Alternative Energy in the Andean Highlands

Thomas J. Decker

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Alternative Energy in the Andean Highlands

by

Thomas J. Decker
Candidate for Bachelor of Science
Environmental Resources Engineering
With Honors

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APPROVED

Thesis Project Advisor: _______________ Dr. Charles N. Kroll, Ph.D

Second Reader: _______________ Dr. Theodore A. Endreny, Ph.D

Honors Director: _______________ William M. Shields, Ph.D

Date: __________________________
Abstract

Abra Malagá Thastayoc is a rural Andean community consisting of approximately 150 Quechua-speaking inhabitants practicing self-sufficient agriculture, pastoralism and traditional weaving techniques. Many in the community earn less than $1.50 per day and survive on the papa nativa (native potato) as well as their livestock consisting of llama, alpaca, pigs, cows, sheep, chickens, and guinea pigs (Abra Malaga, 2013). To supplement their crops and livestock, men work as guides on the Inca trail or work construction, and women can at times sell their textiles.

Similar to many rural communities in Peru, this community lacks a connection to the electrical grid and there is little chance of this happening in the future. Most local households do not have lighting, and community members have to travel approximately 40 km to charge basic electrical devices. Due to limited governmental action in the distribution of electricity to small communities in the Andean Highlands, Abra Malaga was seeking partnerships to complete a project to provide electricity to their community. In 2006, a Cusco, Peru non-profit, Asociacion Ecosistemas Andinos (ECOAN), began the installation of solar panels for a school house as well as for homes in high visibility areas (Vilcanota Project, 2014). The State University of New York College of Environmental Science and Forestry Engineering for a Sustainable Society (ESF-ESS) student organization became connected with Abra Malaga through ECOAN in August 2012 and has continued to support this electrification project, hereby referred to as the project (Decker, 2014).

Through this partnership, the project has provided accessible sources of electricity to nearly twenty households in Abra Malagá Thastayoc using off-grid alternative energy sources while also developing a sustainable model for rural electrification in the Peruvian highlands. The project included the installation of two micro-hydro systems, one low and one high head, and 12 solar panels.
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1.0 Introduction
The purpose of the project is to establish a successful partnership with Abra Malaga to provide the benefits that rural electrification can provide to underserved communities. A component of electrification and the most commonly requested and important application was lighting. Lighting provides two kinds of benefits: direct and indirect. Direct benefits include improvements to lighting, radio access, and television viewing. Indirect benefits include children having more nighttime hours to study, more time for socialization and community activities, and more hours for craft-making and other entrepreneurial enterprises that can generate additional income (Meier, 2010). Within Abra Malaga, electricity can allow for increased productivity of fish ponds, allow for a restaurant at night, encourage the development of small hotels, or even a method for raising guinea pigs and chickens in a warmer environment (Meier, 2010). Electrical lighting also typically replaces kerosene lamps, which emit particles that cause air pollution and increase the risk of respiratory illness.

Another purpose and component of locally available electricity is the reduction in travel times needed to charge batteries for use in basic devices such as radios and cell phones. Increased access to electricity has been shown to increase the use of these devices, helping to keep people more informed of events outside of their community including market opportunities and health care campaigns.

A third purpose of the project is to increase opportunities and self-worth for families in Abra Malaga. Working together to provide sustainable energy shines a theoretical light upon community members and gives them hope and motivation to move forward in their lives.

2.0 Project Context
This project is a partnership with Abra Malaga, Peru, a community containing a population of approximately 150 people. Abra Malaga is a rural community located in the Vilcanota Mountain range (within the Andes) at elevations between 13,000 and 14,000 ft above msl (see Figure 1). The community is situated within a protected private reserve which contains the endangered Royal Cinclodes (bird species) as well as the Poly Lepis (tree species) (Vilcanota Project, 2014). The closest large city, Cusco, is 3.5 hours away and has a population of over 500,000 people. The Cusco area was the capital of the Incan empire and is considered one of the cultural capitals of South America. In current times, intense mining and natural resource extraction has made Cusco the focus of large industry and has led to expansive growth (Steel, 2013). Therefore, politics have begun to play a more influential role in the distribution of funds and support of communities that live within the mountains where natural resources are most abundant.
As for demographical information, a conducted survey showed that generally age in the community ranges from newborn to members in their 70's. There are 32 families (~150 people) in the community with 20 (~95 people) previously without basic access to electricity (Abra Malaga, 2013). The specific educational level of the community is unknown but only a select few know how to read or write and the majority of the elderly population only speaks the native language, Quechua. From a conducted survey, the average daily income is less than $1.50 US (Abra Malaga, 2013).

Beyond Abra Malaga, the Vilcanota mountain range is home to 12 additional rural communities with over 1500 families and 6000 people. These communities present an opportunity for project expansion given the present model is proven successful (see Appendix for a table).

3.0 Project Team
The project includes participation from environmentally focused university students in upstate New York, professional mentors in international development and renewable energy, Peruvian environmental and cultural experts, as well as the community members themselves. Below each of these members of the project team are discussed.

3.1 ESF Engineering for a Sustainable Society
The SUNY-College of Environmental Science and Forestry Engineering for a Sustainable Society (ESF-ESS) is a group of over fifty engineers, scientists, landscape architects and environmental students with an interest in international development. Group members devote their time and energy to help the chapter build sustainable infrastructure abroad while also increasing domestic awareness of the needs of people in the developing world. Students work together throughout each school year to raise funds and write grant applications, and are able to take advantage of local professional and academic engineering knowledge. The project manager is Thomas Decker, the president of ESF-ESS, and the author of this honors thesis. Mr. Decker leads the project in the United States and coordinates tasks with the Peru project team with the club.
3.2 Asociacion Ecosistemas Andinos (ECOAN)

ECOAN is a Peruvian non-profit organization whose mission is to conserve and restore the ecosystems in different parts of Peru. ECOAN employees include biologists, economists and cartographers who are dedicated to combining restoration work with community development and interaction. The organization hosts tourism groups for birding excursions, leads a massive Poly Lepis reforestation program, and has strong ties and trust with the indigenous communities of the Vilcanota Mountain range. ECOAN’s headquarters are based in Cuzco, Peru, the ECOAN branch affiliated with this project. Gregorio Ferro (Project Manager), Abdhiel (GIS Specialist), and Constantino (ECOAN President), are the three primary ECOAN members that are involved in this project. The previous Project Manager of ECOAN, Efrain, now works for the city government and has the potential to provide leverage for future project support. Having the government involved in this project is critical for its long-term success. The government can provide additional financial support and project initiatives may lead to future policy changes.

Mr. Decker has encouraged ECOAN to also reach out to the well-established engineering school in Cuzco. Students there could potentially help with in-country design, implementation, maintenance, and training. Perhaps students could also provide interpretation service if they know English well enough.

3.3 Soluciones Practicas

ECOAN and ESF-ESS are beginning a partnership with Soluciones Practicas, another NGO in Cuzco, to improve local technical capacity to facilitate project success. This initial effort is being coordinated with Rafael Escobar. Soluciones Practicas has previously worked with Stanford University and Green Empowerment of Oregon on renewable energy projects in Peru.

3.4 Mentors

Brian Hettler, an alumnus of ESF-ESS, has worked for The Amazon Conservation team (ACT) since 2012 and assembles and integrates ACT’s cartographic and GIS data, building representational maps to help ACT demonstrate project impact on multiple scales. Previously, with ESF-ESS and Engineers Without Borders (EWB), his many roles include helping to establish projects in Cusco, Peru involving BioSand water filters and participating in the design and implementation of a gravity fed water supply system in Buena Vista, Honduras. Mr. Hettler has previously worked with ECOAN, where he designed several community-based ecotourism facilities in Quechua communities and worked to develop sustainable regional tourism strategies near Machu Picchu. Brian carries a master's degree in Landscape Architecture from SUNY-ESF.

Ryan Storke is a renewable energy expert and currently manages the renewable energy division under The Cazenovia Equipment Company in Cazenovia, New York. Mr. Storke has a passion for implementing renewable energy throughout the world, especially in marginalized communities. He also leads his own consulting business, giving guidance for energy system implementation and maintenance. Mr. Storke provides technical and renewable energy management advice and expertise to ESF-ESS.

Samuel Redfield is the designer of the innovative pico-hydro generator (http://www.five-gallon-buckethydroelectric.org/). Mr. Redfield is a development engineer by practice and has attended a design summit in Ghana with MIT to develop what is now the alternator for a high head pico-hydro system. Sam has installed this generator in both Peru and Guatemala and works from home in New York creating new and inspiring energy producing technologies.
4.0 Site & Community Assessment

4.1 ECOAN’s Role
An important part of the project in the initial stages was site and community assessment. Considering the remoteness and extreme terrain of the project site as well as the cultural sensitivity due to previous failed projects, many precautions and shifts from normal procedures needed to be assessed before beginning the project. For example, the limited participation by women in the community needed to be conveyed to female travelers. ESF-ESS females were instructed by ECOAN to stay quiet to avoid disrespecting the males in the community. Another example is that a previous infrastructure project provided the community with a fish growing facility that was unsuccessful. This led to hesitation by community leaders and ESF-ESS had to rely on ECOAN to convince the community of this project’s feasibility.

Throughout this part of the project, ECOAN’s participation was critical. ECOAN has been involved with these communities for many years and has established a trust with community members. Additionally, many ECOAN employees were raised in these rural areas and understand the cultural intricacies that present themselves during projects within an indigenous community such as Abra Malaga. ECOAN employees are also fluent in Quechua, allowing the ESF-ESS group to bridge the gap between Spanish and Quechua.

Continuing from existing projects with Poly Lepis reforestation and solar panel installations, ECOAN has extensive information, knowledge, and relationships with the people of Abra Malaga. Over the past decade, ECOAN has conducted demographic surveys, led reforestation campaigns where they established nurseries and education opportunities in reforestation, and began solar panel installation in Abra Malaga in 2006. Currently, ECOAN maintains these relationships by holding a community leader meeting on the 15th of every month for the president of each of the 13 Vilcanota Mountain communities. Consequently, the role that ECOAN plays in this project is invaluable in terms of community assessment and capacity building support.

4.2 Surveys
In addition ESF-ESS members and mentors created two surveys to gain more understanding of the issues within the community. Using methods such as triangulation (gaining insight from many different societal groups), focus groups, and individual interviews, ECOAN and ESF-ESS members were able to receive answers to questions displayed in Table 1 and 2 (Mihelcic, 2009). The information gathered by ECOAN allowed ESF-ESS to see that although water, often times an initial focus in development projects, is not a health or abundance issue in the community. ESF-ESS was also able to increase awareness of the project partnership to distant families from the center of the community through conducting surveys.

The next step taken was to gather information regarding site assessment. This was first completed by mentor Mr. Hettler. Mr. Hettler spent time in Abra Malaga and recorded GPS points at each of the homes within the community. The GPS points were needed to understand the spatial distribution homes and which homes had access to solar panels due to the previous ECOAN project. Once the GPS points were mapped, a color code was applied to the points (yellow = electricity and white = no electricity per home) which also showed the density of homes in certain clusters (see Figure 7 in Appendix). Lastly, GPS points and flow values were recorded at sites of potential hydropower production. These sites were used to compare utilization due to cluster density and production due to the combination of flow and elevation difference.

4.3 Pre-Assessment Trip
A third step for ESF-ESS student leaders and mentors was to travel to Abra Malaga, Peru to meet the community and ECOAN. In this step, ESF-ESS initialized the project and partnership after project feasibility was completed from previous surveys and data collection. A first trip was conducted in August...
2012 that introduced ESF-ESS to some Abra Malaga community members and allowed previous ESF-ESS president Amanda Barnett to report back to the club. A second assessment trip was completed in August 2013 in which Thomas Decker, Ross Mazur, and Jessica Straub traveled to the community and participated in a board meeting. During the meeting, the three students were able to see the organization present in the community and the ability of ECOAN to coordinate with ESF-ESS and the community to make such a meeting a reality. Throughout the meeting, motivation for an electricity distribution project was at a high level and a Memorandum of Understanding (MOU) was signed to ensure that all three parties understood their responsibilities. The MOU demonstrated ESF-ESS as providing the capital cost and technical capacity, ECOAN as coordination, administration, and educational training support, and the community of Abra Malaga as the managers of the energy systems that will provide labor and that users will be required to pay a monthly fee in the future.

4.4 Future Steps
A step that should have been completed, but was not was a community risk and capacity analysis. For future initiatives, a risk heat map should be created to assess which project areas or community issues present the most risk (Amadei, 2014). After performing a capacity analysis, a project team can determine the level of risk and determine how capacity can be increased and in what areas. This kind of analysis is lacking in the project thus far but the project team is confident that the community has the capacity to develop themselves, given the increased access to electricity.

5.0 Project Strategy
After site and community assessment with ECOAN and Abra Malaga, ESF-ESS proved that the project could be feasible. Although a feasibility report was not completed, ECOAN’s efforts in the installation of solar panels laid a groundwork that a project could be built off of. Also, the community of Abra Malaga is well established and organized, reducing the initial capacity building that would be required in a development project. The availability of drastic elevation changes and available water near established homes provided justification that a small scale hydropower system could effectively augment power from solar panels. Lastly, ECOAN has vested interest in protecting the forests near Abra Malaga, using community members as environmental stewards. This shows that there will be long term institutional support by ECOAN to ensure sustainability of these energy systems. ESF-ESS members and mentors and ECOAN also created a strategy for project completion. The basis for the project strategy was to incorporate the community into the project as much as possible. A more complete method for a feasibility report would be to create an Action Feasibility Matrix, Gantt Chart, or Multi Criteria Utility Analysis Matrix to understand different routes and solutions to project success (Amadei, 2014). These methods will be considered in future project designs.

The project first component was to continue efforts started by ECOAN to install solar panels. It was decided that ECOAN would no longer install the panels themselves; instead the project would establish and train 1-3 technicians among the 150 person community that would be skilled in the installation and maintenance of solar systems. The second component was to implement small scale hydroelectric generators to take advantage of year round flow and elevation drops. The head drops and flows for the two prospective locations for hydro installation were 87 ft and 13ft, and 200 gpm and 340 gpm, respectively. There was no literature or other examples to follow concerning small scale hydro in the area, so part of this component included heavy monitoring and training of the 1-3 technicians. A third component of the strategy was to ensure project sustainability. This would take the form of ongoing education and the diversion of tourism entrance fees into the Abra Malaga preserve toward a maintenance fund that would assist families with replacement items.

To achieve the project strategy, the timeline below was created to provide a temporal description of expected results.
August 2012: Project initiation and community engagement. Agreed on a commitment of partnership between project participants.

August 2012-August 2013: Understood the lack of electrification in the community of Abra Malaga and potential solutions that are appropriate for implementation (Feasibility Studies). Initial fundraising and training for the construction of renewable energy technology in New York.

August 2013: Conducted triangulation (gaining insight from many different societal groups) and surveys while on a pre-assessment trip to the community (Mihelcic, 2009). The surveys provided initial demographics and initiated contact between the ESF-ESS team, ECOAN, and community. Signed MOU between all project partners. Began Implementation.

August 2013-December 2013: Continuation of fundraising to meet the budget goal of $20,000. Integration of an electricity council and trained technicians into the existing community council.

December 2013: Implementation trip for solar panel and micro-hydro training and implementation.

December 2013-August 2014: Continued working with ECOAN and community towards long-term sustainability while implementing monitoring methods.

August 2014-December 2014: Searched for larger grant programs and investigated a structure where community members can earn income from the implementation of renewable energy in other Vilcanota Mountain range communities using ESF-ESS as institutional support and ECOAN for coordination support.

Year 2015: Begin a sustainable, possibly profit generating system in which other rural communities benefit from the work done in Abra Malaga.

6.0 Project Design/Implementation

6.1 Design
To begin the design process, ESF-ESS students worked with mentors to research and explore the definitions and previous projects concerning solar panels and micro-hydro. After an initial investigation, students were able to see the differences between solar panel and micro-hydro designs and installation. A big difference is that hydro requires more infrastructure and engineering knowledge in both design and installation. Solar panels have already been designed and come in a package from Lima, with easy installation. However, the intake, sedimentation tanks, and penstock allow micro-hydro to produce energy 24 hours a day where solar panels can only produce about 12 hours per day. Solar panel projects are more widespread, with more companies and organizations throughout the world working on the progression of solar panel installations, where micro-hydro work is sparse and less available. Due to this finding along with ECOAN’s experience with solar panels, the ESF-ESS team focused more on hydro design and research for the two best locations identified by the community for micro-hydro.

6.1.1 Solar Panels
Before choosing which systems to use, the team defined some basic electrical parameters based on the assessment surveys. Community members stated that they would need electricity for lights, recharging batteries, powering radios, and in some cases for watching television. Therefore, there was no need to establish an AC power grid. The community was starting at ground zero and thus there were no high
electrical demand devices or equipment in the homes that would require AC. Establishing a centrally located AC grid would also prove difficult given the expansive spatial distribution of homes in the community (see photo below). The team decided to pursue individual installations, with one 90 watt solar panel and a 150 Ah glass mat battery serving 1-2 homes and a 100-200 watt micro-hydro generator and 150 Ah glass mat battery serving 3-4 homes, which run on 12V DC. Having 12V DC allows community members to power a light, radio, or any other basic device that runs on a battery. A load assessment was not completed because the only loads present in the community were radios that ran on AA or AAA batteries. Therefore, a 90 watt solar panel producing electricity for 12 hours a day is able to provide energy for three to four 15 watt compact fluorescent lights (CFL) and two radios to share between two homes. The hydro generators have a greater capacity due to 24 hour production and allow for electrical device charging (cell phones), 6-8 CFL’s based on daily usage, and 2-4 radios.

![Figure 2: The vast, empty surroundings of the one home in the photo's foreground.](image)

The team then completed a brief comparison of prices and electricity production of two different panel systems from the vendor that ECOAN previously worked with (Energia Innovadora). The first system was a 90 watt panel, 150 Ah glass mat battery, charge controller, 15 meters of cable, 3 CFL’s, 1 socket, 1 circuit breaker, and a battery storage box for $750 USD. The second system, a Barefoot 3000, was a 30 watt panel, 24 Ah sealed battery with charge controller, 4 LED tubular lights, and 1 outdoor light for $470 USD. Due to proven effectiveness from 2006-2012, the team decided to move forward in the project with the purchase of 90 watt panels. Limited design was required with the panels because Energia Innovadora provided a package including the 90 watt panel, a 5 amp charge controller, a breaker switch, 12 AWG cable, a 150 Ah sealed glass mat battery, three 15 watt CFL’s and porcelain sockets, two switches, and a box to house all components. However, a lesson learned in the design of the panel systems was incorporating the orientation of the panel. When students participated in a solar panel workshop in New York, the general rule was to orient the panels toward true south and tilt the panels based on community latitude. Once in country, students realized that in the southern hemisphere, the sun is tilted in the opposite direction and the panels need to be oriented toward true north with each panel angled at the latitude of Abra Malaga (13 degrees).

### 6.1.2 Hydroelectric

After completing the design and developing an understanding of the solar panel systems, ESF-ESS began work on finding an affordable and appropriate technology that could produce electricity from hydropower. First, the team created design objectives with the four most important being:
- Locally source materials
- Minimize cost
- Maximize productivity
- Maximize ease of maintenance

In the United States, there were several micro-hydro permanent magnet alternator systems for sale that could have been shipped to Peru with prices ranging from $2,000-$3,000. These systems have high efficiencies and reliable companies that produce them. However, the ESF-ESS team decided that maximizing productivity was the least important of the four objectives and that designing a system that was locally sourced, affordable, and able to be maintained over time was more important. With these objectives in mind, the team discovered the five gallon bucket pico-hydroelectric generator designed by Samuel Redfield. This generator utilizes a rebuilt Toyota Nippondenso 22R car alternator to produce energy as a permanent magnet alternator. Mr. Redfield and the Appropriate Infrastructure Development Group worked together to perform design iterations with the generator. From these iterations, the number of winds in the stator as well as wire gauge used to rewind was optimized. They continued to test the generator with different flow situations and produced Error! Reference source not found. below. Using the generator specifications, Bernoulli’s equation, and Mr. Hettler’s previously recorded elevation and flow data, ESF-ESS was able to design an intake and penstock system at one of the specified locations for the production of 12V DC. Within the alternator is a rectifier with three diodes that converts the AC that is produced by the generator into DC to charge batteries.

Table 1: Test results for the Toyota-Redfield PMA with 25 winds

<table>
<thead>
<tr>
<th>Flow Condition</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Rate (Lpm)</td>
<td>70</td>
<td>100</td>
<td>125</td>
<td>150</td>
<td>170</td>
<td>186</td>
</tr>
<tr>
<td>Velocity Head (m)</td>
<td>0.012</td>
<td>0.025</td>
<td>0.039</td>
<td>0.066</td>
<td>0.072</td>
<td>0.086</td>
</tr>
<tr>
<td>Pressure Head (m)</td>
<td>6.32</td>
<td>10.54</td>
<td>15.87</td>
<td>22.49</td>
<td>27.70</td>
<td>28.11</td>
</tr>
<tr>
<td>Total Head (m)</td>
<td>6.34</td>
<td>10.57</td>
<td>15.91</td>
<td>22.54</td>
<td>27.76</td>
<td>28.20</td>
</tr>
<tr>
<td>Total Head (ft)</td>
<td>20.79</td>
<td>34.86</td>
<td>55.45</td>
<td>73.95</td>
<td>87.83</td>
<td>92.48</td>
</tr>
<tr>
<td>Open Voltage (V)</td>
<td>19.5</td>
<td>55.0</td>
<td>82.2</td>
<td>96.5</td>
<td>110.0</td>
<td>116.0</td>
</tr>
<tr>
<td>Power (W) at 1.2 ohms</td>
<td>0.0</td>
<td>1.4</td>
<td>5.6</td>
<td>11.4</td>
<td>16.9</td>
<td>20.0</td>
</tr>
<tr>
<td>Power (W) at 2.3 ohms</td>
<td>0.0</td>
<td>2.7</td>
<td>10.9</td>
<td>21.3</td>
<td>32.2</td>
<td>36.8</td>
</tr>
<tr>
<td>Power (W) at 5.0 ohms</td>
<td>0.0</td>
<td>5.8</td>
<td>22.1</td>
<td>42.1</td>
<td>62.7</td>
<td>67.7</td>
</tr>
<tr>
<td>Power (W) at 33 ohms</td>
<td>0.0</td>
<td>17.3</td>
<td>53.5</td>
<td>91.7</td>
<td>123.3</td>
<td>136.0</td>
</tr>
</tbody>
</table>

However, of the two locations for micro-hydro, only one was high head. A limitation of the five gallon bucket system is a requirement of at least 30 feet of head (see Appendix for drawings and calculations). The second location only had 13 feet of head which does not allow for the use of the five gallon bucket generator. Instead, the team plans to design a more expensive sluiceway and draft tube low head system or an enclosed penstock system with a more efficient turbine (Powerspout). In this instance, the team sacrificed the affordable design and locally sourced materials objectives due to the projected benefits that would result from the installation of a second, more productive hydro system compared to replacing the second system with solar panels.

7.0 Implementation
From the project concept, completed site and community assessment, and the formulated strategy and design, ESF-ESS, ECOAN, and the community were able to begin implementation during August 2013. Throughout this trip, two five gallon bucket generators were built and three 90 watt solar panel systems were installed by ECOAN and ESF-ESS members (Figure 3 and Figure 4). In addition to the generators, an intake and penstock were constructed for one of the generators with the second generator for backup in case of failure. The intake was a screened PVC pipe that was to be inserted behind a dam that led to a 100
meter section of 64 mm HDPE pipe. Working at such altitudes without any other examples for micro-hydro installation, the team experienced some difficulties and could not finish the micro-hydro installation. There was confusion as to where the implementation site would be based and the team wasted a day relocating all materials to the site. At the intended site, the lost day prevented the construction of the dam for the intake. Also, the correct charge controller for load diversion was not purchased. When testing the generator, the initial charge controller was damaged due to limited internal resistance and no capability to divert excess production to a dump load. However, the installation of the panels was smooth and without incidence, due to previous experience in the community with solar panels.

Figure 3: One of the solar panels installed

Figure 4: The two generators built Aug 13'

Over the course of the December 2013 trip four solar panels were purchased and brought to Abra Malaga. Rather than ECOAN installing the panels, a half day workshop was conducted by ECOAN and ESF-ESS to teach community members the workings and instructions of solar panel installation (Figure 6). A previous ECOAN engineer instructed the community on the difference between positive and negative, how to use a multimeter, how to strip a wire, the meaning of a battery, charge controller and breaker, and how to fully install a panel system. After the workshop, the team stepped back and allowed the community to install the panels themselves, giving them technical ownership of the project (Figure 5). This approach was a great success because the workshop was a positive step in the direction of technical education and community self-sufficiency with solar panel maintenance and installation. The first micro-hydro installation was also assessed for design improvements to the intake, dam, charge controller, and penstock vacuum release. Lastly, while in Cusco, ESF-ESS worked with ECOAN to establish an efficient monitoring plan including monthly meetings with Abra Malaga, a maintenance reporting sheet and schedule, and improved scheduling for communication.

Figure 5: A light illuminated with 12V from a solar panel

Figure 6: A workshop held by ECOAN training potential technician
A third trip in August 2014 was conducted to establish final implementation plans for the solar panel components, perform consultation with Mr. Storke to assess the first micro-hydro installation, confirm the design and location of the low head hydro system, and finally to formally define the role of Elmer, Abra Malaga’s lead technician. Mr. Storke was able to teach Elmer more specific renewable energy details, such as battery type and maintenance, electrical issue debugging, panel orientation, and continuity testing using the multimeter, that ECOAN could not perform in December of 2013.

The struggle with the installation of micro-hydro was due to a lack of a skilled mentor in this area. The important lesson learned is that without a well-versed and knowledgeable mentor, even the best intentioned project can be delayed and even fail.

8.0 Planning, Monitoring, Evaluating, and Learning (PMEL)

8.1 Planning
The planning portion of the project was split into several different components. The first began with the site and community assessment process which included two trips to the community, surveys conducted by ECOAN, as well as GPS and flow data recorded by Mr. Hettler. The second component was the passing of responsibility and decision making to the community in an equitable manner. The community board and president compiled a list of homes without electricity and through efforts to encourage their ownership in the project; they were given the task to choose the order in which homes would receive a solar panel. The order was determined based on how involved a family had been in community organization and progression and meeting attendance. For example, a family that had attended every community meeting and helped in all community events would be on the top of the list to receive a panel. A third component of the planning portion of the project was to choose the two locations for the micro-hydro systems based on utilization rather than the objective to optimizing power produced. For example, a site that has lower production potential with three families surrounding the source was rated a better site than a site with a higher production potential with one home near the source. A fourth and final component was to allow ECOAN to schedule trips, meetings, and implementation times. ECOAN has a thorough understanding of holidays, cultural practices, and social norms that may conflict with implementation dates that ESF-ESS may have chosen.

8.2 Monitoring
The monitoring portion of the project was established to ensure that the installed systems do not degenerate in the future. In the previous solar panel project in Abra Malaga coordinated by ECOAN, there were no technicians to provide support. Rather ECOAN inspected systems on a monthly basis or while passing through the community. However, this project established 1-3 technicians that live in the community and can provide monitoring support each day. For the technicians, ESF-ESS created Table 2 to assist with recording information. The monitoring schedule for the technicians was created to be flexible yet thorough, with all the systems in the community being inspected at least once per month. This timeline for monitoring was meant to coincide with ECOAN’s monthly meeting in the community. This way the technicians are able to convey any issues that they cannot solve to ECOAN and report (using Table 2) what issues they were able to solve.

Table 2: A table for maintenance & monitoring

<table>
<thead>
<tr>
<th>Column1</th>
<th>Column2</th>
<th>Column3</th>
<th>Column4</th>
<th>Column5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Name</td>
<td>The problem</td>
<td>How to repair?</td>
<td>The name of who repaired</td>
</tr>
</tbody>
</table>
8.3 Evaluation
For the evaluation portion, the ESF-ESS team created the following evaluation criteria to determine if the project was successful. These criteria or objectives are impact oriented, time limited, specific, practical, and measurable.

1.) Improve access to electricity: Every home in the community has at least one light and one plug to utilize by December 2014, with an opportunity to have 3-4 lights and 2-3 plugs, maximizing electricity availability
2.) Improve electricity education: The community shall select 1-3 individuals to travel to Cusco to attend an electrical institute and learn about renewable energy in March 2014.
3.) Encourage economic stimulation: Community members will be trained during implementation and may earn an income installing future systems for other communities. Technicians who perform maintenance will immediately be paid via a labor based economy.
4.) Ensure long term success: Establish maintenance and institutional support schedules with ECOAN and secure tourism fees for big ticket maintenance items by Dec. 2014
5.) Encourage ownership of all of the systems by the community after completing installation by Dec. 2014

8.4 Learning
The learning portion of the project was an important outcome for all three partners. ESF-ESS students would learn about international development and different cultures, ECOAN would learn from practices implemented by ESF-ESS members, and the community would be able to learn about renewable energy, project planning, monitoring, and evaluation, and how to communicate effectively with all project partners. More specifically, the learning plans included a workshop performed by ECOAN to train prospective technicians as well as bringing those technicians to Cusco and place them into a renewable energy training school.

From the monitoring process with the technicians of the community, there can be increased learning about the state of the systems. Monitoring provides the ability for ECOAN and ESF-ESS to understand common issues that occur frequently and to come up with long-term solutions. Monitoring also gives community members maintenance organization skills, and builds their note taking and observational skills.

To improve the project’s learning outcomes, quantification and verification also needs to take place. There needs to be measurable evidence of how the project impacted a community and what actual benefits were realized similar to World Bank Reports completed in Peru (Bariloche, 2013).

9.0 Strategic Results
Since the investigation phase of the project where the strategy was devised, ESF-ESS and ECOAN have made great strides toward completing the aforementioned objectives. Since August 2012, the number of homes without electricity has decreased from 20 down to 5, and the ability of community members to elongate their workday has increased, with actual numbers to be assessed in future surveys. Within this progress is the first part of the strategy: community involvement. The project has successfully integrated the community into each step of the project process and has encouraged them to take ownership of their systems. For example, a family decided to leave the area for parts of the year and return for the other part. When changing homes, the family takes their solar system with them and re-establishes the system at their new home each time they move, exhibiting the ownership that ESF-ESS hoped to achieve. ESF-ESS has also maintained the MOU agreement with the community for the entirety of the project, ensuring that
the community is made aware of all independent and shared responsibilities. A second part of the strategy was the solar panel installations, which have been largely successful, with some of the panels in the community providing sustainable light since 2006. The new method of transitioning responsibility to Elmer, the local technician, to install the panels, has given him self-confidence and skills to manage solar panel systems. A third part of the strategy that has also been successful are the monitoring and evaluation plans. All families that have panel systems know that Elmer is the head technician and are able to communicate with him effectively if there is a problem. In turn, Elmer has the ability to record all inspections and report back to ECOAN with any issues.

However, there have been a few unexpected issues with following the strategy. The first has been with the installation of the first hydro system. Although the hydro system has many benefits and outperforms the solar panel systems, the remoteness and lack of professional expertise has led to a delayed installation. However, with an expert on board, installation of the first and second hydro systems are progressing according to a new schedule. A second issue has been with finding an instructor at a renewable energy institute that can communicate in Quechua. Only a few members of the community know Spanish (Elmer is one), and when conversing in Spanish, concepts and ideas are often lost. The community members are more apt to understand new concepts when conveyed in Quechua and up to this point ECOAN has been unable to find an instructor capable of communicating in this language. A third issue that has prevented the strategy from being followed has been funding. With more funding at an earlier time, all the needed panels could have been purchased and installed by community technicians.

10.0 Reflections
Throughout the project period, there have been great strides in community progression. One of the largest positive aspects of the project has been a noticeable change in the community’s pride and how they represent themselves. Having a new resource allows them to have hope for the future. Another positive impact that was seen almost immediately was the ability for young women and mothers to teach themselves how to read and write at night (statistics to be gained in future studies). A mother was witnessed weeping in joy after having a solar panel installed and described how in the past she had no free time during the day. She was either taking care of her kids, cooking, cleaning, or herding sheep. Now at night when all tasks are done and the kids are asleep, she can take time to improve her own skills. Another positive aspect has been empowering Elmer, the community technician, to take on a new role in the community and learn new and exciting concepts that he can apply to other parts of life.

Even when considering how much of a positive impact this project has achieved, there are still a few negative aspects as well. The first is the delay of hydro installation. When a part of a project goes incomplete for a period of time, there is a certain tendency for community members to lose faith. In this instance, planned installation strategies may remedy this problem, but there may also be doubt in the community over the effectiveness of this system. A second negative aspect is that Elmer was trained after the panels were installed, rather than before, limiting his ability to install additional systems. A third negative aspect is that currently, the system does not produce a profit to benefit the whole. The system sustains in other ways, but having a labor based economy does not pay for a new batteries or solar panels when needed. As a solution, ECOAN has agreed to pay one half the price of the battery and the family is required to pay the other half. In the instances where a battery has needed to be replaced, this model has worked. For small parts, families are able to buy replacements.

Given some of the positive and negative aspects and considering the project as a whole, one thing we would have initially done differently was to encourage technician training and community based solar panel installation during the Aug 2013 trip. ESF-ESS members and ECOAN conducted the installations rather than the local technician. Had this been done, the technician would have had more time to understand the systems when a second trip was made in Dec 2013. Another thing we would have done differently relates to the handling of the hydro systems. More time should have been taken to install the
systems and the rushed nature of implementation may have been a contributing factor to the delay of installation. The first trip taken to the community by the current project team and manager in August 2013 should have been a site assessment. Instead, the team relied on GPS and mapping information rather than on ground experience and local observed data. If the team gathered elevation and flow data on the ground and better understood the, a second trip to begin implementation may have been more successful. A third thing that could be done differently is putting more consideration into the administered survey shown in Tables 4 and 5. The questions were sometimes asked in a way where the community member was led to the answer, and others made assumptions about the knowledge or background of the community members. When creating the surveys, the project team was solely comprised of engineers. There is value of not only having engineers, but also social scientists and language and cultural experts. In the future the ESF-ESS team plans on working with Syracuse University anthropologists and language experts to form better-structured surveys and evaluation forms.

11.0 Conclusion
Even though there have been some halts and delays, there has been considerable progress and great work done in this community. ECOAN’s original panel project has been able expand into the entire community. There are currently 26 panels in the community with 10 panels purchased and installed since August 2012. In 2006, all 32 homes were without electricity and now there are only 2. Men, women, and children have experienced the benefits of electrification with many more expected benefits to come in the future with project expansion.

12.0 Bibliography
## 13.0 Appendix

### Table 3: General Information Questions

<table>
<thead>
<tr>
<th>Q.1</th>
<th>Q.2</th>
<th>Q.3</th>
<th>Q.4</th>
<th>Q.5</th>
<th>Q.6</th>
<th>Q.7</th>
</tr>
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<tr>
<td>Number of Family Members?</td>
<td>What do you have that needs electricity?</td>
<td>Where do you recharge batteries?</td>
<td>Where do you get water?</td>
<td>Is the water contaminated?</td>
<td>Are there any stomach problems?</td>
<td>Do you have a river source for hydropower?</td>
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<td>Punto 3</td>
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<td>no</td>
<td>no</td>
</tr>
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<td>Recarga de celular, Radio transmisor, y TV</td>
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<td>Punto 1</td>
<td>No, turbia cuando llueve</td>
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<td>no</td>
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<td>2</td>
<td>Radio transmisor</td>
<td>No</td>
<td>Punto 3</td>
<td>No, turbia cuando llueve</td>
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<td>Recarga de celular, Radio transmisor</td>
<td>No</td>
<td>Punto 3</td>
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<td>Recarga de celular, Radio transmisor, y TV</td>
<td>Nuera (panel solar)</td>
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<td>no</td>
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<td>5</td>
<td>Recarga de celular, Radio transmisor, TV y video</td>
<td>No</td>
<td>Punto 1</td>
<td>No, turbia cuando llueve</td>
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<td>Distrito</td>
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<td>Rumira Sondormayo</td>
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Table 5: Demographic and Electricity Information Questions

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<th>Q.7</th>
<th>Q.8</th>
<th>Q.9</th>
<th>Q.10</th>
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<tbody>
<tr>
<td>Name</td>
<td>Sector</td>
<td>Sex</td>
<td>Age</td>
<td>Occupation</td>
<td>Do you know about the electricity project in the community?</td>
<td>How do you think electricity can change the community?</td>
<td>What will you use the electricity for?</td>
<td>Can you tell me how much money you make each day?</td>
<td>&quot;Electricity is good for the community.&quot; Do you agree? Why do you think so?</td>
</tr>
<tr>
<td>Modesto apaza sichi</td>
<td>cruz moqo</td>
<td>M</td>
<td>20</td>
<td>porter</td>
<td>knows that the project is present because of the solar panel installations</td>
<td>yes it’s good, one can work more &amp; use electronic equipment like radio, television</td>
<td>charging batteries, lanterns</td>
<td>25.00 sols a day as a porter only when the opportunity exists, he doesn't have an amount in mind for his farming/animal-raising work</td>
<td>yes</td>
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<td>claudio huaman quispe</td>
<td>chico abra malaga</td>
<td>M</td>
<td>67</td>
<td>farmer</td>
<td>yes, is aware of the project's intervention</td>
<td>it’ll provide better lighting service for the community</td>
<td>television, radio, it can be used for other things but they’ll need more information</td>
<td>he doesn't have an idea of how much he makes, he only works for food/sustenance</td>
<td>yes, they won't use kerosene anymore and service is good for each house</td>
</tr>
<tr>
<td>juan tilca aviles</td>
<td>qosni ritti</td>
<td>M</td>
<td>20</td>
<td>porter</td>
<td>is not very aware, but recently moved to the community</td>
<td>it’s good because everyone’s homes will have energy</td>
<td>television, radio, charging cell phones, lanterns &amp; light for all houses</td>
<td>35.00 sols for work as a porter &amp; in construction, only when the work is available</td>
<td>yes he agrees because light service will reach all houses</td>
</tr>
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<td>juan huaman llaquey</td>
<td>inka raqay</td>
<td>M</td>
<td>36</td>
<td>farmer</td>
<td>yes, is aware</td>
<td>it will better our homes, education and the use of electronic devices</td>
<td>radio, charging batteries, hot showers</td>
<td>5.00 (sols) a day; he doesn't have an idea of how much he makes in mind an amount per day for his farming work</td>
<td>yes he agrees, they can improve their houses &amp; won't be dependent on candles/kerosene</td>
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<tr>
<td>jacinta quispe machaca</td>
<td>ttasta pampa</td>
<td>F</td>
<td>42</td>
<td>her house</td>
<td>yes, he knows, they receive support in exchange for caring for the forest</td>
<td>they will have light, the population will grow and education will improve</td>
<td>light for the house, radio, television, computer &amp; to dedicate to crafts/trades and computer work</td>
<td>she doesn't know, neither does she have an idea of how much she makes</td>
<td>yes she agrees, it's important for her family</td>
</tr>
<tr>
<td>hila tilca aviles</td>
<td>qosni ritti</td>
<td>F</td>
<td>29</td>
<td>her house</td>
<td>yes, she knows - they're helping her family</td>
<td>to have light for one's self/home, better education for children</td>
<td>light, radio, television</td>
<td>she doesn't know, she's always in the house with her children &amp; she helps with farming/fieldwork</td>
<td>yes because it will bring light to the house</td>
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<tr>
<td>martina huaman echame</td>
<td>inka raqay</td>
<td>F</td>
<td>77</td>
<td>her house</td>
<td>yes, she knows, along with all the other projects that ECOAN is doing</td>
<td>it’s good because they’ll have clean energy, not from candles or kerosene</td>
<td>to have light</td>
<td>she doesn’t know, she only supports/helps her children in farming/fieldwork</td>
<td>yes, she agrees</td>
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<td>exaltacion apaza huaman</td>
<td>centro ttastay oc</td>
<td>M</td>
<td>37</td>
<td>farmer</td>
<td>it benefits and includes the community</td>
<td>they will have light and clean energy</td>
<td>to have light while saving money &amp; for the use of electronic devices</td>
<td>20.00 sols working as a porter</td>
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<td>Fortunato quispe atwayo</td>
<td>qosni ritti</td>
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<td>her house</td>
<td>she doesn’t know much about the project</td>
<td>it’s good because he will have energy for his house and it will</td>
<td>radio, light, television &amp; other equipment/electronics</td>
<td>she does work for the good of the community, she doesn’t know/have an idea of how much she makes</td>
<td>yes she agrees, we can all have light for all of our houses</td>
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<td></td>
<td>ridiculously</td>
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<td>improve the children's education</td>
<td>light &amp; other electronic equipment</td>
<td>30.00 sols only when he works as a porter, he doesn't know/have a good idea of how much he makes for the rest of his work</td>
<td>it is good, it's compensation for caring for the forests</td>
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<td>timoteo quispe</td>
<td>kacho pata</td>
<td>M 34</td>
<td>farmer</td>
<td>yes, he knows</td>
<td>we will have energy in everyone's houses, better children's education &amp; computer use</td>
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<td>Eulogio Apaza</td>
<td>ttastay oc-croz royo</td>
<td>M 49</td>
<td>farmer &amp; porter</td>
<td>yes, he knows, ECOAN has already begun the project</td>
<td>it's good, everyone can have a solar panel &amp; it will better support community children</td>
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<td>light for houses, radio &amp; the use of minicomputers in school</td>
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<tr>
<td>yesica vargas</td>
<td>ttastay oc-croz royo</td>
<td>F 19</td>
<td>her house &amp; weaving</td>
<td>yes, he knows</td>
<td>radio, television, charge cell phones</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>huaman</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>she doesn't know, she only farms and weaves for her own use</td>
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<td>isidro calisaya</td>
<td>kallqui moqo</td>
<td>M 30</td>
<td>farmer</td>
<td>yes, he knows</td>
<td>light for houses, radio, television and to be able to work more with crafts/trades</td>
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<td></td>
<td>will better homes, the work of community crafts &amp; trade workers &amp; children's education</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ritchi</td>
<td></td>
<td></td>
<td></td>
<td>yes, he knows</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hermenegildo</td>
<td>qosni ritti</td>
<td>M 28</td>
<td>construction</td>
<td>yes, he knows</td>
<td>betterment of his home</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>apaza cordova</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>his own light, radio &amp; other things</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fortunato tillia</td>
<td>qosni ritti</td>
<td>M 52</td>
<td>farmer</td>
<td>yes, he knows - ECOAN is the first group to help with this project</td>
<td>he will have his own light, and the children's education will improve</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>radio, electronic devices, blender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>600.00 sols a year, from the sale of his animals and potatoes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- It is good, it’s compensation for caring for the forests
- Yeas, it’s good, it will better family involvement/working together as a community
- Yes she agrees
- Yes he agrees
- It’s good, there is even interest in other communities
- He agrees, it will bring development
- He agrees, they need training/education
Figure 7: A Map of Original Electricity Distribution
Calculations of Pico Hydro Power Production

Table 6: A Table of the Given Values for Fluid Mechanics Calculations

<table>
<thead>
<tr>
<th>Flow (m^3/s)</th>
<th>Length (m)</th>
<th>Atmospheric Pressure (Pa)</th>
<th>Diameter (m)</th>
<th>Penstock Pressure Gage (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.012</td>
<td>100</td>
<td>63,327</td>
<td>0.063</td>
<td>380,000</td>
</tr>
</tbody>
</table>

Penstock Cross Sectional Area \(= \frac{\pi}{4} (0.063^2) = 0.00312 \text{ m}^2 \)

Under the condition that \(V_1 = 0, V_2 = 3.85, P_1 = \text{atmospheric pressure}, \) and \(P_2 = 380,000 - P_1 \)

\[
\Delta H = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} - \frac{P_1}{\rho g} - \left(\frac{V^2}{2g} * f * \frac{L}{D}\right)
\]

Where \(f\) is found using relative roughness and Reynold’s Number

\[
\varepsilon = \frac{K}{D} = \frac{1.5e^{-6}(K \text{ for PVC})}{0.063} = 0.000024
\]

\[
Re = \frac{\rho V D}{\mu} = \frac{(1000)(0.012)(0.00312)}{1.1e^{-3}} = 2.2e^5
\]

Using the moody diagram, \(f = 0.0158\)

Therefore

\[
\Delta H = \frac{316.673}{9810} + \frac{3.85^2}{19.62} - \frac{63,327}{9810} - \left(\frac{3.85^2}{19.62} * 0.0158 * \frac{100}{0.063}\right)
\]

\[
\Delta H = 7.8 \text{ meters available after friction}
\]

\[
\Delta H = 26.6 \text{ meters available before friction}
\]

Based on these values the theoretical power at this point is

\[
\text{Power} = \frac{\rho \times g \times \Delta H \times Q}{(\text{conversion factor})3.6e^6}
\]

\[
\text{Power} = 3.1 \text{ kW}
\]

Due to more losses and a generator efficiency of 15-30%, 100-200 watts can be produced realistically with the five gallon bucket generator.
Figure 8: Five Gallon Bucket Generator

Figure 9: The Modified Shaft and Rotor Assembly