AC 2009-1680: CREATING A SUSTAINABLE-ENERGY BUSINESS IN RURAL HONDURAS

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Creating a Sustainable Energy Business in Rural Honduras

Abstract

International service learning has become a significant component of many engineering education programs. Much of the work has been done as volunteer projects where a group of students and faculty go to another country and install some engineering project in a poor community. The students then go home and leave the local community to try to maintain it.

Many of these projects have a long term effect upon the student participants as they gain a perspective on the needs of the world. However, their impact on the local community they tried to serve can be much shorter in duration.

This paper describes our work in rural Honduras. Several years ago we started out by designing and installing a micro-hydroelectric system in a poor mountainous village. It began operations in 2007 in a village of about 50 homes. Although the villagers were trained in the general operation of the equipment, they were not trained well enough to operate a small business with it. Therefore, cash was not available to repair or maintain the system. We have, therefore, transitioned to a different working model that not only deploys equipment, but also provides a system of enterprise which helps the system operate as a financially sustainable venture.

During July and August of 2008, ten students and two faculty members worked for extended periods of time in Honduras. Part of the project was to create a pico-hydroelectric utility company in a village of 25 homes. A pico-hydroelectric system was deployed to generate electricity and a company was formed to collects fees from villagers, maintain the system, and prevent theft of electricity. These fees pay the salaries of three families to work for the company on a part-time basis. This local company will be a franchise. Part of their profits will be paid to the franchiser. The franchiser is a second, parent company, incorporated in the United States with operations in Honduras. Fees paid by the franchisee to the franchiser will allow another energy company to be created in a nearby village. We are in the beginning stages of the process, having formed only one franchise at this present time. Future papers will describe the results of this franchising.

This project can have a broader impact than just rural Honduras. The choice of franchising was made for rapid scalability. We can use the knowledge gained by creating these micro-hydroelectric systems in other developing countries. Cheap and clean electricity, along with local jobs, can help improve the health, education, and economic burden of rural people.

Project Background

Our program of international involvement is a significant step in our goal to make service learning a larger component in our engineering program. This project is also one step in the process of expanding our research work in appropriate technology. We use the term "appropriate technology" to mean technology that is culturally appropriate, environmentally benign, financially sustainable, and repairable with the infrastructure available to the people using it.

Our students gave up significant amounts of time, effort, and money to serve poor people in another part of the world. This application of appropriate technology in a developing country is very consistent with Baylor University's mission, part of which is:

"to educate men and women for worldwide leadership and service."

Our students created a student organization to promote such experiences both locally and internationally. Some of them take part in trips to assist poor communities in other countries. Furthermore, they change our students' perspective about themselves and our world.

This work grows out of our university's work doing international engineering service projects in developing countries over the past several years. We installed a wind powered electrical system in the Kibera slums of Nairobi in 2006[1]. At the same time we installed a water purification system for a school that also had no source of electricity[2]. This required installing a solar powered system that could be used to power the purifier as well as provide lights for their building. Over the last four years students have gone on additional service learning trips to Armenia (2 trips), Papua New Guinea, the Philippines, and Vietnam. Projects like these can tremendously change the people who go as well as help the people to whom the project is aimed.

We have begun to realize that a key problem with many of our projects is that making them sustainable is difficult. Our desire to have sustainable projects has let us to explore issues related to entrepreneurship. We have begun to incorporate entrepreneurship topics into a number of our courses[3,4].

The location and scope of these projects have all been chosen based on prior contacts with a poor community that needs some engineering help. We have gone only to places where the people in the local community indicate to us that they have a need our students can help fulfill. With this prior contact our students are able to partially design the project on our campus and then complete the design and deploy it as part of an international trip. There are often so many unknowns that the design cannot be completed until students arrive on-site, and this also provides rewarding contact with the "customers."

For a project to be successful, there are some things that need to be done before the project can be implemented. They are:

1. Have contacts in the country who are interested in having us do the project and who can act as a resource.
2. Know enough details about the project so that the design work can be begun during the academic year at our university.
3. Raise enough money to pay for travel to the country and to purchase the needed equipment.
4. Have someone from our university handle logistics on the ground in the other country so that the faculty member and students can concentrate on the engineering project and not get overwhelmed by just surviving in that country.

Local contacts are a critical component for the trip to be successful. For this to occur, there may need to be a small exploratory trip before the major trip can be organized. For example, six students and three professors from our university went to several locations in Kenya in spring 2005. These locations were based upon prior contacts that the professors had with people in the country. While there were some minor engineering projects completed during that trip, the main purpose was to explore future possibilities. We have previously reported on this trip at the spring 2006 ASEE regional conference in Baton Rouge[5].

This exploratory trip resulted in two groups of students going to Kenya in 2006. One group installed a wind powered electrical system in the Kibera slums of Nairobi. The other one put in a water purification system at a Deaf School in the western Kenyan town of Oyugis[2]. This school did not have a permanent source of electricity to run the purifier. Therefore, part of the project was to design and install a solar powered electrical system for the school.

In January 2007 a professor led a small team of students to Honduras to examine the possibility of installing a small hydroelectric system in a mountainous village. This led to a larger group going in the summer of 2007 to do the actual installation. We have since received a grant from a foundation that allowed us to replicate this in other villages.

One of the authors went to Rwanda in January 2008 to examine potential projects. There are several electrical and water projects that could engage and challenge our students. This includes helping out the Sonrise School near Musanze, Rwanda, and a medical clinic in Shyira, Rwanda. Good contacts were established at these two places. They are very interested in our coming back with students to help them in late spring 2009.

Presently there are at least 1.1 billion people world wide who live without clean water[6] and there are almost 2 billion who do not have access to proper waste treatment via either sewage treatment or at least outhouses[7]. There are about 0.9 billion who do not get enough food each day[8] and there are 1.6 billion who do not have access to electricity[9]. Although this last piece of data might seem out of place in the list of needs such as food or water, access to electricity provides many benefits. Access to electricity allows for an increase in security due to better light, the removal of dangerous liquid fuel-burning lamps from living areas, the ability to preserve food, and even charge cell phones, which are used in emergencies. Furthermore, electricity and other infrastructure has been shown to be linked to economic development. The World Bank says "The precise linkages between infrastructure and development are still open to debate. However, infrastructure capacity grows step for step with economic output – a 1 percent increase in the stock of infrastructure is associated with a 1 percent increase in gross domestic product (GDP) across all countries."[10] Furthermore, "It is widely recognized that electricity is a central element for social and economic development. It contributes to economic growth and underpins a range of basic welfare services, such as clean water, health, communications, and education. Research on rural electrification suggests that rural people without access to electricity only need small amounts of energy to improve their quality of life and their income. In most cases, electricity is necessary for the provision of lighting and community services such as education and health."[11] This project is about reaching as many of these people with electricity as possible, to improve their lives in tangible and intangible ways.

Traditionally development work has been done by good-hearted people who desire to help the poor. Their typical mode of development is to enter into an area and try to give aid by building hospitals, clinics, schools and churches that are funded entirely through foreign monies. Although it is never their intention, what they most often succeed in developing, is a culture of dependency that relies on the incoming gift monies from developed nations.[12] Most often the poor are incorrectly seen as being incapable of taking care of themselves and must therefore be provided for, rather than taking a positive approach of helping them develop business opportunities that they come up with.

Our university has sent several teams around the world to do engineering projects that help the poor. Recently the student group has started focusing on the country of Honduras and two of the authors were on the first student trip. During this first trip and following trip the students did site survey work, design, construction and installation of a battery charging station. However there was a failure to leave behind a completed business structure that resulted in a lack of accountability to ensure the business and operational objectives of the project were continued. This resulted in a nearly complete “business” failure, in part because the technology was not really what they wanted, and that resulted in a lack of societal uptake and therefore a lack of societal acceptance of the battery charging station. Their strong preference was to be able to use appliances that required more power and higher voltages than was practical with a battery charging system. Also during this trip, we did not have the vision or plans to try and spread the technology around to other towns in similar situations.

This paper revolves around our second try at developing an electrical system in Honduras. We have learned a lot from our first try and from further research in the area, and although we have a similar purpose, this time we have a totally different set of directions, goals and methodologies. This time around we want to make the system sustainable in as many ways as possible, and we do want to spread this technology around to affect as many people as possible.

Creating a Company

When a person lacks access to electricity, they are severely hampered in their ability to be productive and efficient with their time. There is greater difficulty and greatly increased time requirements in completing simple tasks, such as drilling holes, sewing clothes, and even grinding grain. With electricity the hazards of fumes from indoor kerosene lamps disappears due to the introduction of electric lighting. The pollution caused by burning kerosene and the improper disposal of discarded flashlight batteries also goes away.

For this project to be successful it will have to meet several criteria and milestones within the next coming years. One of the biggest goals of this project is to impact 100,000 people who presently do not have electricity within the next five years. We also want to have the projects pay for themselves without having to use donor money. The money to start up these projects will need to come from local banks or possibly large lending agencies such as the World Bank, or quite possibly from investors who are looking for more than just a financial return on their investment. And finally, as alluded to above, we want this project to be vastly scalable and quickly replicatable across Honduras, and ultimately across the world.

Presently, the people use a combination of disposable D-cell flashlight batteries and homemade kerosene lamps to light their houses. The kerosene lamps pollute the air in their houses and are very hazardous, because they are only an accident away from having them break and burn much like a Molotov cocktail. Figure 1 shows a typical home-made lantern. The batteries that they purchase for their flashlights are very low quality alkaline batteries that do not last long and once they are dead, are thrown out the back door like all the other (biodegradable) trash. Although alkaline batteries are less toxic than other forms they do contain potassium hydroxide and may contain small amounts of mercury, which can leak out and leach into the ground and water.[13]

Figure 1: A Molotov cocktail style home-made kerosene lantern, an obvious fire hazard.

All of these dangers disappear when people switch to electric lights; they no longer have fumes in their homes, they no longer have toxic chemicals leaching into their fields, and there is no longer a constant danger of fire from bottles of kerosene breaking and spilling in the home.

Another great benefit is in the quality and cost of light. The kerosene lamps presently used are expensive to operate and produce very little light. When kerosene costs about one dollar per liter, a typical kerosene lamp produces 90 lux-hours of light for one dollar, where as a 15 watt compact florescent lamp produces 2310 lux-hours for the same dollar when running off of power generated from our grid.[14] This results in a 25 times increase in the quantity of light per dollar that a villager receives. Figure 2 shows the illumination of a kerosene lantern and 15 Watt compact fluorescent bulb in a village house.

Figure 2: Illumination of kerosene lantern versus 15 Watt compact fluorescent light.

When people switch over to electric lights they receive not only better quality light, but they also receive an important increase in their social status. When a village goes from lacking electricity, to having electricity, it helps to generate a sense of self worth.[15] Also when people have electricity made available to them they are able to utilize it for many other purposes, something that is impossible with kerosene.

During our trips to Honduras several reasons have been observed as to why the people are not presently connected to the national electric grid. One of the top reasons is that the electricity is generated in a distant location and must be transported over long distances; this can be quite costly, especially because the grid utilizes old technology. Also their monthly consumption will be quite small, which will result in their bill being small in comparison to the cost of paying for someone to read the meter. An even bigger financial reason is that the cost of installing the grid in their area is so expensive in comparison to their yearly electricity consumption bill that it will take a very long time to recoup the cost of installation. Further the national grid is presently losing $200 million per year and they lose more than they gain for every kilowatt-hour of electricity sold due to old and even corrupt contracts with the electricity producers. Also quite a bit of the electricity is stolen or lost due to mismanagement issues.[16]

Design in the Context of Development

Design, whether in engineering or in business, is about filling an unmet need. In this situation we have a physical need that can only be sustainability filled with a combination of business and engineering. Without the engineering we would not have the ability to design the power generation and distribution systems in the villages. Without the business we would not have the ability to determine what is needed financially to build, support and sustain the operations over a period of time. In this project we are utilizing many off the shelf engineering components, and many common business concepts to operate effectively. We are however applying the engineering components and business concepts in slightly novel ways.

For example, hydro power is commonly done around the world, but we are operating in the micro-hydro segment of the market that has not received a lot of attention from the large commercial vendors. On the business side of things we are using the very familiar concept of a franchise in a new way, buy applying it to the very small scale as a micro-franchise model, which allows local people to potentially own the electric grid in their village.

Our system will utilize these modified common design principles to fix the problems that we have observed in Honduras that are keeping people from being connected to the national grid. The solution we are presenting will produce power locally to be delivered to local people. We are utilizing natural resources that are abundant and non-polluting to generate our power and that have very low costs of operation. We are utilizing local people to build and maintain the system, which keeps costs down. We have also built in checks and balances in our paper work system to prevent theft and corruption. And finally and most importantly we are set up to serve small customers with small amounts of power.

Technology Overview

Although the main purpose of this paper is to emphasize the need for business plans and business training for these types of projects, we will present a brief overview of the technology involved installing micro-hydro systems in rural Honduran villages. The technology breaks into three main parts: the hydro power turbine and electricity generator, the electrical distribution system, and the metering systems.

The hydro turbines and electricity generators we are presently using produce power levels in the range of 1-10 kilowatts of deliverable power. The water is taken from a stream or river and channeled into some form of flume or piping system that conveys it down stream to where the hydro turbine and generator sit. The water usually never leaves the banks of the stream or river, but is rather conveyed down the river channel via a different course, hence the name run-of-river. The systems rarely require a dam, as usually a small diversion wall or some other form of water entrainment device can be installed. Figure 3 shows the construction of piping system built with two, 12 inch PVC pipes. These delivered approximately 63 liters of water per second to a chamber containing the hydro generator (not shown). From there the water fell vertically approximately 10 feet into the pool below through a 6 inch PVC pipe. A propeller-like turbine was secured in this vertical pipe and was turned by the falling water.

The present set of generators that we are using are "off the shelf" units, but this causes some problems due to rigid requirements of specific head and flow needs. In the near future we are hoping to design and build our own turbines based off of existing well established designs concepts. These would be constructed in the local area where they are installed and will provide further cost reductions. The electrical generators we are considering using are standard induction motors with a external capacitor and control systems, or maybe custom built axial flux motors that we can make ourselves.

Figure 3: The construction of the piping system to deliver water to the generator.

In the first system that we installed we created a battery charging station where people where supposed to bring their rechargeable batteries and pay a small fee to have them recharged. The people did not really accept the system and did not wish to pay for the expensive proper deep cycle batteries which would last longer being used in this way. In the next system we installed and in future systems we are going to be bringing the power to the homes, delivered via wires, just like normal grid systems in more developed locations. To keep costs low and because of the ever present problem with termites, we are presently using live trees as electricity poles to hold up our lines. The type of tree is presently used in a similar fashion when the farmers build their fences using the Madreado tree. The amazing thing about this tree is that a branch can be cut from a living tree and inserted directly into the ground and it will start to root and grow a new tree in that location. Therefore, instead of depleting the region by over 100 trees cut down for electricity poles, we have instead planted over 100 new trees. Figure 4 shows a small structure built to house equipment and a series of large branches, cut from Madreado trees, used as electricity poles. Since this photograph was taken, new growth has taken place on the poles.

Figure 4: Madreado tree branches used as electricity poles.

The latest system that we installed utilized a "pay per unit of electricity used" concept that resembles the system used in developed countries. The electricity for each house is limited to a maximum amount by a small fuse. Following the fuse is a small meter that measures the total consumed energy. At the end of the month the meter is read and the user pays according to the amount of energy consumed. The meters that we utilized for this were off the shelf Kill-a-Watt EZ meters that are normally used in the states by home owners to determine the total amount of energy consumed by an appliance. These meters can be programmed with the price per kilowatt hour so that they display the cumulative monthly bill in dollars, or in our case, Honduran Lempiras.

In future systems we are planning to utilize a subscription type service system much like that of a cable TV company. The home owner will pay an up front fee for use of electricity, based on the desired maximum current (0.5 A, 1 A, etc.). The maximum current will be limited by an electronically resetable circuit breaker specially made for this application called PowerProviders. If the user pulls more current than allowed the circuit breaker shuts off for 15 seconds and then automatically resets. This gives the user a feel for what is allowed, but does not create a penalty for accidently going over and blowing the fuse.

Financial Plans and Considerations

The business strategy is the portion of this project that we have been working on most diligently. It is not that it is any more important than the technical side of things, but rather that it is what has caused us the most problems in the past and is what we are least familiar with due to our background.

One of the major things that we have been pushing for is self-sustainability in everything we do. Although this phrase has now become a major buzzword, it is truly one of the major changes that has occurred in recent years that has allowed many people to go from one time, short-lived successes to long term maintainable ventures within the development community. This venture is going to be a for-profit company, but at its heart is a non-profit purpose: we wish to help the poor via providing them with resources to improve their lives. We desire to develop this method of deploying electric systems so that we can rapidly scale these installations to as many people as possible around the world. In this way we have an attitude of "go big or go home."

In business a manager or owner needs to know how much money is coming into the company and how much money is leaving and then finally how much is "left over" at the end. A typical profit and loss statement includes several sections. The first of which is the revenue portion which represents the amount of money coming into the company from a variety of sources. These sources are sometimes broken out into several sections but often one line gives the gross revenue, or the amount before any deductions. The next section shows the operating expenses, with the various categories broken out and then the total summed up at the bottom. The operating expenses are subtracted from the gross revenue leaving the net income before interest and taxes. The interest payments are then subtracted from this total amount and then the appropriate tax is levied against the remainder, leaving the net income, which is the "left over" portion. This is a very simplified explanation of a profit and loss statement, as they sometimes become much more involved and can be used to do more detailed analyses.

Table 1 shows a monthly profit and loss statement for an average Honduran village household in the region in which we are working. This statement is used for future planning, and was created after, not before, our most recent system was deployed. The gross revenue number is taken from interviews with local people and from experience working with them and paying them during our project. We believe that most of these people make about 100 Lempira per day (approximately $5) and that they work five and a half days a week. The operating expenses are all estimations other than the energy costs. During our time in the villages we conducted two detailed surveys concerning the kerosene and battery usages. We found that the average weekly cost for these energy sources came out to $1.25 per week, or $5.42 per month average. In the P&L below the electricity price is set at exactly twice their previous energy cost. This is what we believe the villagers are willing to pay based on data collected from our pay-per-use system already deployed. We are assuming that the village household is paying a fixed rate electricity subscription that allows the family to replace all of their kerosene and battery use with electric lights and allows them to utilize small appliances such as fans and radios. The remaining $2.93 is the family's expendable income for this assumed profit and loss (P&L).

Table 1, Assumed Villager's Profit and Loss Statement

Gross Revenue	$ 126.13
Operating Expenses	
Work Tools & Clothing	$ 5.91
Food	$ 45.63
Shelter	$ 38.02
Household	$ 22.81
Electricity	$ 10.84
Total OE	$ 123.21
Net Income	$ 2.93

Using Simulations

In Table 2 below, the calculated P&L statement for the village level franchise is shown. The gross revenue, operating expenses, net income, interest payment, taxes and net income are calculated for the first six years of the franchise. These calculations where originally done monthly for the first year, quarterly for years two and three, and then yearly for years four five and six, but for this paper it was necessary to compact the results into a smaller "package" to express the outcomes more easily. Because there are startup lags in the payment schedule during the first year, the income is lower, which results in a lower net income for year one. Years two through five are shown to have a constant income stream, and then in year six, the loan that was taken out to pay for the installation of the system, has been paid off and the net income jumps up due to the principle and interest payments being removed. In the next few sections we will explain the process used to calculate this table and show how a Monte Carlo analysis was used to determine the variability of the results and to try and find out what is required to make things work.

Table 2, Franchise Profit and Loss Statement for First Six Years

	Year 1	Year 2-5	Year 6
	2009	2010-2013	2014
Gross Revenue	$ 6,444	$ 7,364	$ 7,364
Operating Expenses			
Labor	$ 1,009	$ 1,101	$ 1,101
Supplies	$ 33	$ 36	$ 36
Principle Payment	$ 1,519	$ 1,519	$ -
Replacement (fund)	$ 674	$ 735	$ 735
Total OE	$ 3,234	$ 3,390	$ 1,872
Net Income Before Interest & Taxes	$ 3,210	$ 3,974	$ 5,493
Interest Payment	$ 980	$ 980	$ -
Net Income Before Taxes	$ 2,230	$ 2,994	$ 5,493
Taxes	$ 268	$ 359	$ 659
Net Income	$ 1,962	$ 2,635	$ 4,834

The above table was calculated using a Microsoft Excel add-on program called @RISK, which utilizes the Monte Carlo method to model business risks where there is lots of uncertainty present in the input variables. We utilized the program to fluctuate six variables according to a statistical distribution that we chose for each, according to our understanding and knowledge of the statistic. The program then ran a simulation that consists of 10,000 iterations where each statistic is varied for each iteration and the resulting data is tabulated and statistics such as mean and standard deviation are developed for the results were calculated.

Franchiser Economics

The results from the above analysis were used to calculate the profit and loss of the franchiser over the first five years of start up and operation.

Table 3, Franchiser Profit and Loss Statement

	Year 1 2009	Year 2 2010	Year 3 2011	Year 4 2012	Year 5 2013
Gross Revenue	$ 9,913	$ 68,689	$ 205,336	$ 528,640	$ 1,013,480
Carbon Credits	$ -	$ -	$ 22,650	$ 46,650	$ 79,650
Gross Profit	$ 9,913	$ 68,689	$ 227,986	$ 575,290	$ 1,093,130
Operating Expenses					
Engineer(s) Salary	$ 140,000	$ 140,000	$ 140,000	$ 140,000	$ 140,000
National(s) Salary	$ 15,000	$ 30,000	$ 45,000	$ 90,000	$ 135,000
Equipment	$ 20,000	$ 10,000	$ 10,000	$ 20,000	$ 10,000
Total OE	$ 175,000	$ 180,000	$ 195,000	$ 250,000	$ 285,000
Net Income Before	$ (165,088)	$ (111,311)	$ 32,986	$ 325,290	$ 808,130
Taxes	$ -	$ -	$ 4,860	$ 39,035	$ 96,976
Net Income	$ (165,088)	$ (111,311)	$ 28,126	$ 286,255	$ 711,154

Table 4 shows the number of systems installed per year and the cumulative number of systems installed over the five year start up period. The number of installed systems in their first year are multiplied by the first year mean value from Table 4, and the systems that have been installed longer than that are multiplied by the second through fifth year income. These values make up the Gross revenues for the company in table five. Because we are generating electric power from a renewable hydro source in Honduras, we are able to sell our carbon offset credits on the international market. We did not think that we would be worth the effort until we have a base of generating units producing power, which happens in the third year. The operating expenses are broken out into their various categories. From the start we have two American employees and one Honduran national, but by the end of year five there are nine national employees on the payroll. The equipment costs include such things as drills and saws, but also include the purchase of used pickup trucks in years one and four.

Table 4, Number of Systems Installed

Year	1	2	3	4	5
Number of Systems Installed	12	49	90	160	220
Cumulative Systems Installed	12	61	151	311	531

The next step in the process of doing these calculations is to increase the complexity of the franchiser's P&L by taking into account the mean and standard deviation of each of the systems produced.

Future issues

When we return to Honduras in the next year we will have two main obstacles to overcome before the company can start implementing our main plans and goals. The first has to do with government regulations and their openness to change. Presently we do know that there is a government organization similar to the Environmental Protection Agency that governs water rights. We know that there are requirements that must be met, but we are not sure if we are subject to these because we do not take water from the stream, we only run it through a generator and then return it. Secondly the government owns the electric grid right now and the rules presently state that once distribution equipment (power lines, transformers…) is connected to it, those become property of the national grid. We need to ensure that we can get these small grids installed in such a way that we do not violate their rule but also that we do not give away our grids. There is also a major issue of liability, and we presently do not know what the government requires of us for insurance. Finally there is the simple matter of getting the business legalized and figuring out how taxes are paid.

The second major issue facing us is that of proving that our financial models, like any other mathematical model, correctly represent reality. This will require additional beta testing in more villages and the establishment of functional franchises. We need to prove to ourselves and to potential investors that we are financially viable, that we can get our costs down, that we can replicate this quickly in other villages. This will allow us to get the investment money we need to continue the project and succeed in the long run.

Contributions of this work

There has been considerable work in the area of engineering service learning. There are also growing amounts of work in the area of engineering entrepreneurship education. This paper's value is in combining these two topics. Engineering service learning is used as a vehicle through which sustainable companies can be created that can provide long term good for the community.

There has been a considerable amount of work done by others in the area of engineering service learning. One example of this is the EPICS program that was started at Purdue University. They have an annual conference dealing with engineering service learning. William Oakes and Marybeth Lima have written an excellent book on engineering service learning[17] that is based in part on what they have learned through the EPICS program.

Several papers were presented at the 2007 EPICS national conference that attempt to alleviate some faculty concerns about the real engineering content of engineering service learning courses. Hefzy from the University of Toledo[18] and Zoltowski from Purdue[19] made presentations about how to do service learning based capstone design courses. Budny and Lund[20] from the University of Pittsburgh have written about how to use engineering service projects in first year engineering courses.

Most of the engineering service learning courses mentioned above have involved service projects within poor communities near the college campus. However, international service learning is increasing as well. Kelley[5] has written about service projects in East Africa. The author has reported on a project in rural Western Kenya[2]. The group Engineers without Borders has grown dramatically in the last few years. Professors from Rice University[21] have written about their projects with Engineers without Borders. Part of the motive behind international service learning projects is to help our students develop a global perspective. Pines and Gallant have written about their work in this area at the University of Hartford[22].

Service learning has become mainstream enough to be discussed in a major article in ASEE's Prism magazine[23]. While there may be some local disagreements within engineering programs concerning the legitimacy of engineering service learning, on a national basis there appears to be an acceptance of this approach.

What is new about this paper is that it goes beyond just examining service learning, but uses service learning as a vehicle through which to teach and do entrepreneurship. While each service learning project has an immediate goal to help a poor community, entrepreneurial service learning has the additional goal of creating a business that is sustainable and will help the local community for a considerable period of time.

Conclusion

The idea of installing small electric grid power plants utilizing locally generated hydro power has many promising aspects and potentials. There are obviously many difficulties to overcome before we are able to reliably and cost effectively install these systems, but we are excited about the possibility of moving forward with this project. The analysis and calculations shown in this report demonstrate the great potential that is available to us as we move forward and hopefully these results will provide powerful insight that will allow us to avoid pitfalls and pursue the most productive paths.

Bibliography

1. Thomas, Brian, "A Wind Powered White LED Lighting System for the Kibera Slum of Nairobi", International Journal for Service Learning in Engineering, Vol 2, No. 1, pp. 16-31, Spring 2007.
2. Jordan, W., Ballard, B., Morton, A., Sanders, B., and Wakefield, J.K., Implementing a Service Learning Engineering Project in East Africa, presented at the Gulf Southwest Regional Meeting of A.S.E.E., South Padre Island, TX, March 2007. In CD based Proceedings (no page numbers).
3. Jordan, W., Bradley, W., Grinols, A., Blalock, G., Leman, G., and Fry, C., Incorporating Global Entrepreneurship Courses Into an Engineering Curriculum, Proceedings of NCIIA 12th Annual Meeting, Dallas, March 2008, pp. 87-94.
4. Jordan, W., Blalock, G., Bradley, W., Fry, C., Grinols, A., and Thomas, B., Using Technical Entrepreneurship and Service Learning to Promote an International Perspective in an Undergraduate Engineering Program, presented at the A.S.E.E. Annual Meeting in Pittsburgh, June 2008. In CD based Proceedings (no page numbers).
5. Benjamin Kelley, Walter Bradley, and Brian Thomas, Student-Aimed Appropriate Technology Engineering Projects in Kenya, presented at the ASEE Gulf Southwest Conference, Baton Rouge, 2006, in CD based proceedings, no page numbers.
6. U.S. Centers for Disease Control and Prevention. Atlanta, GA. "Safe Water System: A Low-Cost Technology for Safe Drinking Water." Fact Sheet, World Water Forum 4 Update. March 2006
7. http://www.who.int/mediacentre/news/releases/2005/pr23/en/index.html
8. http://www.worldhunger.org/articles/Learn/world%20hunger%20facts%202002.htm
9. Evan Mills, "The Specter of Fuel-Based Lighting", Science, Vol 308, 27 May 2005
10. World Development Report 1994, Infrastructure for Development, Executive Summary, p.2
11. Sanchez, Teodoro, "Electricity Services in Remote Rural Communities, The Small Enterprise Model", Intermediate Technology Publications Ltd., UK, 2006
12. Concepts taken from a plenary session at the Global Missions Health Conference where Dr. John Patrick spoke about medicine in the developing world , MP3 recorded message.
13. http://www.ecy.wa.gov/programs/hwtr/demodebris/pages2/demobatteries.html
14. Evan Mills, "The Specter of Fuel-Based Lighting", Science, Vol 308, 27 May 2005
15. Based off of conversations with Nathan Chesang, director of the Kenyan operations of Community Uplift Ministries which deploys electric lighting and gas cook stoves in developing communities in East Africa, 2006.
16. "Problems at State Electric Company Darken Honduran Energy and Fiscal Outlook", A November 2007 report from U.S. Embassy, Tegucigalpa

17. William Oakes and Marybeth Lima, **Service Learning: Engineering in Your Community**, Great Lakes Press, St. Louis, 2006, 323 pages.
18. Samir Hefzy, John Jaegly, Christian Smallman, Developing a Successful Engineering Capstone Senior Design Course Using Service-Learning, presented at the 2007 EPICS conference, San Diego, May 2007, on the following web site: epicsnational.ecn.purdue.edu/public/conferences/files/2007_National/A1-Hefzy.pdf Author: Mohamed Samir Hefzy, John Jaegly, Christine Smallman
19. Carla Zotlkoski, Using Multidisciplinary Service-Learning to Meet Capstone Requirements, presented at the 2007 EPICS conference, San Diego, May 2007, on the following web site: epicsnational.ecn.purdue.edu/public/conferences/files/2007_National/A1-Zoltowski.pdf
20. Dan Budny and Laura Lund, Benefits and Challenges of Service Learning for Freshman Engineers, presented at the 2007 EPICS conference, San Diego, May 2007, on the following web site: epicsnational.ecn.purdue.edu/public/conferences/files/2007_National/C4-Budny.pdf
21. Ross Gordon, Alex Gordon, and Philip Bedient, Rice University Engineers without Borders: An Exercise in International Service Learning, presented at the ASEE National Conference, 2006, Chicago, in CD based proceedings, no page numbers.
22. David Pines and Brian Gallant, Providing Engineering Students a Global Perspective through a Project for Developing Communities—Lessons Learned at the University of Hartford, presented at the ASEE National Conference, 2006, Chicago, in CD based proceedings, no page numbers
23. Jeffrey Selingo, May I Help You?, ASEE Prism magazine, Summer 2006, pp. 41-45.