Water Activated Low Torque Energy Rig

Energy and the Environment Senior Capstone

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ABSTRACT

As world electricity consumption increases and energy prices continue to rise, there is a growing need for affordable, clean power producing technologies. With this in mind, we set out to design a hydropower generator able to power small electronic devices and cheap enough to be affordable to some of the world's poorest communities.

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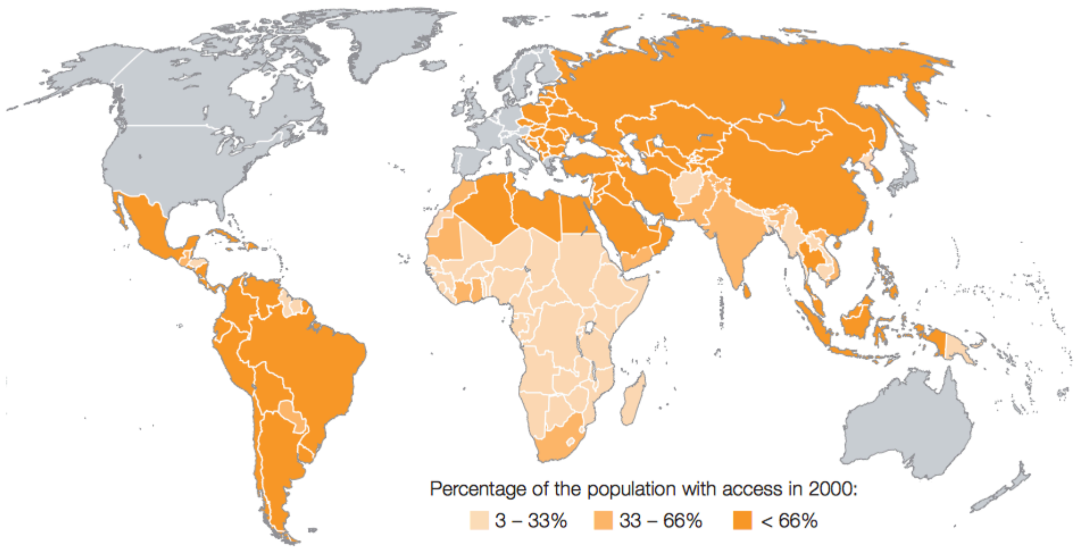
Introduction to the Problem

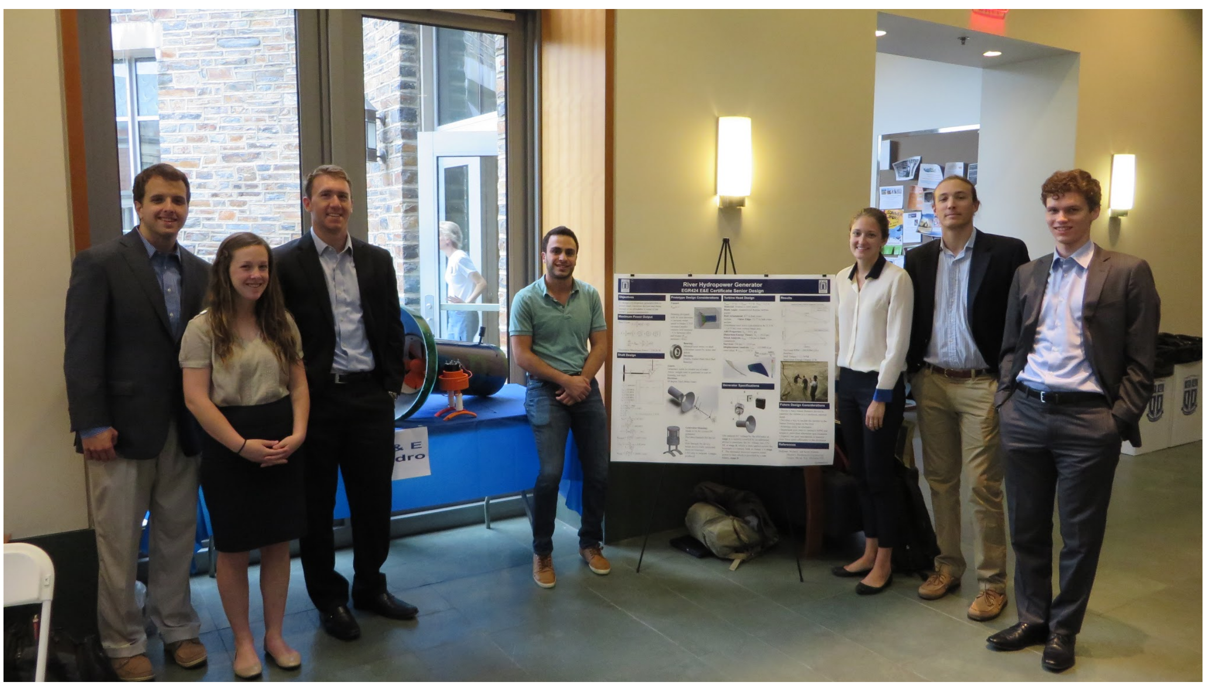
Electricity is the cornerstone of our modern, technologically dependent world. It powers our factories, lights our homes, and charges our iPhones. For most, it has become a basic necessity of life. Yet ready access to energy is still an important determinant of economic prosperity, with the richest, most developed countries generally having sophisticated, reliable power rods. While developing countries have made great strides towards electrification, approximately 1.5 billion of the world's poorest are still years away from being integrated into an electric grid. In many cases, supplying them with electricity is simply a matter of designing a technology flexible enough to be installed in often remote, rural settings and cheap enough to be affordable to these generally poor communities.



Source: World Bank

The idea, of course, is to base such a technology on principles of environmental sustainability. The rest of the world pollutes enough as it is that GHG emissions from power production has damaged the environment beyond repair, often impacting these poor, rural communities the hardest. Giving these people electricity-generating technology that might contribute to the further degradation of their environment would be depressingly ironic. Besides, as countless studies have show, clean renewable electricity can easily pay for itself in the long run through avoided fuel costs without even accounting for the environmental benefits. A clean, renewable supply of energy at a minimal upfront cost could therefore solve the problem of electrifying poor, remote communities without the added environmental impact of 1.5 billion new consumers.

Our goal when starting this project was therefore to develop a clean power-producing device. It would have to be cheap enough to be affordable to some of the world's poorest communities – most likely through a micro financing or similar-NGO sponsored scheme – and efficient enough that the generated power could have an important impact on the daily lives of the users. At the same time, not wanting to limit ourselves to the poorest regions of the world, we wanted our product to also be applicable in developed countries, or more generally, in any unelectrified rural settings. Clean, renewable power can always be useful as long as there are people around to use it. With this in mind, we set about designing a river water turbine, characterized by its portability, its visual discreetness, and its wide range of placement options. What follows are the steps we took in designing and assembling the turbine, along with further studies on the environmental and economic impacts it might hate. Also included is a plan for marketing and selling our final product.



Preliminary Considerations

Our first step was to narrow our scope and settle on a definite type of renewable power source to design. Both out of interest and as a challenge to ourselves, we decided to build a small hydro turbine meant for any fast flowing river. This decision came about for two main reasons. First, small hydro power, despite being man's first mechanical power source, has been more or less ignored as the renewable industry pushes forward with wind, solar, and biogas energy. Second, the few small hydro turbines that have been developed are still very expensive and are often limited in where they can be installed. Of course, some of these more expensive turbines are far more sophisticated than the one we were looking to build and they can output a much higher a much higher wattage than what we aimed for. Still, quick calculations told us that if we were able to design a turbine that could have an output between 50 and 100 watts for between $300 and $700, our turbine could be economically competitive. After a bit of researching we learned that the product we were looking to make is commonly referred to as picohydro power.

The initial phase of the design process involved outlining what we foresaw as the primary consumer needs. The table below shows our rough rankings of the characteristics of a basic water turbine. We concluded that our primary concerns should center around:

- Cost
- Ease of installation,
- Flexibility of installation
- Power output

However, by focusing on these traits, we realized we would have to make some compromises. Material durability, for one, was something we realized would probably suffer. As we planned on using 3D printed components, we realized that the plastic might not provide the yeas of durability that machined pieces would. Similarly, keeping the turbine relatively small would most likely limit our power output. But overall, by focusing on power output and low cost, we believed that we would be able to build a turbine whose installation could have as large an impact on users' lives as possible.

Need	Relative Importance (1-5)
Cost	**5**
Ease of Maintenance	3
Ease of Installation	**4**
Size	2
Manufacturability	3
River Disruption	1
Life	3
Power Output	**5**
Flexibility of Installation	**4**

Pugh Matrix

The pico and micro hydro markets, though relatively small, have nonetheless produced a few turbines with similar ambitions as ours. Most produce much more than our target power output, but they also all cost significantly more to purchase.

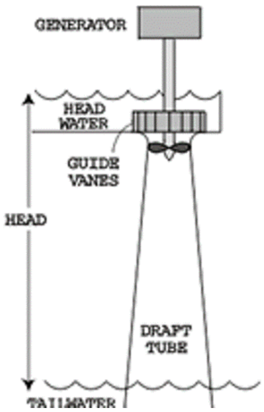
- The **PowerSpout** is very similar to the turbine we intend to make in that it is one of the cheapest picohydro turbines on the market, costing around $1,300. It relies on a pelton wheel turbine to generate up to 1.2 kW for their basic model, and it is built of durable, recycled materials. However, the PowerSpout can be difficult to install, requiring a fairly complex piping system to guide the water into the turbine housing. It is also heavily reliant on the speed of the water, though this will definitely be something that applies to our design as well. Multiple power spouts can be linked together to increase the overall power output.[1]

Installed PowerSpout system

Exploded view of the turbine

[1] http://www.powerspout.com/
[2] http://www.microhydropower.com/our-products/low-head-stream-engine/

- The **Micro Hydro LH1000** is a vertical Kaplan turbine that relies on a water drop to produce power. It requires between a 2 and 10 feet drop to function and can produce up to 1 kW of power at the maximum head. It costs around $3,000 and is made of durable, non-corrosive parts. It does however require installing a sluiceway to create enough head speed to generate power. This resembles our design in its use of a Kaplan turbine, though this one is placed vertically while ours will be horizontal.[2]

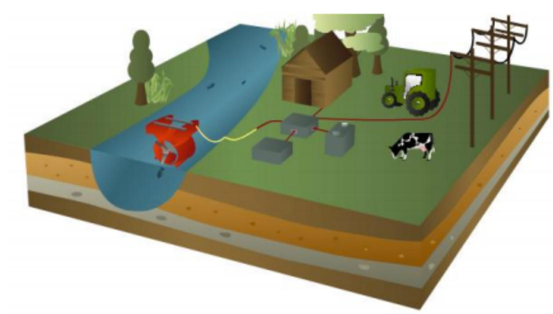


Sketch of the turbine

Installed turbine with the sluiceway

- The **Smart Hydro Power** turbine, designed by German engineers, is a significant step up in terms of price and power output. The turbine is very similar to our projected design in that it uses the energy of streams flowing between 1.5 to 3.5 meters per second to generate electricity. The shroud casing also accelerates the flow slightly, thereby allowing more energy to be transferred. It can thus produce up to 5 kW of energy, though it does cost around $32,000. [3]

Turbine is very large



Our installation will be similar

[2] http://www.microhydropower.com/our-products/low-head-stream-engine/
[3] http://www.smart-hydro.de/en/product/turbine.html

Design Process

This section focuses on describing how the various parts of our turbine were thought of, designed, and built. These include calculations and design of the Kaplan turbine itself, the housing, the electricity generating system, and the stress calculations and considerations for all the other components of the finished turbine. Also included are our collected and predicted results for energy generation and future improvements.

Turbine Design

One of the crucial components of our design can be found at the front of the device: the turbine head. In order to ensure full flexibility in design choice, we decided to print the turbine using Duke's Dimension SST 1200ES three-dimensional plastic printer. The turbine was designed in SolidWorks and printed in ABS plastic. While the relative lack of information dictating the design of small-scale water turbines was disappointing, we were able to pool together enough resources to yield a practical design. To begin, we were aware of the physical limitations of the available printer. In order for our design to be one single piece of printed plastic, the design could not exceed 10 inches in total diameter. Though we could have explored a design in which the turbine head was consisting of multiple parts attached together, we decided on a single-piece design to improve rigidity. Thus, our turbine's maximum diameter is roughly 9.7 inches.

We next accessed information pertaining to Kaplan turbine design, the general type of turbine which we had decided to use. We evaluated our turbine's specific speed and found that for low-head river flows, which are the only flows to be used with this design, we could set the hub-to-total-diameter ratio equal to ¼.

Turbine Specific Speed: $N_s = \frac{N\sqrt{P}}{H^{5/4}} \approx \frac{constant}{H^{0.486}} \approx f(\frac{1}{H})$

Hub to Total Diameter Ratio: $\frac{D_{hub}}{D_{total}} = (0.25 + \frac{0.0951}{N_s})$

For low head values, N_s becomes larger: $\frac{D_{hub}}{D_{total}} \to 0.25$

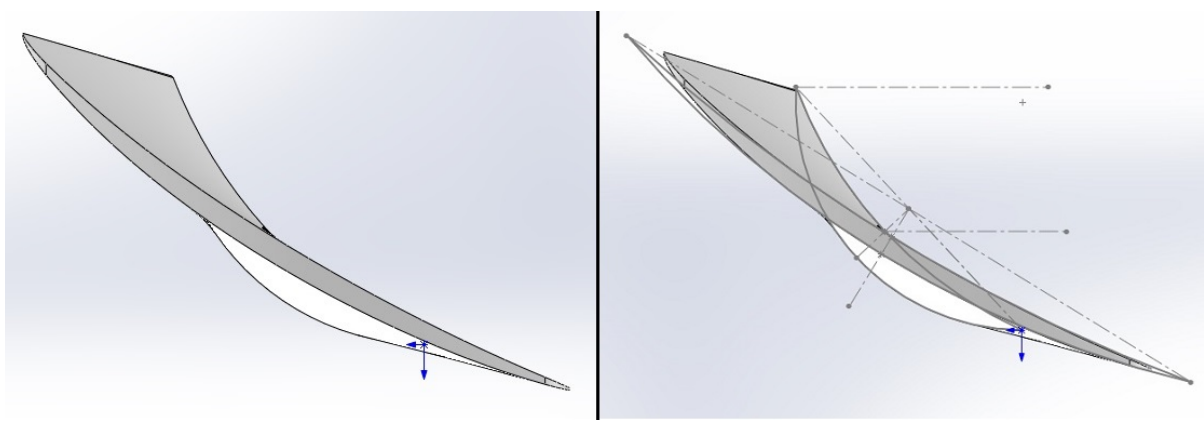
With this information along with the previously-determined printer limitation we were able to specify the hub diameter to be 2.5 inches.

Printer Limitation: $D_{total} < 10$ in → $D_{total} \approx 9.7$ in $D_{hub} = 2.5$ in

For the blade design, we found a resource from Actuation Engineering dictating the standard angles of both ends of the blades for Kaplan turbines. The hub end should be at a 47° angle to the turbine hub cross section, while the far end should be at a 31.5° angle to the hub cross section. SolidWorks supplied a convenient tool that meshed both end drawings into a 3-dimensional contoured blade shape.

Blade Angle: standardized Kaplan turbine angle values

Hub Attachment: 47° to hub C-S   Outer Edge: 31.5° to hub C-S



We next had to determine the level of curvature of the blade – should the blade have a bucket-shaped cross section, or should it be flat? Unfortunately little to no information existed regarding this design aspect. Duke ME professor Dr. Kenneth Hall indicated that it was mostly dependent on the choice of turbine type and the system setup. As a result, we went with a design that followed the general Kaplan design in which the bucket shape is present at the hub and decreased out towards the outer blade edge, yielded a flatter outer edge. We then reformed the outer blade edge such that when the turbine was viewed from the front, the blades maintained the same radius of curvature as the hub to give our turbine a round and symmetric look. We lastly attached 7 turbine blades to the hub, since 7 blades filled the entire turbine front view and would force all river flow to interact with the blades.

Finally we needed to design the shape of the hub. We sized the shaft attachment to accept a ½ inch shaft and added four setscrew holes (pairs of 2 at 90 degree angles to each other) that could be tapped for ¼-20 setscrews. We shaped the front of the hub to a common hemispherical dome design seen in many Kaplan turbines. The total hub length was specified to be well under 10 inches, making our design fit for printing.

Blade Analysis

In order to ensure our blade design would resist failure when placed in a river, we performed a static analysis in SolidWorks. We assumed a single blade to be fixed at the hub end and applied a distributed river force across the blade. To find the river force, we assumed the dynamic pressure to be $\frac{1}{2}\rho V^2$, and applied this normal to the blade in which the force is equal to this pressure times the blade area. We used data from the testing location, the Eno River, to find the pressure. While this is an oversimplification, we believe that this would be a high estimate of the force because the river does not actually flow normal to the blades and we did not apply Betz's law to readjust the force. After running the analysis we found our blade to be more than capable of surviving the provided river flow. The maximum stress found in the blade was much lower than the blade's shear yield strength, and the maximum displacement in the blade was a miniscule value less than 1/50 inches.

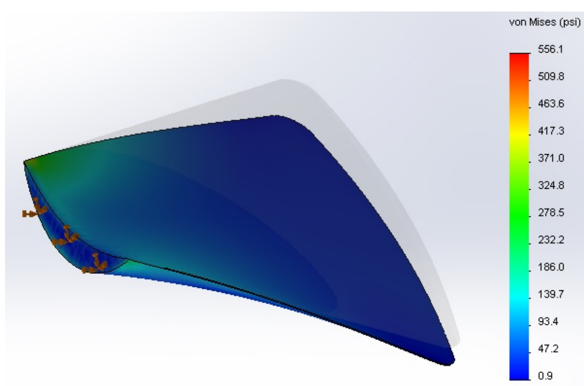
Blade Static Analysis: distributed river force (calculated to be 11.9 N = 2.675 lbf) over normal blade area

ABS Properties: S_{ut} = 4351 psi   Distortion-Energy Theory: Ssy ≈ 2510 psi

Stress Analysis: σ_{max} = 550 psi at blade connection

Survival: 550 psi << 2510 psi

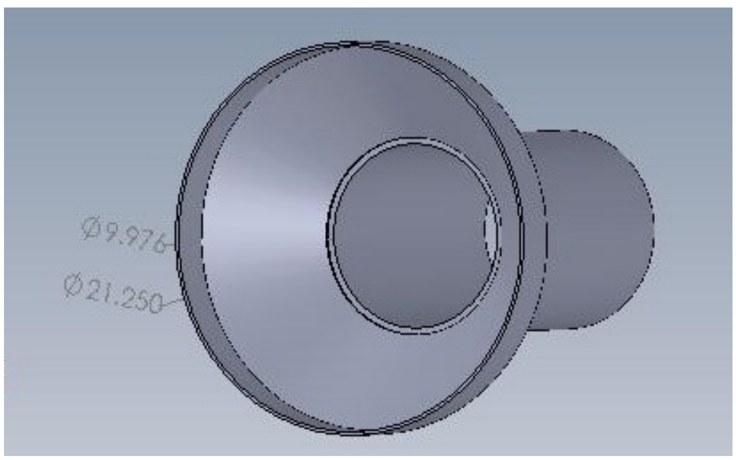
Displacement Analysis: y_{max} = 0.01884 in at outer edge → y_{max} < 1/50 in



Turbine Housing

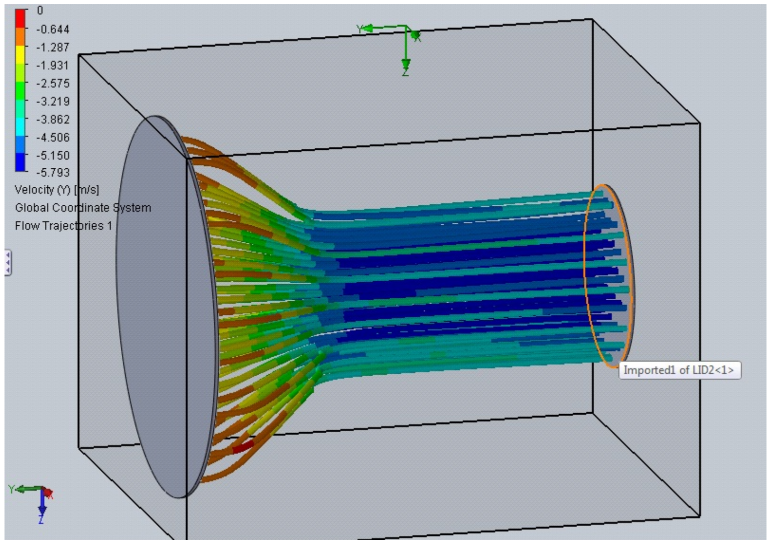
In designing an outer housing for the turbine, the primary consideration was increasing the velocity of the water. From Betz's law, the maximum attainable power from our turbine is proportional to the cube of the velocity, $P_{max} \propto v^3$. From the continuity principle, $A_1 v_1 = A_2 v_2$ in a flow channel, so decreasing the area of the flow channel increases the velocity of the water entering the turbine blades.

The figure below shows the housing design:



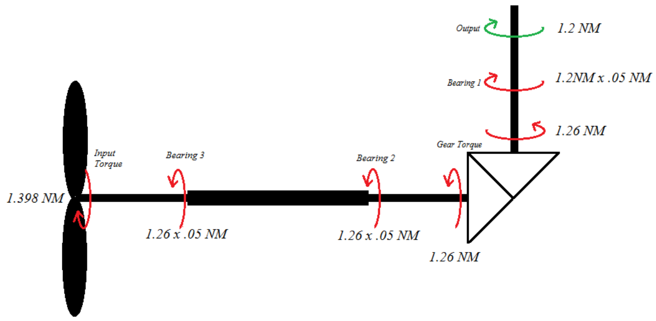
The housing consists of two pieces: a polyethylene funnel, with a 21.25" outer diameter and 20.89" inner diameter, and a PVC pipe with a 10.75" outer diameter and 9.976" inner diameter. The end of the funnel is cut so that the inner diameter of the funnel matches the outer diameter of the PVC, and the two pieces are held together using both brackets and an epoxy. The turbine blades are positioned at the front of the PVC. The total cross-sectional area decreases from the inlet of the funnel to the turbine blades by a factor of 4.4.

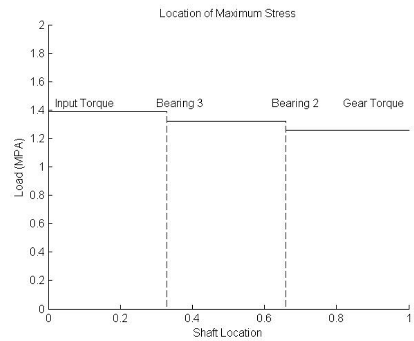
The continuity principle predicts that the water velocity in the housing will increase by the same factor that the cross-sectional area is reduced by. In reality, though, secondary flow interactions mean the water will not speed up as much as predicted. The figure below shows CFD simulations of the velocity in the housing:



The results of this simulation predict the velocity in the housing will predict by a factor of about 3.5. As the maximum theoretical power from the turbine is proportional to the velocity cubed, the maximum power in the turbine increases by a factor of 42.9.

Stress Calculation:





$$\tau = \frac{Tr}{J} = 3.4538\ MPA$$

Adjusted Fatigue Strength:

$$k_a = aS_{ut}^b = .9862$$
$$k_b = 0.879d^{-0.107} = 1.402$$
$$k_c = .59$$
$$k_d = k_e = 1$$
$$k_f = .5$$

$$S_e' = k_a k_b k_c k_d k_e k_f S_e = 39.36$$

Aluminum Material Properties:

$$S_{ut} = 310\ MPA$$
$$S_y = 276\ MPA$$
$$S_e = 96.5\ MPA$$
$$\sigma_a = 3.45\ MPA$$
$$\sigma_m = 1.726\ MPA$$
$$f = .5$$

Modified Goodman Criteria:

$$\sigma_{rev} = \frac{\sigma_a}{1 - \frac{\sigma_m}{S_{ut}}} = 3.47\ MPA$$

$$a = \frac{(fS_{ut})^2}{S_e} = 248.9\ MPA$$

$$b = -\frac{1}{3}\log\left(\frac{fS_{ut}}{S_e}\right) = -.457$$

$$N_{Goodman} = \left(\frac{\sigma_{rev}}{a}\right)^{\frac{1}{b}} = 11497\ Cycles$$

Gerber Criteria:

$$\sigma_{rev} = \frac{\sigma_a}{1 - \left(\frac{\sigma_m}{S_{ut}}\right)^2} = 3.45\ MPA$$

$$N_{Gerber} = \left(\frac{\sigma_{rev}}{a}\right)^{\frac{1}{b}} = 11643\ Cycles$$

Design Considerations

Shaft: Based on the above calculations, the shaft will be able to undergo alternating flow cycles for ~11000 cycles. These numbers were all based on extremely conservative assumptions including a low coefficient to account of water corrosion and an increase of 5% overall torque per bearing due to friction. These calculations value the life of the shaft at about 30 years if sized at ½". Therefore, the corrosion of other parts is of higher concern for ultimate failure.

Bearings: Based on the stress calculations of the shaft, there will not be noticeable axial loads on the shaft. The primary loading will be torsional and the bearings will not need to bear any significant axial load. For this reason straight plain steel ball bearings were selected. Because every bearing will be exposed to the water, it was necessary to specify a seal for the bearings to protect against corrosion. The bearings used in the prototype were double sealed plain steel ball bearings. A press fit was specified and machined for the shaft, and then the bearings were pressed into place.

Bearing Positioners: These pieces were machined out of stock aluminum. Aluminum was chosen for its ease of machining and cost. 3 holes were drilled and taped at 120 degree offsets. All-thread rods would connect the sides of the housing and the positioners. The bearing was placed in the center hole, and then the rods were inserted, acting as a set screw on the bearing so account for any unpredicted axial stresses in the system. Once the bearings were press fit, the positioners were attached to the bearings, and the all thread rods were placed in the slits drilled into the housing. Nuts were then attached to the ends of the all thread rods to keep them in place. Adjusting the nut allowed the shaft to be positioned directly in the center of the housing.

Gears: The electrical component of the device needs to be near the power shaft output to minimize losses, and needs to be located out of water. 90 degree steel miter gears were used to transfer the rotation upwards, and allow the generator to be positioned immediately above the turbine. In the prototype, the gears were free and not a part of an enclosed gear system. There was also no gear reduction system. In future design iterations, a gearbox with a gear reduction ration should be used both to optimize the RPM and torque inputs to the generator, and maximize ease of assembly.

Coupling: In order to couple the output shaft to the generator input, a coupling was needed. Because perfect positioning would prove difficult, a flexible coupling was chosen. This allows for small imperfections in positioning and misalignments to not drastically affect the power output of the shaft. A rigid coupling would fail if debris from the river knocked either the shaft or the generator out of perfect alignment. A flexible coupling allows this to occur and still have the device function properly.

Epoxy: An epoxy was used to secure the bearing fit onto the output shaft into the housing. This technique allows two connection points on the output shaft (the second being the coupling), and allows for more precise positioning of the output shaft. An epoxy was also used to seal the front of the housing to the funnel to minimize water that would escape through gaps.

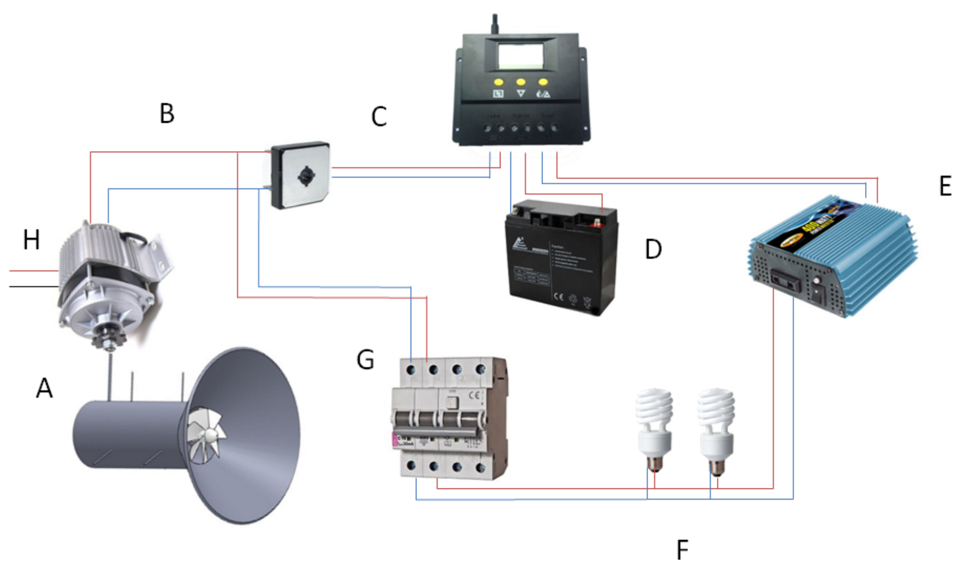
Metal Flanges: In addition to the epoxy, bent metal flanges bolted the housing to the funnel. These are more robust than the epoxy, and will keep the funnel in place with respect to the housing against the force of river flow. The epoxy and metal flanges work together to take the 2 parts of the housing and fuse them as one.

Power Generation

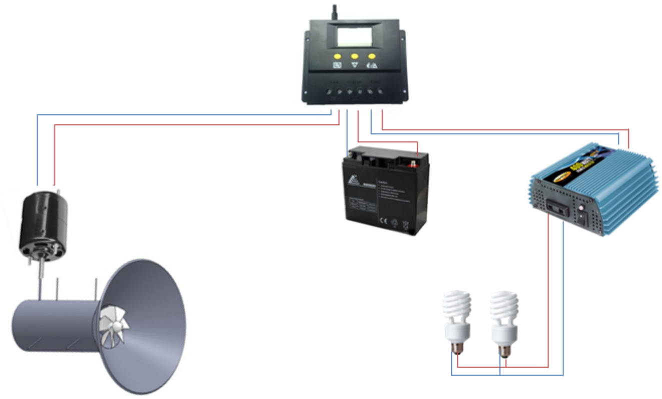
Theory:

In a fully integrated system, an alternator is used as the electric generator to transform the mechanical motion of the shafts into electrical power that is stored in batteries offshore. The induced AC voltage by the alternator (stage A) is initially rectified by an additional circuit to transform the voltage from AC to 12V DC (B). Later the 12V are applied across the charging terminals of the charge controller (C), which is important in insuring a safe charge and discharge cycles of the attached battery bank (D). A load can be attached to the charge controller directly of via a DC to AC transformer (E -> F).

Using an alternator also allows the user to power an electric load using the alternator only by passing AC to DC to AC conversions and storage. Electric loads such as phone chargers or light bulbs can be attached to alternator directly if a circuit breaker and an AC regulator are present (G), both serve to protect the electric loads from current surges and maintain a constant voltage. It is also important to make sure that the alternator has a sufficient energy supply attached to it (H). The following diagram represents the entire system described above.

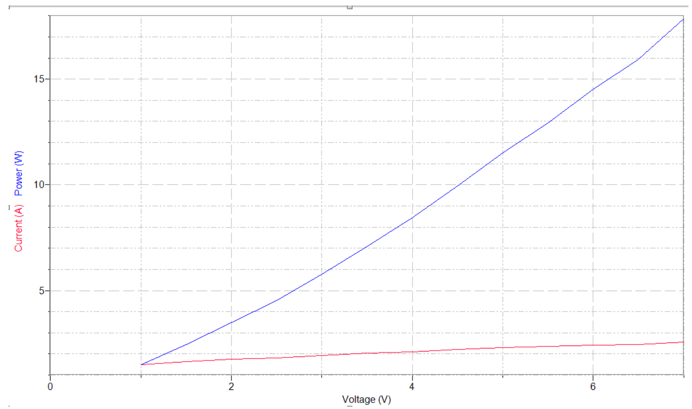


The graph below represents our current system with the DC generator we have obtained.

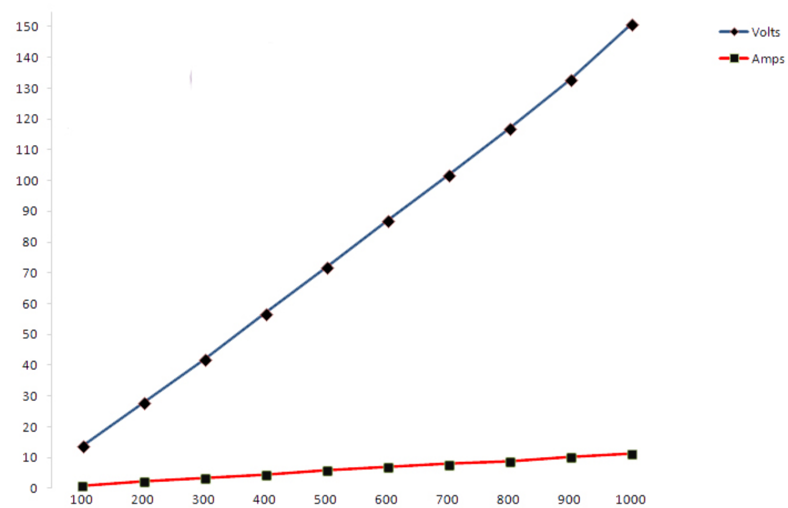


Approach:

To make the project more feasible due to budget restrictions and time constraints, we have decided to eliminate the rectifying stage by using a DC motor in reverse direction as our generator. Currently we are using a FASCO DC142 12V-24V DC motor as out electric generator that we have obtained from the ME department. This motor is rated to operate using 12VDC and a maximum of 28.5A at torque of 90 Oz/in and 3150 rpm, with a total max power of **342W**. In theory reversing the direction of rotation should not reflect a significant drop in the output power, but since our generator is a brushed DC, high torque with high rpm requirements we are limited to approximately 4.5A in reverse current at around 12V DC. This brings down the maximum expected power output to approximately **60W**, which exceeds the range expected for our project. We have designed our turbine to achieve approximately 350 (NOT SURE) rpm however this will vary depending on the speed of water flow in the river. Figure () shows the current produced when different voltages were induced across the terminals of the motor; this can help us predict the expected maximum power output (Voltage x Current) of the generator.



The following graph represents the possible output if we have used an alternator.



Generator RPM	100	200	300	400	500	600	700	800	900	1000
Volts	14	28	42	57	72	87	102	117	133	151
Amps	1	2.2	3.4	4.6	5.8	7	7.9	8.8	10.4	11.2
Watts	14	61.6	142.8	262.2	417.6	609	805.8	1029.6	1383.2	1691.2

From our measurements we were able to achieve 120 rpm with the generator as a load, and if it was the case that we have used the Missouri alternator mentioned, we can possibly achieve 10 + Watts of power at voltages 12V+. This will be ideal since that a battery of 5 amps capacity would require 5-6 hours to charge fully, 60 Watts or so.

Power Calculation:

Theoretical Calculation for Energy harvesting from River flow;

From Betz' law:

$$\dot{E} = \frac{1}{2}\dot{m}(v_1^2 - v_2^2)$$

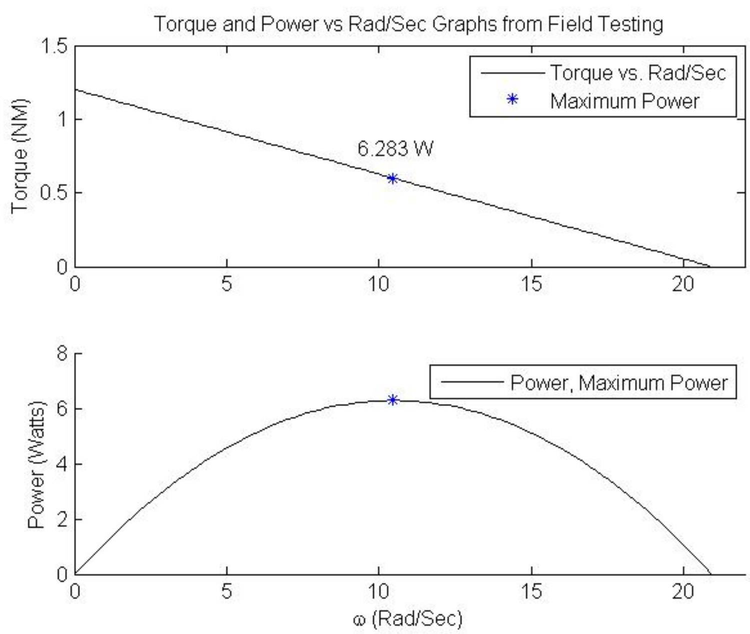
$$\dot{E} = \frac{1}{4}\rho S v_1^3 \left(1 - \left(\frac{v_2}{v_1}\right)^2 + \left(\frac{v_2}{v_1}\right) - \left(\frac{v_2}{v_1}\right)^3\right)$$

$$\frac{dE}{dv_1} \rightarrow P_{max} = \frac{16}{27} * \frac{1}{2}\rho S v_1^3$$

Because available power scales with the third power of velocity, it behooves the design to increase flow velocity, which is why the funnel was used to scale up velocity by 3.5.

$$P_{max} = 274.26\ W$$

Power harvested. Based on the experimental values of stall torque and no-load speed and using a conservative straight line interpolation, the maximum energy available from the turbine is 6.283 Watts



Future Considerations

After testing our prototype in the Eno river, we realized that our design could use a number of improvements both to make it more practical and to increase its power output. Though we did not have time to add test these, we do not foresee any of these steps as being too difficult to implement.

- One of the most pressing design components we still need is to devise a buoy-based flotation device to maintain the turbine at a consistent, optimal depth. For testing purpose so far, we have relied on holding the turbine underwater ourselves, which is not a viable long-term solution.
- To go along with the buoy system, we need to develop a way to anchor the turbine at the fastest flowing point in the river. We believe a rod and tensioner system could provide an easy anchoring solution that relies on only one riverbank to provide stability.
- As mentioned in the Power Generation section, we are also considering the addition of an alternator to make our power output greater.
- To go with that, we also need to implement a better gear ratio to optimize RPM and torque to individual alternator specifications.
- Finally, we need to improve our gear mechanism to transfer river force more efficiently to the alternator.

Environmental Considerations

One of our chief concerns the design of the turbine was minimizing the environmental "impact" that it would have, while also maximizing the energy savings and carbon offsets. There were many factors that went into making this happen, let us begin with how environmental impact was reduced. Firstly, we looked into the optimal location for the device to be implemented. The river must be flowing fast enough to generate significant torque through the turbine, but not so fast that it would create damage. Ideally, something above $1m^3/s$ should provide sufficient torque. Additionally, it must be deep enough for the entire turbine housing to be submerged. With a full anchoring system, the turbine would be placed in the center of the river, however we did not have the capacity to try this in our testing. As such, we were limited in our options for testing, particularly since we did not build an anchoring system for the prototype. Having studied river flow rates around Durham using US Geological Service data, we realized that we most of the rivers were too gentle, and that we would have to carry out testing sometime after heavy rainfall. We ended up choosing a testing site to the north of Durham, The West Point on the Eno Park (36.07 N, 78.91 W). We chose this site for various reasons including the accessibility, the width of the river, and the proximity to a small dam. The presence of the dam increased the flow rate just downstream, which gave us better testing results.

Another point of concern revolves around the wildlife impact of the device, particularly with regards to fish in the river. Evidently, the presence of spinning turbine blades in the middle of a river presents a danger to any fish or amphibian populations. There are two ways to approach this issue. Firstly, a river that is known to have high fish populations or heavy migratory patterns should be avoided. Secondly, future designs beyond the prototype would have to take this consideration into account. One idea would be to install a dome shaped grate over the front of the housing. This would serve a double purpose, as it would also prevent any large debris from entering the turbine. The downside to this approach is that any sort of grate over the front would create a noticeable reduction in the flow rate before it enters the turbine. Another, more complicated, approach to solve this problem would involve removing some of the water from the river through a grate, having it run down a tube offshore, and then into the turbine and back into the river. This would require a significant amount more infrastructure, and may not be a viable option based on our price point.

One final potential problem with the design is the use of a lead-acid battery. These can present serious toxic risks in the event of any sort of leakage, so the casing would have to be designed in order to minimize the possibility of any leak.

Energy

After we carried out preliminary tests, we were able to come up with some numbers relating to the environmental impact of the turbine with regards to energy generation. Firstly, we calculated the amount of CO_2 emissions the device avoids for each of the conventional fossil fuels. We should note that these numbers are based off 100% operation, using a power output of 20W as suggested by the engineering team, as such they are hypothetical values which could become a reality after design improvements.

Fuel	Emissions level (lbs CO_2/100Wh)	Emissions avoided with turbine (lbs CO_2)
Natural Gas	0.122	213.7
Oil	0.168	294.3
Coal	0.212	371.4

Source: Energy Information Administration

As we can see, even operating just one of these devices offsets a significant amount of carbon emissions. In looking towards the marketing of the device later, this aspect could be particularly useful in targeting certain consumer markets.

Another aspect of the power generation that is particularly important with respect to our technology is the cost of the power. Because of the high cost of the device relative to power output, we expected the cost to be very high. In the United States, electricity costs about 11.65 c/kWh on average (residential). Using our data, we calculated the cost of power to be 156.96 c/kWh for a one-year lifespan, and 78.48 c/kWh for a two-year lifespan. For each additional year added to the lifespan, the cost is cut in half. In turn, the time it takes to recover the cost of the device is therefore also cut in half. With a one-year lifespan, it would take 7 years to recover the cost, making it unviable. However, this is a conservative estimate, and we would expect it to last at least 2-3 years.

As demonstrated through some of our data, the device we have produced is an energy efficient prototype. With that being said, there are serious design considerations to be looked at in order to make the device cost efficient. The turbine successfully offsets a significant amount of carbon emissions that would otherwise come from conventional power sources. However, the cost of the electricity generated remains high, which will make the device difficult to market. Depending on the approach taken, the device could be made attractive to a variety of different target buyers for different purposes. In the business strategy that follows, we will explore how the marketing could be handled.

Cost and Marketing

People

One the largest restrictions on our marketing scheme is that of location. Our product requires a source of water. As very few waterways with enough depth and speed run through backyards and our product only produces approximately 20W of electrical output, we will target very specific markets and industries.

The main selling point of our product is its ability to charge a cell-phone or a comparably small device.

Our Charging Speed	0.4 amps/hr
Typical Cell Phone Battery Capacity	850mA-1A
Time to Fully Charge a Cell Phone	2.5 hours
Energy Lost in Process	-(35-55%)
Actual Time to Fully Charge One Cell Phone	~4-6 hours
Cell Phones charged per day	4-6

Target Consumers

Off-Grid Locations that could benefit from our product	**Who Actually Pays?**
National Parks	Government
Disaster Zones	Government or Consumer*
Rural Area of Developing Country	Consumer* or NGO
Remote Research Location	Organization
Conspicuous Conservationist	Consumer*

*Consumer refers to person unassociated with larger organization, paying out of pocket.

Target : National Park Service

Our first target consumer is the National Park Service. In January of 2013, it was announced that greatly expanded cell-phone and wifi service was to be tested at five National Parks. The largest reasons behind this expansion is increased safety. “Alerting visitors to impending changes in the weather, construction projects, or other issues in the parks could be done more quickly and effectively via Wi-Fi,” the spokesman said. In the articles covering the announcement, there is zero mention of the resulting increased demand for charging the cell-phones or GPS devices.

An Example: Around 14,000 Yellowstone National Park visitors camp in one of 300 backcountry campsites each year. These backcountry campsites truly place visitors out in the wild. A portion of the higher safety risks associated with backcountry camping could be negated if visitors are able to charge a GPS device or cell phone. Our product provides an off-grid environmentally friendly way to do so 24 hours a day. All backcountry campsites are located near water resources and the vast majority appear compatible with our device. Our product’s durability would only require annual installation and de-installation once winter weather has subsided in the spring and returns at the end of October. Lastly, our product’s low charging capability prevents visitors from bringing more intrusive devices unwanted in the pristine wilderness.

Between 1992 and 2007 there were 11.2 search and rescue missions a day within U.S. National Parks, averaging $895 per mission. Total SAR costs during that period reach $58.6 million. With a charged cell phone or GPS device, park visitors could more easily stay on the right trails, be warned regarding weather changes, contact help if needed, and be located in an emergency. Something about willingness to pay on park and visitor side.

Competition? Our product falls into the category of a Stand-Alone Power System, a “SAPS” or “SPS”. In these systems, energy is generated by micro hydro, solar panels, wind turbines, geothermal sources, diesel or biofuel, or micro combined heat & power. Our most significant competitor is a solar panel. A solar can produce similar amounts of power with zero emissions. That said, the production of solar panels is a very energy intensive process, while our product’s production requires a more standard amount of energy input.

A solar panel’s largest advantage over our product is it’s low price. A 1.4x1.4 ft 20W solar panel can be found on Ebay for $41.95.

Despite this cost advantage, the hydro generator runs 24.7, and does not need to be in direct sunlight. The hydro generator's sturdiness allows it to weather the elements more easily. The generator does require flowing water and would not work in locations where water resources freeze. This is a non factor to National Parks as only 5% of total annual campers come from November-May.

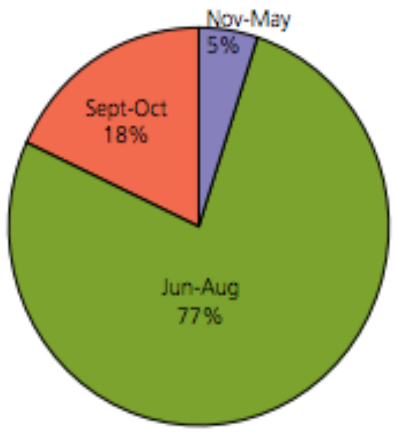


Figure 2. 2006 backcountry use by season.

Similar to National Park Service, we also look to market our turbine to those doing research in remote locations near water resources.

Target: Disaster Response Organizations and Victims

Climate change has contributed to a rise in extreme weather events - including higher-intensity hurricanes in the North Atlantic and heavier rainfalls across the U.S. Scientists project that climate change will increase the frequency of heavy rainstorms, putting many communities at risk for devastation from floods. The increase in frequency of heavy rainstorms and increased flooding is a factor not just in the U.S. but on every continent around the world, excluding Africa, and especially on Islands. Flooding, specifically from high-intensity storms like hurricanes, will most likely be partnered with short and long term power outages. Our product solves immediate low-wattage power needs.

Targeting disaster electricity generation needs can be done through two sources: consumers and government organizations like FEMA. Here we can sell directly to a consumer looking to be prepared for a coming storm or an organization that can hand them out proactively or reactively to the victims of the disaster.

Competition? Again, solar is the main competitor. In our opinion, solar would be less durable than our product in disaster scenario. For example, heavy winds could take such a portable panel right off the roof of a house. Additionally, solar can only generate energy during the day. While it could charge a battery for later use, those in disaster situations would likely need as much energy as possible all day long.

Target: Developing Country Rural Communities with Access to Water Resources

Approximately 1.3 billion people worldwide do not have access to electricity. Using both maps below, we can see that there is strong energy demand *and* significant renewable water resource supply in Latin America, Southeast Asia, and a few areas of Sub-Saharan Africa.

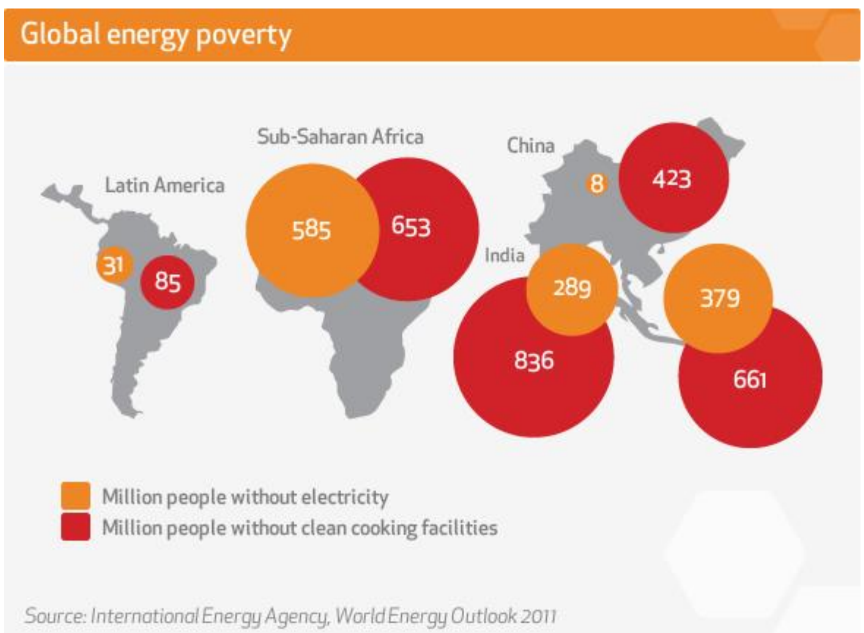
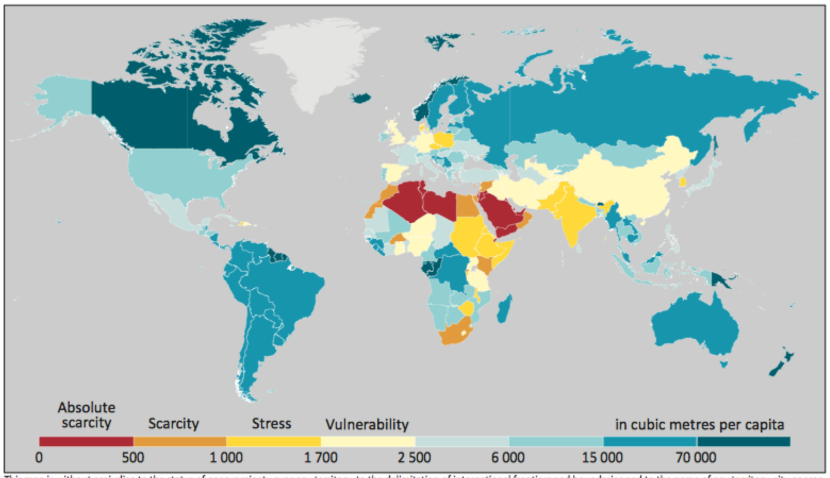


Figure 17.2 ▷ Renewable water resources per capita in 2010

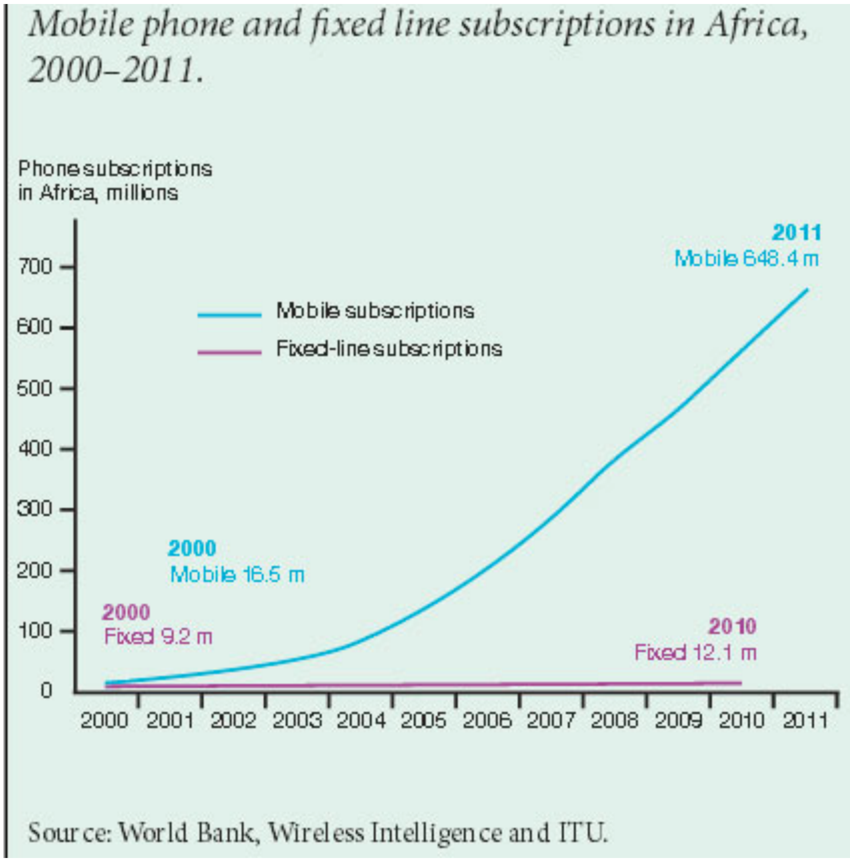


This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Source: UN FAO Aquastat database.

The energy demanded in these areas is much greater than our device can provide. Pico-hydropower is any hydroelectric power generation under 5kW. We have found many successful pico-hydro schemes in Nepal and Kenya that have used water resources successfully. While our product falls into this category by default, producing around 20W, the pico-hydro schemes found involve energy distribution into multiple homes in one location, producing 1.1 and 2.2 kW respectively. We may not be able to provide this amount of power and distribution however our device can act separately in similar communities using the same water resource.

The pico-hydro schemes mentioned above have been used to power lights and various cooking appliances in homes, necessities. Cell phone are not considered a necessity in low income countries around the world. Despite this fact, cell phone demand has increased dramatically over the past ten years in surprising locations like Africa and Rural Latin America .



We see our product as a small business opportunity in a rural location. In Kenya, Sara Ruto used to travel three-hours one way each week to charge her cellphone. Each charge cost her $0.30. Eventually, Sara bought a solar panel to put on the roof of her house for $80. By making this purchase she saved $20 a month from travel. Additionally, she began charging neighbors $0.20 to charge their phones.

Purchasing our device for around $425 and being able to charge on average, 5 cell phones a day at $0.50 each, the payback period falls at 170 days. We would recruit a local salesperson to go into the rural communities and sell our product. This would not only make community members more interested and trustworthy of the product, but it would act as a small business venture for the salesperson. We would provide him or her training to operate, install, and make small fixes in the turbine.

Competition? Solar is the clear competitor again, especially, because of its use in the Kenya case study. A panel would be easier to carry, install, and immediately generate electricity. Again though, it does not generate electricity all day long like our product. In locations where pico-hydro schemes are already in place it would be easier to add in another tool for electricity generation than create new infrastructure for solar.

Target: Environmentally Conscious

In the world of increasingly popular green technology, we cannot forget about the market for "conspicuous conservation". "Conspicuous Conservation" refers to engaging in activities that are environmentally friendly in order to obtain or signal a higher social status. As more and more reports come out about Climate Change and the negative effects the human population has on our environment, being environmentally friendly has become "cool". For something to be cool, others have to see it or know about it, a "green signal" must be sent. CNW Marketing Research found that the number one reason for driving a Prius, the ultimate green signal, was not it's low emissions or great gas mileage, but "the statement it makes about [the driver]". Sexton and Sexton found that the mean willingness to pay for the green signal provided by the Prius was between $430 and $4,200. In a survey done by Harvard and Yale in 2011, the average U.S. citizen said they were willing to pay $162 a year more to support national policy requiring 80% "clean" energy by 2035, a 13% increase in electric bills nationwide. Using the popularity of green products, we would market our turbine to the upper-middle class, known eco-friendly communities like Asheville, NC, and small businesses looking to be known as "green". Extensive knowledge of state and federal incentives for renewable energy will help convince locals to make purchases. For example, we would inform North Carolina citizens that the state offers a tax credit equal to 35% of the cost of eligible renewable energy property constructed, purchased or leased by a taxpayer and placed into service in North Carolina during the taxable year.

Profit

	Prototype Realized Budget
Shaft	$15
Bearings	$34
Bearing Housing	$15
All Thread Rods	$12
Gears	$6
Funnel	$98
PVC	$52
Shaft Coupling	$53
Blades	$158
Generator/*Alternator* Housing	$100
Generator	Borrowed ($80)
Charge Controller	Borrowed ($35)
12VDC to 110AC 300W Converter	Borrowed ($22)
Total Realized for Prototype	$543
Total Projected w/ Generator	$680

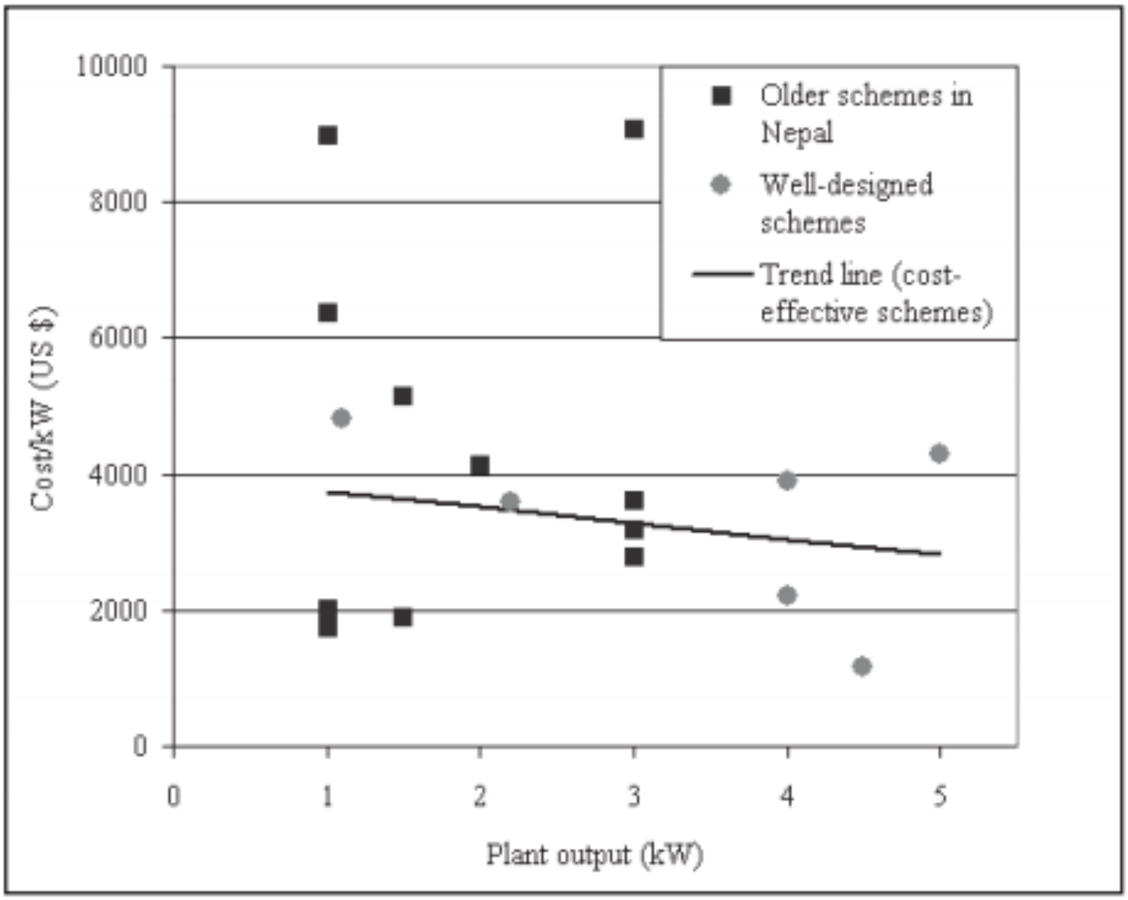
If Used an Alternator

Alternator (if used instead)	***$100***
Total Projected w/ Alternator	$700

Projected Costs under a model of mass production (about 200 units/mo).

Model (Injection Mold)... $60
Additional Parts ………………………………..……….....$100
Alternator, Charge Controller, & DC to AC converter…......$100
Man-Hours ……………………...……………………......$15
Total …………………………………………………..... $275

Looking at other pico-hydro schemes, we came across this graph.



Source: http://www.hedon.info/docs/BP53-Williams-6.pdf

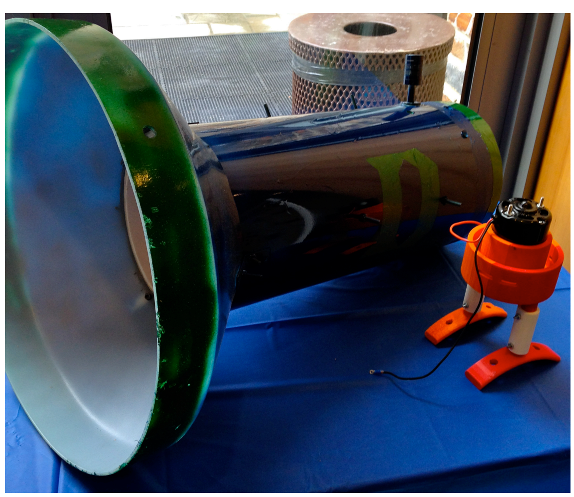
Following the cost trend line, a larger scale pico-hydro scheme, 1kW, cost approximately $3750. Following this trend our 20W scheme should cost around $75. Unfortunately, this is not a possible pricing for us currently, but we do wish to keep the price as low as possible to expand our customer pool to the lowest income possible. With our current cost to produce at $275, and assuming a $50 marketing cost for each turbine (which would hopefully decrease as they become more known), our final cost would be around $325. At first we plan to sell for a $100 profit on each turbine, at $425.

Conclusion

The W.A.L.T.E.R. has proven to be more successful than we originally anticipated. The turbine has proven capable of generating enough energy to power small electric devices, and our cost calculations, both of the actual prototype and of theoretical large scale produced models shows that we can be relatively competitive on the open market. Similarly, our calculations of the environmental impact of the turbine seem to indicate that we have produced a clean power generator that, although not immense, can offset small levels of atmospheric pollution.

This paper presented the steps we undertook to design our prototype, starting with our initial consideration of the problem facing the world due to rising electricity demand and energy-fuelled environmental degradation. We outlined the steps undertaken to conceptualize and build the prototype, along with our calculations and results for power generation. Our environmental analysis showed that although small, the turbine does have a positive environmental impact. Finally, our cost calculations and marketing strategy showed that the turbine can be an affordable option for bringing electricity to areas removed from the grid.

We would like to thank Dr. Emily Klein and Dr. W. Neal Simmons for guiding us in designing our prototype. We also would like to thank the staff of Pratt School of Engineering and the Nicholas School of the Environment for their support throughout.



The W.A.L.T.E.R

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