to collect the data was designed as follows in Figure 12:

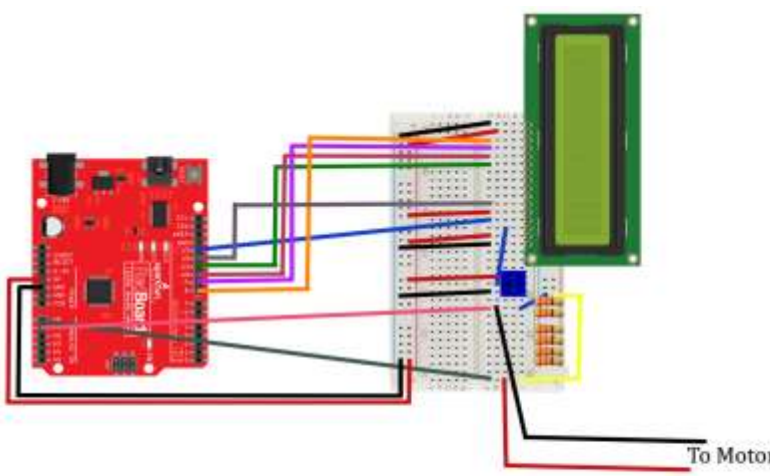


Figure 12: The circuit we created to measure the power output by the motor.

This circuit makes use of the SparkFun RedBoard, which is an Arduino board. Using the analog input pins (A0 and A1) on the board, we measured voltage across a set of parallel resistors. These resistors, in parallel, created a resistance of about 55 ohms. Based on the difference in these voltage readings, and using the known resistance values, we could calculate current, power, and total energy using the following equations:

$$V = IR \qquad P = VI \qquad E = Pt$$

We used Arduino code (Appendix 1) to read these values, calculate the current, power, and total energy, and then send those values back to the computer over serial and also display them on the LCD.

Arduino is a microcontroller platform frequently used by novices because of its simplicity compared to C/C++ while still maintaining fine control over hardware such as the GPIO. Using Arduino on the SparkFun board, another platform frequently used by novice engineers, was a great opportunity for us to learn about these technologies and how they can be used in engineering problems where circuit creation and device management are required. This was an excellent educational experience and was a great way to become more familiar with professional engineering skills.

We tested the flow rate of the sink we used by testing how long it took to fill up a one gallon jug: 2:21.13. This translates to a flow rate of 0.425 gallons per minute, which gave us a baseline for how efficient our generator was relative to flow rate. We then ran a series of tests using the sink and measured data using the SparkFun circuit, which collected the data and sent it back to a connected computer for us to process later.

Results

Two of the aforementioned trials were performed under a controlled faucet to get an accurate determination of the average amount of power that could be generated by our device. By measuring voltage in V and current in mA over time through the use of the SparkFun circuit, we were able to calculate the power being used at any point in time in mW, as well as the overall accumulation of energy generation in mJ.

An excerpt of the data we collected from the second trial is displayed in Table 3 to give an example of how the data was laid out after being collected from the circuit. The total data from both of the trials is too numerous to all be placed in this portion of the document. It can be seen that at each point in time, the current voltage, current, and power were all recorded. Additionally, the total energy accumulated over time is recorded and is constantly increasing as seen in the last column of the table.

Time (s)	Voltage (v)	Current (mA)	Power (mW)	Total Energy (mJ)
18.912	0.06	1.07	0.06	1.37
19.006	0.06	1.16	0.07	1.38
19.097	0.1	1.87	0.19	1.4
19.19	0.11	1.96	0.21	1.42
19.284	0.1	1.87	0.19	1.44
19.424	0.11	1.96	0.21	1.46
19.519	0.05	0.89	0.04	1.47
19.612	0.06	1.16	0.07	1.47
19.706	0.07	1.25	0.09	1.48
19.799	0.07	1.34	0.1	1.49
19.939	0.11	1.96	0.21	1.51
20.033	0.07	1.34	0.1	1.52
20.126	0.1	1.78	0.17	1.54
20.22	0.09	1.69	0.16	1.56
20.314	0.12	2.14	0.25	1.58
20.453	0.07	1.34	0.1	1.59
20.547	0.07	1.25	0.09	1.6
20.641	0.08	1.52	0.13	1.61
20.734	0.11	1.96	0.21	1.63
20.828	0.1	1.87	0.19	1.65

Table 3: A small excerpt of the data collected from Trial 2.

After we recorded the data for each trial, we plotted the total energy generated over time for Trial 1 and Trial 2 shown in Figures 13a and 13b, respectively. The first trial generated 7.23 mJ over a flow time of 60 seconds, while the second trial generated 7.29 mJ over the same amount of time, resulting in an overall average energy generation of 7.26 mJ between the two trials.

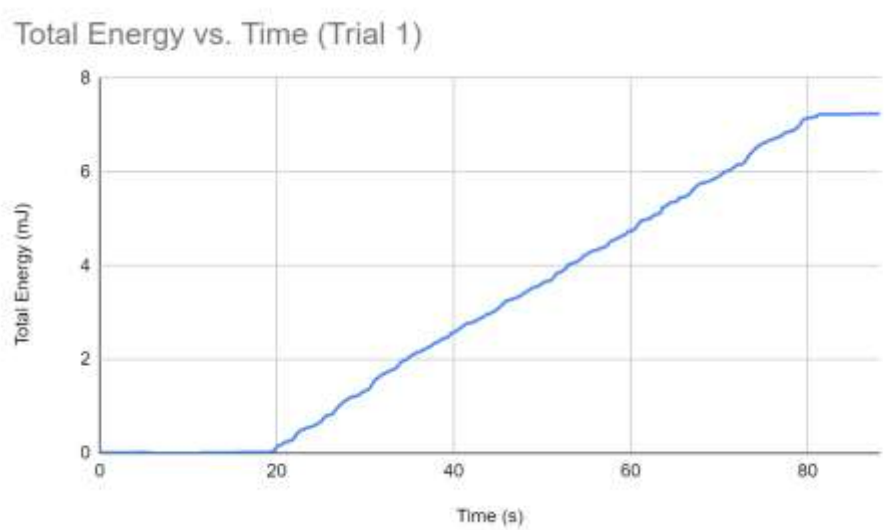


Figure 13a: Graph of Total Energy (mJ) vs. Time (s) for first sink trial

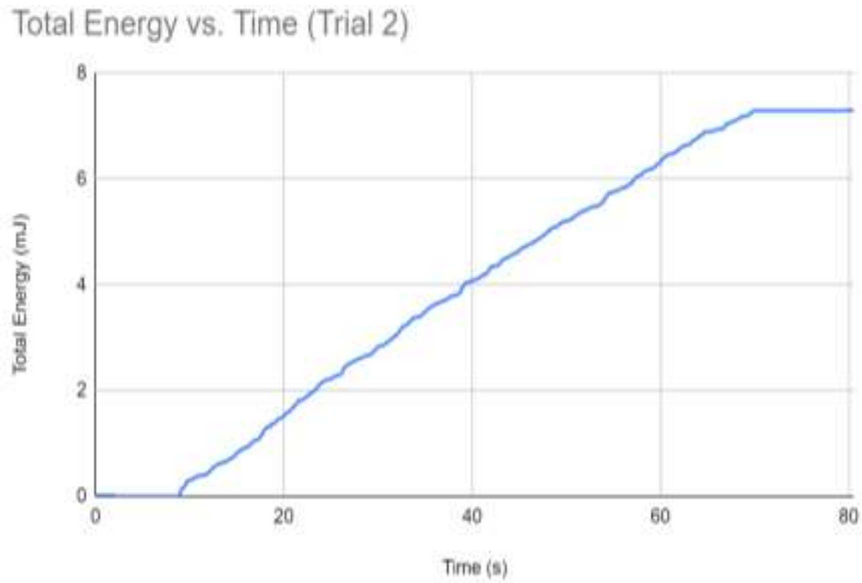


Figure 13b: Graph of Total Energy (mJ) vs. Time (s) for second sink trial

We also created plots of the voltage, current, and power over time for each of the two trials. It is important to note that these plots are trailing moving averages with a period of 10 for each of the data sets. These plots can be seen in Figures 7c through 7h.

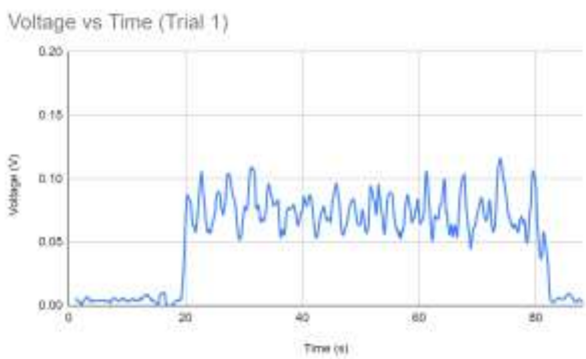


Figure 13c: Moving average of Voltage (V) vs. Time (s) for first sink trial

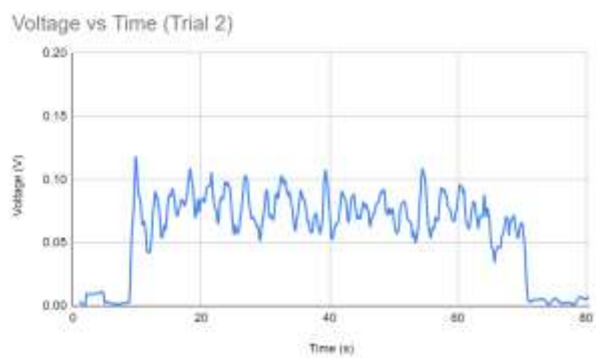


Figure 13d: Moving average of Voltage (V) vs. Time (s) for second sink trial

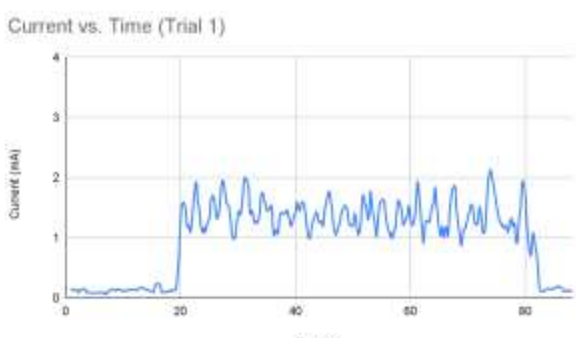


Figure 13e: Moving average of Current (mA) vs. Time (s) for first sink trial

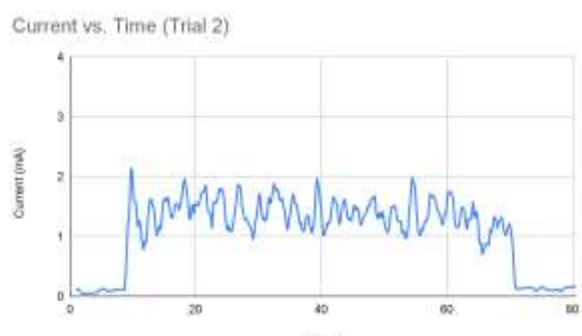
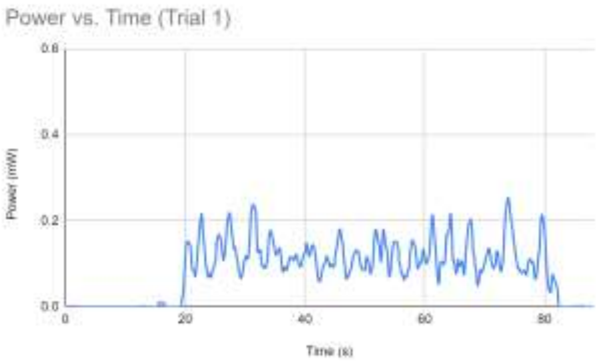


Figure 13f: Moving average of Current (mA) vs. Time (s) for second sink trial



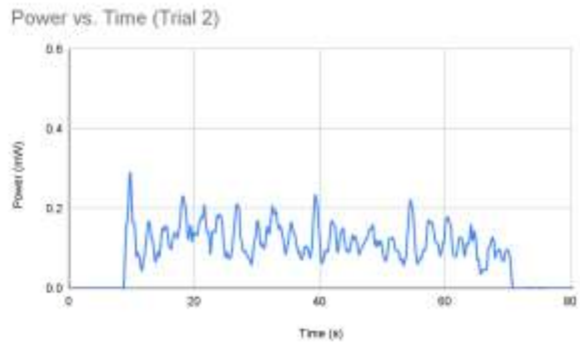


Figure 13g: Moving average of Power (mW) vs. Time (s) for first sink trial

Figure 13h: Moving average of Power (mW) vs. Time (s) for second sink trial

To have a better understanding of how much output can be expected from the device at any given time, an average of the voltage, current, and power of all of the active data points from Trials 1 and 2 were calculated. By active data points, we mean that all points outside of the sixty seconds in which the faucet was running were excluded from the calculations. The results of these calculations can be seen in Table 4.

Average Voltage (V)	Average Current (mA)	Average Power (mW)
0.075	1.385	0.122

Table 4: Average Voltage (V), Average Current (mA), and Average Power (mW), calculated from the data points of both trials

Discussion

The relatively low power output of this device is largely a result of the various limitations of the design that could be improved with additional resources, time, and design iterations. First, the SparkFun motor that was used as the power generator was used since it was an already available resource, and not because it was an optimal generator. More power output could be obtained with a generator that is optimized for the purposes of this project.

To get a sense of how an improved generator would increase our energy output, we experimented with the SparkFun motor to determine its efficiency as a generator compared to as a motor, which is what it was designed to do. We did this by testing the rotational speed required to generate a voltage and comparing this value to the rotational speed generated by providing the motor with a voltage. The results of this test are shown below in Table 5.

Input Voltage (V)	Output RPM
5	181
3.3	120
1.5	46
0.15	4.6 (expected)
Output Voltage (V)	Input RPM

0.15	12

Table 5: Results of voltage vs RPM testing on the SparkFun motor.

From this, we can see that we had to spin the motor 2.6 times faster to generate the same output voltage than we would have expected, as, based on our testing, we would have expected to spin the motor at 4.6 RPM to get the same 0.15 V output. Using Equation 1 below, we can scale our overall results using this value by multiplying the total energy output we got by 2.6^2 to account for the squared voltage in the energy equation. Using this correction, our energy output should have been 49.6 mJ on average for both of our sink tests.

$$E = \llbracket t * V \rrbracket \ \hat{}2/R$$

Equation 1: Energy (Joules)

t = time, V = voltage, R = resistance

We extrapolated our data to see how our device would perform during an average rainstorm. The average amount of rain during a three hour rainstorm in the northeast United States is 2.5 mm/h [10]. In addition, the average roof size for a house in the United States is 1,700 square feet [11]. Using this data, we calculated that the total amount of water that rains on the house per hour is 104.23 gallons. Dividing this number for four different downspouts on the house and converting the time to minutes gives a flow rate in each gutter of 0.434 gallons per minute. This number is very similar to the flow rate of the sink we used, which was 0.425 gallons per minute. The total amount of energy we generated at this flow rate for one minute was 7.26 mJ, so for three hours of use during the storm, each generator would output a total of 1.31 J.

The design could further be improved with a different approach to the funneling system used to collect the water together. The current slide funnel seems to significantly reduce the kinetic energy of the water when the water comes into contact with it. Finding another way to ensure that all of the water lands in the right place that is not so disruptive to the overall flow of the water would result in a higher efficiency.

It is also important to note that our testing involved the water flow being started only a few inches above the device. In a real-world situation, the water would be falling for many feet through the gutter before landing onto the turbine, meaning that there would likely be more kinetic energy at the time of contact with the turbine, also resulting in more energy generation than measured in our testing.

Relevance to Engineering Education

Our project can be widely applied in engineering education because of its focus on design principles and careful problem solving. As students, it was beneficial because it exposed us to the basics of problem solving and the engineering design process, since we found a problem, brainstormed ways of tackling it, decided on the best method, and executed it. Furthermore, the project also taught us valuable skills regarding fabrication, design, analysis, and technical writing. The project gave us a chance to further develop our CAD, research, and teamwork skills. This design also provides applications in the realm of engineering education. The project itself can serve as an introductory-level design project and solution with a design process that can be applied at a wide level of introductory engineering, allowing other students and aspiring engineers to get the same experience out of the project as us.

Conclusion

Our prototype proves that generating electricity using the rainwater from house gutters is possible. Although our energy output is low, there is much more potential energy to be captured. With more testing and a professionally fabricated product, it should be possible to generate enough electricity to successfully recharge batteries or other small items during large rainstorms. There are many places in the world with large amounts of rainfall that would greatly benefit from these small generators. This product can also be utilized in every downspout connected to a house, boosting the electricity generated. We hope that this research will contribute to the development of new technology to generate clean energy, moving our world away from its dependence on nonrenewable energy.

References:

[1] "Revolution...Now -- 2016 Update." Office of Energy Efficiency & Renewable Energy. https://www.energy.gov/eere/downloads/revolutionnow-2016-update (accessed Dec. 9, 2021)

[2] "Documenting a Decade of Cost Declines for PV Systems." The National Renewable Energy Laboratory. https://www.nrel.gov/news/program/2021/documenting-a-decade-of-cost-declines-for-pv-systems.html (Dec. 9, 2021)

[3] "Renewable Energy on the Outer Continental Shelf." Bureau of Ocean Energy Management. https://www.boem.gov/renewable-energy/renewable-energy-program-overview (accessed Dec. 9, 2021)

[4] "Hydropower explained: Hydropower and the Environment." U.S. Energy Information Administration. https://www.eia.gov/energyexplained/hydropower/hydropower-and-the-environment.php (accessed Dec. 9, 2021)

[5] A. Nazarli. "If You Can Make Energy from Wind, Why Not from Rain?" The Irish Times. https://www.irishtimes.com/news/environment/if-you-can-make-energy-from-wind-why-not-from-rain-1.3530666 (accessed Oct. 8, 2021)

[6] B. Brownell. "Pluvia Generates Energy from Rainwater." The Journal of the American Institute of Architects. https://www.architectmagazine.com/technology/pluvia-generates-energy-from-rainwater_o. (accessed Oct. 8, 2021)

[7] A. Levitan. "Rainwater Microturbines Purify Water, Make Some Electricity." IEEE Spectrum. https://spectrum.ieee.org/rainwater-microturbines-purify-water-make-some-electricity. (accessed Oct. 8, 2021)

[8] "New droplet-based electricity generator: A drop of water generates 140V power, lighting up 100 LED bulbs." ScienceDaily. www.sciencedaily.com/releases/2020/02/200205132354.htm. (accessed Oct. 8, 2021)

[9] R. Fearon. "Raindrop Electricity: Generating 'Blue Energy' from Rainfall." Discovery. https://www.discovery.com/science/raindrop-electricity--generating--blue-energy--from-rainfall. (accessed Oct. 8, 2021)

[10] M. Thorp, B. C. Scott. "Preliminary Calculations of Average Storm Duration and Seasonal Precipitation Rates for the Northeast Sector of the United States." *Atmospheric Environment*, vol. 16, no. 7, pp. 1763-1774, 1982, doi: 10.1016/0004-6981(82)90269-4.

[11] E. Fleming. "What is the average surface area of a roof?" SidmartinBio.org. https://www.sidmartinbio.org/what-is-the-average-surface-area-of-a-roof/ (accessed Dec. 9, 2021)

APPENDIX

Appendix 1: Arduino Power Generation Circuitry Code

```
const double resistance = 54.8; // Constant resistance value in circuit
const double delayTime = 100; // Time to wait between measurements

uint32_t prevMillis = 0;
double maxW = 0;
double totalJoules = 0;
#include <LiquidCrystal.h>       // the liquid crystal library contains commands
for printing to the display

LiquidCrystal lcd(13, 12, 11, 10, 9, 8);   // tell the RedBoard what pins are
connected to the display
void setup() {
  Serial.begin(9600);
  pinMode(A0, INPUT);
  pinMode(A1, INPUT);
  lcd.begin(16, 2);
  lcd.clear();
}

void loop() {
  double v0 = analogRead(A0) * 5 / 1023.0;
  double v1 = analogRead(A1) * 5 / 1023.0;
  double voltage = abs(abs(v0 - v1));
  if (voltage < 0.05) { voltage = 0;}
  double current = voltage / (resistance / 1000.0);
  double power = abs(abs(current * voltage));
  totalJoules += power * delayTime/1000;

  if (power > maxW) {maxW = power;}
  if (millis() - prevMillis >= 500) {
      prevMillis = millis();
      lcd.clear();
      lcd.setCursor(0, 0);

      lcd.print(printPad(String(current) + "mA", String(voltage) + "V", 16));
      Serial.println(printPad(String(current) + "mA", String(voltage) + "V", 16));
      lcd.setCursor(0, 1);
      lcd.print(printPad(String(power) + "mW", String(totalJoules) + "mJ", 16));
      Serial.println(printPad(String(power) + "mW", String(totalJoules) + "mJ",
16));
  }
  delay(delayTime);
}

// Prints nicely padded strings to the LCD
String printPad(String one, String two, int padLength) {
  String finalStr = one;
  finalStr += spaces(padLength - (one.length() + two.length()));
  finalStr += two;
  return finalStr;
```

```
}

// Generates strings of spaces for easier formatting
String spaces(int num) {
  String spaces = "";
  for (int i = 0; i < num; ++i) {
      spaces += " ";
  }
  return spaces;
}
```