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IV. EXECUTIVE SUMMARY

NCER Assistance Agreement Project Report Executive Summary
Date of Project Report: March 23, 2009
EPA Agreement Number: SU83392501-0
Project Title: Self-Contained Human and Solar Powered LED Lighting System for Use in the Developing World
Faculty Advisors(s), Departments, and Institutions: Robert Stevens, Mechanical Engineering, riseme@rit.edu; Brian Thorn, Industrial and Systems Engineering, bkteie@rit.edu; James Myers, Multidisciplinary Studies, Andres Carrano, Industrial and Systems Eng. alceie@rit.edu, Rochester Institute of Technology, Rochester, NY
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Project Period: August 15, 2008 through August 14, 2009

Description and Objective of Research:
A large portion of the world’s population currently does not have access to clean and reliable sources of artificial lighting which is vital for furthering one’s education, enabling some income generating activities as well as providing a richer and healthier family and community environment. Currently over two billion people in the world go without lighting or use unhealthy and polluting lighting sources such as kerosene lamps, candles, or other unsustainable fuel based lights. In fact, approximately 33% of the world energy use for lighting is by kerosene lighting alone. Rural families spend a significant portion of their income on kerosene fuel for lighting. Many families in the world can spend as much as $8-15 per month, which is substantial considering that most rural incomes are below $2/day per person.

Besides the economic and poor light quality issues of fuel based lighting systems, these systems also pose a huge environmental problem. The entire world’s use of kerosene lighting emits more than 200 million tons of CO₂ per year. During a recent global lighting study, Evan Mills of Lawrence Berkeley National Laboratory concluded that “The single-greatest way to reduce the greenhouse-gas emissions associated with lighting energy use is to replace kerosene lamps with white-LED electric systems in developing countries; this can be accomplished even while dramatically increasing currently deficient lighting service levels.” Although there has been significant progress in the development of LED applications, most work has been geared towards the developed world applications with little focus lighting technologies for kerosene users. For these reasons, the proposed project’s goal is to develop improved options for artificial lighting for the developing world that will not only have lower long-term operating costs but will also reduce the negative impact on the local and global environment associated with fuel combustion while also creating local wealth generating opportunities. The specific objectives for the first phase of the project are to

- Form and advise a multidisciplinary engineering student team to assess the lighting need and develop appropriate engineering specifications. Guide the student team through the entire design process.
- Design, build, and conduct preliminary tests of a prototype white-LED lighting system and to lay the groundwork for future development of the technology.
- Develop collaborative partnership(s) with organization(s) working in the developing world where access to high quality and clean lighting technology is currently lacking.
- Send first generation prototype lighting systems out for field testing and observations by partner(s) and solicit input on the design in order to make future prototypes more easily manufactured by local microenterprises.

Summary of Findings (Outputs/Outcomes):
A student team of mechanical, electrical, and industrial engineers was formed in the fall of 2008. Using a network of RIT Alumni, the Phase I student team developed a working relationship with two non-profit organizations, Sustained Organic Integrated Livelihoods (SOIL) and Haiti Outreach - Pwoje Espwa (H.O.P.E.), which have a focus on development in Haiti. Working closely with these two organizations, the team established the needs of the end customer, rural families in Haiti. Fifteen needs were identified to create an effective lighting solution that would be not only more functional than the current kerosene lamps available in Haiti, but also beneficial economically, environmentally, and to personal health. The most important of these needs are; provide improved lighting levels and distribution, be more environmentally friendly than the current kerosene lamps used, does not require the use of the electric grid, has a lower purchase and operating cost, and could be manufactured in developing nations. The team developed twenty-five engineering specifications based on the established customer needs. The specifications were used by the student team along with input from project partners and industrial representatives to guide the concept generation and final design selection.

The final concept selected by the team consisted of small inexpensive individual rechargeable lighting units charged by a central community based charging station. The primary advantage of the small lighting units with a central charging system is to reduce the initial cost to the individual user. Cost reduction is critical for populations living on less than $2/day. The material cost for an optimally designed system are expected to be less than $20 per unit and will be sufficient to provide 50 Lux of lighting on a two square meter surface, which is more than adequate for reading and significantly better than the kerosene based lighting currently used. The designed lighting units are far superior to the typical cheap consumer LED products available today. The units have higher light intensity and more efficient circuitry enabling them to operate for several nights between charges. The units are modular, so as a family’s needs and available resources change additional lighting units can be purchased.

The central charging stations consist of a bike with a small generator. Future power generation systems could be done on a communal or individual basis and could include a small treadle with a generator, photovoltaic module, or thermoelectric generation unit. Having a centralized charging system has the advantage of creating an income generating activity using local resources rather than importing fuel or batteries, which removes wealth from the local community. The central charging system also better ensures that the individual lighting systems are well maintained since the units can be inspected and serviced on a regular basis by a local expert who has a financial incentive to keep the lighting units working properly.

The project team has currently built the lighting unit housing and assembled the power charging circuitry on a breadboard and conducted preliminary testing. The light distribution tests
demonstrated that the unit’s lighting quality and distribution is far superior the current kerosene units. The charging power conditioning circuitry also performed as expected. The team is currently in the process of testing the LED unit circuits and developing the printed circuit board layouts for both the lighting and charging units. The team expects to complete several prototypes during the spring of 2009. The units will be tested to ensure they meet all engineering specifications developed earlier.

**Conclusions:**
Upon completion of initial testing, the team will enter a redesign phase to address any deficiencies in the design. By addressing these deficiencies in the alpha prototype design it will be possible to ensure that the beta prototype is truly ready for field testing deployment.

Field testing will be done with the help of the team’s partner organizations in Haiti. One charging system and six to ten light units will be sent to H.O.P.E. and SOIL during late spring or summer for distribution to the households in Northern Haiti. Daily use of both modules should provide valuable feedback with respect to the utility, durability, and desirability of the current design. Upon receiving this valuable feedback from field testing, the team will be able to prepare a plan for future phases of the project to be conducted by future student design teams.

**Proposed Phase II Objectives and Strategies:**
The second phase of this project will build on the successes of Phase I. The second phase objectives will be to

- Develop two generations of improved individual lighting modules and a communal power generation system prototypes,
- Conduct extensive field testing and observations of the lighting systems to both qualitatively and quantitatively measure the potential environmental, economic, and social impact of the lighting system adoption and to provide feedback for further design improvements,
- Develop business plans for the creation of local microenterprises in Haiti and an initiative for broadening the lighting project on a regional or global level, and
- Develop pilot projects in three communities in Northern Haiti.

To build on the success of the first phase of the project, several first generation assembled lighting units and unassembled lighting kits will be sent to the project partners, H.O.P.E. and SOIL tech centers. The tech centers will assemble the units and document issues with assembly and then provide feedback to the project team on areas for improvement with techniques and design modifications that are more appropriate for local fabrication and assembly. The tech centers will also distribute several of the lighting systems and a charging system to the end users and follow-up with a survey and observations for future improvements. This feedback will be instrumental in the development of a second generation lighting unit and power generation system prototypes. A modification of the prototype lighting and power generation system designs will be made by multidisciplinary design teams based on the field testing feedback.

A team of engineering and business students with an interest in socially responsible business practices will be formed during the first year of Phase II to develop a business model with the focus on developing sustainable microenterprises that will help build local wealth, ensure the lighting systems are well maintained and adoption of the technology continues to accelerate and
be sustainable. The team will take advantage of an existing entrepreneurial infrastructure at the Simone Center for Innovation and Entrepreneurship (SCIE) at RIT. An initial business model will be developed within the context of the MBA Entrepreneurship and New Venture Creation course and possibly move on to RIT’s Student Business Development Lab. A second plan will be developed during the second year of Phase II with the goal of developing the blueprint for an initiative to expand the adoption of the LED lighting systems on a regional or global level. The focus of this plan will be on how best to develop an organization for duplicating the successes of the Haitian LED microenterprises in other parts of the developing world. These business development activities will fit well into RIT’s new Social Entrepreneurship Initiative.

During the second year of Phase II, the project team in partnership with the H.O.P.E. and SOIL tech centers will identify three communities in Northern Haiti to initiate pilot projects based on the microenterprise business plan developed during the first year. Both H.O.P.E. and SOIL will assist in conducting user surveys that will focus on evaluating both the technology and the business structure for distributing and charging the units.

**Publications/Presentations:** Technical article in preparation for RIT KGCOE Multi-Disciplinary Senior Design.

**Supplemental Keywords:** lighting, LED, community power, third world.

**Relevant Web Sites:** The working project website can be accessed at [http://edge.rit.edu/content/P08427/public/Home](http://edge.rit.edu/content/P08427/public/Home).
A. SUMMARY OF PHASE I

1. BACKGROUND AND PROBLEM DEFINITION

Although citizens of developed nations have come to take electricity and clean lighting for granted, according to the International Energy Agency (IEA), nearly two billion people around the world lack access to electricity. As of the year 2000, the IEA estimates that 14% of urban households and 49% of rural households in developing nations are without electricity [1]. In addition, many of the clinics, schools, workplaces, and markets in these parts of the world are completely without light. In most developing regions of the world, the population is growing significantly faster than the ability to provide electricity to them. In those areas without electricity, lighting is currently provided by fuel-based lamps which are inefficient, costly to operate, and produce large amounts of potentially harmful byproducts and greenhouse gas emissions [2]. Fuel-based lighting accounts for 33% of all residential lighting and 12% of all lighting [3]. These fuels include kerosene, diesel, propane, biomass, candles, and yak butter [2, 4]. In addition to the aforementioned portions of the population, there are 35 million people in the world living in refugee camps, most of whom are without any lighting at all [1].

Lighting is one of the principal sources of power consumption. There is a great deal of disparity in the efficiency of these systems. While some may be able to obtain efficiencies of about 100 lumens per watt, there are many who are forced to use systems that operate well below one lumen per watt [5]. Additionally, it is important to note that these less efficient light sources provide less light and produce a less uniform dispersion than the more efficient systems. For example, a candle provides about 10 lux (lumens/m²) on a workspace if at a distance of 1 foot from the source, while typical on-workspace levels found in industrialized countries range from 400 to 500 lux, and this is accomplished with either desk lamps or ceiling lighting. It is estimated that fuel-burning lighting systems are the primary, if not only, source of light for 25% of the world’s population. These applications consume some 17% of the world lighting energy budget, but produce only about one tenth of one percent of end-use lighting. Thus, the costs of lighting for a family in a developing nation are comparable to a family in a fully-powered, industrialized nation [4]. The bottom line is that end-users pay a great deal less for a better end product when using electricity rather than burning fuels for their lighting needs. Additionally, the inefficient and low-quality nature of fuel-based lighting makes it very difficult to use for such applications as working, reading, or cooking, and also poses a health and fire threat.

Although the efficiency of these lighting systems has been examined quite thoroughly, the impact to the world as a whole has only recently come under consideration. As stated by Evan Mills, it is estimated that fuel-based lighting accounts for about 20 billion gallons of fuel annually at a cost of some 38 billion U.S. Dollars [3, 6]. In addition to the economic hurdles presented by fuel-based lighting, there is a heavy environmental burden as well. The byproducts of the combustion of these fuels are numerous and vast in nature. A single kerosene lamp will produce a sooty residue which will adhere to all surfaces of the area in which it is used, and also produce more than 200 pounds of carbon dioxide each year. This fact, in conjunction with the number of fuel-burning lighting applications, accounts for more than 200 million tons of greenhouse gas emissions into the atmosphere every year. The use of biomass as a lighting, cooking, and heating fuel also leads to a great deal of deforestation as noted by the International Energy Agency [1, 2, 4].
In order to understand the impact to the human element, we must first look at the added burden to the portion of the population who access light through the use of fuels. Depending on the fuel, between 30 minutes and 7 hours a day may be spent in the pursuit of fuel for domestic use. This task is generally performed by the women and children of the household using time which could be better spent working or learning. Electric lighting allows families to read without having to strain or deal with the sound and smell from the kerosene lamps. Artificial lighting can also extend the potential workday so that family members may engage in additional income generating activities in the evening [2, 4]. There has been a great deal of research done to show that there is a positive relationship between increased educational opportunities made possible by electric lighting, resulting in higher lifetime earnings.

There are also significant health benefits and improvements to public safety. The byproducts of combustion are hazardous to the health of those exposed. Lack of proper ventilation in the areas of use allows for the buildup of carbon monoxide to levels many times higher than the World Health Organization (WHO) standards. It has been shown that, due to their increased exposure, women and children suffer most from these emissions. The WHO estimates that 2.5 million premature deaths of women and children may be attributed to breathing the fumes from burning biomass for domestic use [7].

Modernization and electrification are spreading to all reaches of the planet, but they are unable to keep up with the ever increasing demand. In many developing communities it is not feasible to connect these rural areas to the power grid, and power companies are hesitant at best to supply power due to the high risk of power theft [8, 9]. Thus, a self contained lighting system would seem to be the solution to the current problem. White LED’s have recently undergone a great technological advance and can now reach efficiencies of up to 100 lumens/watt, as opposed to 0.1 lumens/watt for the average flame-based lantern. Additionally, a 1-watt, white LED requires 20% of the electricity needed to power the most efficient and smallest compact fluorescent light on the market [4]. LED’s are also significantly more robust and have a factor of five to ten times longer lifetime than fluorescent lighting. These facts indicate that a self-sustaining lighting system centered on the use of white LED’s to provide illumination may be an answer to the developing world’s lighting woes [10].

2. PURPOSE, OBJECTIVES, SCOPE
The project goal is to develop and deploy efficient, high quality, and economically viable lighting systems for use in the developing world based on recent advances in the LED technology. The specific objectives for Phase I of the project are to

- Form and advise a multidisciplinary engineering student team to assess the lighting need and develop appropriate engineering specifications. Guide the student team through the entire design process.
- Design, build, and conduct preliminary tests of a prototype white LED lighting system and lay the groundwork for future development of the technology.
- Develop collaborative partnership(s) with organization(s) working in the developing world where access to high quality and clean lighting technology is currently lacking.
• Send first generation prototype lighting systems out for field testing and observations by partner(s) and solicit input on design in order to make future prototypes more effective and easily manufactured by local microenterprises.

Completion of the first phase of the project would position future teams and activities in such a way that they could continue to work with sponsoring organizations in the field to design future iterations of the lighting system and ensure that it could be easily manufactured by local microenterprises.

3. DATA, FINDINGS, OUTPUTS/OUTCOMES
Using a network of RIT alumni, the Phase I student team was able to find two non-profit organizations, Sustained Organic Integrated Livelihoods (SOIL) and Haiti Outreach - Pwoje Espwa (H.O.P.E.), with a focus on development in Haiti. Working closely with these two organizations, the team established the needs of the end customer, rural families in Haiti. Fifteen needs were identified to create an effective lighting solution that will be more functional than the kerosene lamps currently available in Haiti, and also provide economical, environmental, and health benefits. The most important of these needs are to: provide improved lighting levels and distribution, be more environmentally friendly than the kerosene lamps now in use, decrease purchase and operating costs, and have the capacity to be manufactured in developing nations.

The team developed twenty-five engineering specifications based on the established customer needs. See Table 1. These metrics provided quantitative targets the lighting system would have to meet to be successful. The specifications were used to evaluate the proposed and developed concepts and prototypes. Ten initial concepts were devised. After concept generation, the team began to analyze the potential of each concept to meet the engineering metrics and customer needs. In addition to the team’s analysis of the concepts, the ideas were sent to the partners in Haiti for feedback. Both sets of analyses confirmed that the team should look into creating a two part system. The primary module would be a rechargeable and recyclable lighting unit that would, in turn, be charged on a regular basis by the second subsystem – a power generation unit that would be located in a community-central location. Two primary concepts were developed for the power module. The first uses energy generated by an individual’s pedaling a bicycle, while the second uses solar power to charge the batteries in the lighting modules. Concept sketches for the bike and photovoltaic designs may be seen in Figure 1 and Figure 2.

The team held a system level design review attended by RIT professors, industrial representatives, and peers. The feedback from this review coupled with additional feedback from the sponsor contacts in Haiti representing the interests of the final customer were instrumental in determining the final prototype design. The team also constructed a rating rubric in which the two concepts were ranked based on their ability to meet the engineering specifications. Using the aforementioned criteria, the team selected the community bike charger as the final design for the power module as it rated highest in all classes of feedback. Functional system diagrams were developed for the lighting units and power generation systems as shown in Figure 3 and Figure 4.
### Table 1. Established Engineering Design Specifications

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<th>#</th>
<th>Metric</th>
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<th>Ideal</th>
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<td>*****</td>
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<td>20</td>
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<td>2</td>
<td>Power Module Production Cost</td>
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<td>3</td>
<td>Usable Temperature Range</td>
<td>°F or °C</td>
<td>***</td>
<td>(4.5–38)°C</td>
<td>(0–50)°C</td>
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<td>4</td>
<td>Water Resistant</td>
<td>IPX Standard</td>
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<td>5</td>
<td>Particulate Resistant</td>
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<td>6</td>
<td>Storage Capacity @ 100 Lumens</td>
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<td>***</td>
<td>4</td>
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<tr>
<td>7</td>
<td>Battery Lifetime</td>
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<td>8</td>
<td>Base Unit Lifetime</td>
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<td>Color of Light</td>
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<td>***</td>
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<td>10</td>
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<td>17</td>
<td>Hook-up Time (LM to PM)</td>
<td>sec</td>
<td>***</td>
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<td>&lt;10</td>
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<td>18</td>
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<td>sec</td>
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<td>Charge time (biking)</td>
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<td>20</td>
<td>Recyclable Parts</td>
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<td>&gt;75</td>
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<td>24</td>
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<td>25</td>
<td>Lighting Module Weight (Mass)</td>
<td>lb (kg)</td>
<td>*</td>
<td>&lt;5kg</td>
<td>&lt;3kg</td>
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</table>

![Figure 1. Community Bike Charger](image1.png)

![Figure 2. Community Solar Charger](image2.png)
The actual design of the lighting unit required several iterations of customer and advisor feedback, before the final prototype design was selected. Conversely, the bike was relatively straightforward and could make excellent use of low-cost, off-the-shelf parts for the proof-of-concept prototyping. For the detail design phase of the project, the end product was split up into multiple areas pertaining to each student’s area of expertise. The two electrical engineers were tasked with designing the power generation, storage, and distribution systems as well as all circuitry to connect those systems. One mechanical engineer, who also had a good deal of design experience was tasked with housing design and CAD drawings, while the other mechanical engineer was assigned design of the mechanical interface of the bike and generator as well as the thermal analysis to determine the proper heat dissipation methods needed for the lighting module. The team’s industrial and systems engineer was placed in charge of the life cycle assessment for the proposed lighting system. The entire design process was overseen and organized by the student team lead with assistance from the faculty advisor.

As previously mentioned the power module was simply constructed using low-cost, off-the-shelf parts, while the light module required a more detailed design process. The final iteration of the light module design utilizes a recycled metal can as the housing. Not only is this design compact
and simple to construct, but it makes use of common “trash” to provide this much needed product. Ensuring sufficient space for all of the components was somewhat of a challenge given the size of the necessary batteries, but in the end the design was created so that cans ranging in size from a small tuna can to a soup can could be used for the light module housing. Detail designs of all components and subsystems were presented to peers, industrial representatives, and faculty. The final designs for the power and light modules are shown in Figure 5 and Figure 6. The assembly view of the light module and first generation prototype can be seen in Figure 7 and 8.

The most complex portions of the system are those associated with the electrical systems. The power generation system must be able to handle a wide range of operating conditions such as various pedaling cadences and multiple lighting units having to be charged all at various states of discharge. The spinning wheel turns a specially selected inexpensive 200 watt generator that in
turn drives a power conditioning circuit. The conditioning circuit enables a single operator to simultaneously charge four or more LED lighting units, all at different states of discharge. The designed circuitry ensured that the batteries would not receive more current than they could handle, nor would they ever be overcharged. As an added benefit to the user generating the power, small color-coded LED’s were added to the system to indicate when a battery was charging and when it was fully charged. The power conditioning circuit has been tested and operates as expected. The team is in the process of developing the printed circuit board layouts for the final prototype.

The lighting module makes use of a long life Cree XLamp XR-E LED capable of producing 107 lumens of white light at 1.2 watts and can be driven up to provide over 200 lumens if needed. Since the use of an LED requires an LED driver to ensure that the proper current is being applied to the diode, the team looked for a reasonably priced driver that could be used at low (4.8V) voltage. This need was met using a 1A step-down LED driver. The power storage needs for the system were met using four fast-charging Nickel-Metal Hydride (NiMH) AA batteries assembled into a single power pack. The NiMH batteries were chosen for their high storage capacity, extended lifetime compared with other rechargeable batteries, relatively small profile, and worldwide availability. The batteries should provide up over seven hours at full light levels (100 lumens) and fifteen hours at partial light levels (50 lumens), which is controllable by a three way switch. The team is currently assembling and testing the prototype LED units.

Due to the highly directional nature of the light generated by the LED, it was necessary for the light to pass through a diffuser before it would be truly utilized. Various diffusers were sampled to determine the best choice. The team was able to achieve a more even light distribution by using a prismatic diffuser. The light distribution on the surface of interest using the proposed LED was nearly an order of magnitude brighter than that provided by a typical kerosene lamp currently used. The prototype design also has significantly better light intensity compared to that from the inexpensive consumer products that have recently emerged based on white LED technologies. Due to the cost of using the premade prismatic lenses, the team opted to use an LED with a wide emission angle and a roughened acrylic plate as a diffusing surface, which is significantly less expensive than a prismatic diffuser and nearly as effective.

With the completion of the design, the team proceeded to the alpha prototype construction and testing portion of the project. The team opted for a more conservative approach for this portion so assembly and testing were first completed on subsystems. The proposed electrical circuits were constructed on breadboards so that they could be tested before committing the design to a printed circuit board. The bike and the generator were tested together to ensure that a person pedaling at a sustainable rate could produce the power necessary to charge several lighting units at once. Tests were run on the LED/heat sink assembly to ensure that the heat sink provided significant heat dissipation to account for the heat generated by the LED. Upon completion of subsystem construction and testing, the complete modules were assembled and then tested to ensure that their performance was on par with the engineering specifications set forth at the beginning of the project.

Upon obtaining all of the power generation components, the team assembled the bike charging system and conducted a series of tests to determine the actual power that a person could generate
for a given level of effort. The testing was done for two possible scenarios. In the first case the biker was asked to maintain a pace that they could sustain for a standard workday – as would be the case with someone using the power generator as a business. In the second test, the biker was asked to use a pace that would be more strenuous, which would represent a scenario where multiple bikers are used to charge the lighting units. This would be the case if the unit were in a more community oriented location. In the case of the sustainable biking the power module was able to generate 50 watts while under the more strenuous pace, the generator system produced 135 watts. In both cases it would be possible to charge four or more lamps at a time.

The team’s industrial engineer conducted a lifecycle assessment using Simapro Life Cycle Assessment Tool. Simapro was used to compare the proposed LED prototype with the kerosene lamps currently used. With this tool impacts on ecology, resource depletion and human health associated with the individual components of each system are compiled. These factors are compared using the metric of Eco-points. One hundred Eco-points is the equivalent of the environmental impacts attributed an average UK citizen per year. Eco-points are generally used to compare products and material options as well as track improvements in a system.

Figure 8 shows a graph comparing the compiled Eco-point scores of a typical kerosene lamp and the proposed LED lighting system. The functional unit for this lifecycle assessment was the usage of one lighting system for two years. Included in the LED light lifecycle are the recycling and disposal phase and a percentage of the charging station required for its effective use. Not included in the kerosene lantern lifecycle are the transportation of the glass lantern unit and the potential for volatile organic compound emissions of varying types created from the burning of kerosene. As quite clearly illustrated in Figure 8, the proposed lighting system has a greatly diminished environmental impact when compared to the kerosene lamps currently used (~0.5 Eco-points versus ~21.5). This is primarily attributed to the production and burning of kerosene.
The estimated first generation LED prototype retail cost is under $20 per unit. It is estimated that approximately 20% of this cost can be used to support local fabrication and retail activities. Although the initial cost is higher than a kerosene lantern which typically is $3-4, the economic benefit of the LED system is in the lower on-going operating cost. SOIL estimates that it costs approximately $0.13 per hour for the use of a kerosene lamp. The proposed LED system is estimated to cost less than $0.03 per hour using a business model where a microenterprise collects fees for charging units. In addition the LED units will provide far superior lighting. For the case where a family replaces a kerosene lamp with a LED unit for three hours a night, the simple payback will be almost immediately, less than two months. The annual energy savings for a family could be over $100, a substantial economic benefit to the local economy that would no longer rely on imported fuel.

The proposed central charging system prototype is expected to retail at $100 assuming the use of a locally available bicycle or obtaining bicycles through the numerous recycling programs in the U.S. A microenterprise could be setup to recharge units at $0.20 per charge. The charging unit should be able to charge over 30 units per eight hour work day, resulting in a simple payback of less than a month and an annual income generation potential of over $1,500, well above the regional average of less than $2 per day. The microenterprise central charging system would also create a local expert who could service and retail units. This enterprise would have a financial incentive in ensuring the sustainability of the lighting units. During Phase II some sort of lending structure for these microenterprises would be developed.

4. DISCUSSION, CONCLUSIONS, RECOMMENDATIONS
Upon completion of initial testing, the team will enter a redesign phase to address any deficiencies in the design. By addressing these shortcomings in the alpha prototype design it will be possible to ensure that the beta prototype is truly ready for field testing deployment.

Field testing will be done with the help of the team’s partner organizations in Haiti. One power module and six to ten light modules will be sent to H.O.P.E. and SOIL during late spring or summer of 2009 for distribution to households in Northern Haiti. Daily use of both modules should provide valuable feedback with respect to the utility, durability, and desirability of the current design. Upon receiving feedback from field testing, the team will be able to prepare a plan for future phases of the project to be conducted by future senior design teams.

Once a functional product has been proven and an appropriate business model has been established, additional teams will look into expanding the target area to other countries. One of the major aspects of the product is the need for universality so once the design that has been applied well in Haiti it can be further deployed in other nations such as El Salvador, Guatemala, Honduras, and Nicaragua. To ensure this transferability of the product concept, future teams will also address the fact that, while a bicycle is an appropriate method of power generation in Haiti, it may not be in Latin America. This fact might necessitate the design of additional methods of charging the batteries of the unit (solar modules, clockwork mechanisms, etc.). It is the belief of the current team that with the proper application and modifications to the initially manufactured design a lighting solution for the entire developing area of the Americas may be provided.
B. PROPOSAL FOR P3 PHASE II

Lighting a Third of the World: Development and Demonstration of LED Lighting Units with Community-Based Power Charging Systems

1. P3 Phase II Project Description

Challenge Definition and Relationship to Phase I

A large portion of the world’s population currently does not have access to clean and reliable sources of artificial lighting, vital for furthering one’s education, enabling some income generating activities, and providing a richer and healthier family and community environment. Currently over two billion people in the world go without lighting or use unhealthy and polluting lighting sources such as kerosene lamps, candles, or other unsustainable fuel based lights [6]. In fact, approximately 33% of the world’s energy use for lighting is by kerosene lighting alone. Rural families spend a significant portion of their income on kerosene fuel for lighting. This is no more apparent than in Haiti where the project key partners are serving. In Haiti fuel must be imported and can cost a family $8-15 per month, a significant sum considering the average income in Haiti is less than $2/day according to our partners in Haiti.

In addition to the economic and poor light quality issues, fuel based lighting systems pose a huge environmental problem. In Haiti alone, approximately 240 million kg of CO₂ are emitted each year from kerosene use, which is equivalent to emissions of about 50,000 U.S. cars. Globally kerosene lighting emits 244 million metric tonnes of CO₂ per year [3]. During a recent global lighting study, Evan Mills of Lawrence Berkeley National Laboratory concluded that “The single-greatest way to reduce the greenhouse-gas emissions associated with lighting energy use is to replace kerosene lamps with white-LED electric systems in developing countries; this can be accomplished even while dramatically increasing currently deficient lighting service levels”[6]. Although there has been significant progress in the use of LED technology, much work has been geared toward the developed world with little attention on a major portion of the world’s population, the kerosene lamp users. For these reasons, the goal of the proposed project is to develop improved options for artificial lighting for the developing world that will lower long-term operating costs, reduce the negative impact on the local and global environment associated with fuel combustion and create local wealth generating opportunities.

The second phase of this project will build on the successes of phase I, which included developing the needs and engineering specifications for small independent artificial lighting systems; designing, building, and preliminary testing of a lighting prototype using advanced LED technology; and creating partnerships with NGOs working in developing nations. The second phase objectives will be to

- Develop two generations of improved individual lighting modules and communal power generation system prototypes,
- Conduct extensive field testing and observations of the lighting systems to both qualitatively and quantitatively measure the potential environmental, economic, and social impact of the lighting system adoption and provide feedback for further design improvements,
- Develop business plans for the creation of local microenterprises in Haiti and an initiative for broadening the lighting project on a global level, and
- Develop pilot projects in three communities in Northern Haiti.

**Innovation and Technical Merit**

Although small lighting systems are becoming relatively common in developed nations, there has been little development of technologies appropriate for the rest of the world. As described in *Design for the other 90%* design must be cheap, use locally available resources and fabrication practices as much as possible, be expandable, generate income quickly, and be replicable [14]. The technology must also be easily used by rural families with limited education and must be transferrable and allow for modification to improve design and customize the design for new applications or uses. The approach the RIT student team has taken to date has been to develop a design that could be assembled and serviced in Haiti by local craftsmen. Although the first design prototype the team has been developing will meet most if not all of the engineering specifications developed early on in collaboration with the project’s Haiti’s partners, there is a need for multiple iterations of field testing and user surveying followed by redesign to ensure an optimal lighting system.

The current system design consists of small rechargeable lighting units that are charged by a communal power generation station, which is a bike with a small generator. Future power generation systems could be done on a communal or individual basis and could include a small treadle with a generator, photovoltaic module, or thermoelectric generation unit. The primary advantage of the small lighting units with a central charging system is to reduce the initial cost to the user. Cost reduction is critical for populations living on less than $2/day. The material cost for an optimally designed system are expected to be less than $20 per unit and will be sufficient to provide 50 Lux on a two square meter surface, more than adequate for reading and significantly better than the kerosene based lighting currently used. The small units are modular, so as a family’s needs and available resources change additional lighting units can be purchased.

Having a centralized charging system has the advantage of creating an income generating activity using local resources rather than importing fuel or batteries, which removes wealth from the local community. A charge costing only 20¢ will typically last four nights, so the family lighting cost will be well below the 25-50¢ per night currently paid daily for the inferior lighting by kerosene. A central charging unit being developed is expected to charge more than 30 units a day resulting in more than a $6/day income for a local business. The central charging system also better ensures that the individual lighting systems are well maintained since the units can be inspected and serviced on a regular basis by a local expert who has a financial incentive to keep the lighting units working properly.

To build on the success of the first phase of the project, several first generation assembled lighting units and unassembled light kits will be sent to the H.O.P.E. and SOIL tech centers. Both H.O.P.E. and SOIL are project partners that have strong community programs in Northern Haiti with emphases on health, education, economic development, sanitation, and clean water. The tech centers will assemble the units and document issues with assembly and then provide feedback to the project team on areas for improvement with techniques and design modifications more appropriate for local fabrication and assembly. The tech centers will also distribute several of the lighting systems and a charging system to the end users and follow-up with a survey and
observations for future improvements. This feedback will be instrumental in the development of a second generation lighting unit and power generation system prototypes.

Two RIT multidisciplinary senior design teams will be formed during the 2009-10 academic year and develop the second generation systems. A subset of the faculty guides and students will visit the H.O.P.E. and SOIL tech centers and rural communities in Northern Haiti during the summer or fall of 2009 to better assess the needs and resources. A second iteration of the field testing and redesign will be done during the 2010-11 academic year to make further improvements and perfect a final design for full scale distribution.

Often technologies that are introduced in the developing world have a limited long-term acceptance because there is little attention paid to how to best incorporate the technology into the economic structure of the community. To this end, a team of engineering and business students with an interest in socially responsible business practices will be formed during the first year of Phase II to develop a business model with three objectives: to develop sustainable microenterprises that will help build local wealth; to ensure the lighting systems are well maintained, and to guarantee accelerated and sustainable adoption of the lighting technology. The team will take advantage of an existing entrepreneurial infrastructure at the Simone Center for Innovation and Entrepreneurship (SCIE) at RIT. An initial business model will be developed within the context of the MBA Entrepreneurship and New Venture Creation course and possibly move on to RIT’s Student Business Development Lab. A portion of the student team will visit Haiti and meet with local businesses to better understand current practices and better assess the needs. The team will research successful microenterprise models and ultimately develop a plan with a focus on increasing wealth sustainably while reducing the impact on the environment.

A second plan will be developed during the second year of Phase II within the context of the RIT’s student incubator program. The plan will be developed by a multidisciplinary team lead by from the Kate Gleason College of Engineering, the Simone Center for Innovation and Entrepreneurship, and the Sanders College of Business. This second plan will be the blueprint for an initiative to expand the adoption of the LED lighting systems to a regional or global level. The focus of this plan will be on how best to develop an organization for duplicating the successes of the Haitian LED microenterprises in other parts of the developing world. These business development activities will fit well into RIT’s SCIE’s new Social Entrepreneurship Initiative.

During the second year of Phase II, the project team in partnership with the H.O.P.E. and SOIL tech centers will identify three communities in Northern Haiti where three pilot projects based on the microenterprise business plan developed during the first year will be initiated. Both H.O.P.E. and SOIL will assist in conducting user surveys that will focus on both the technology and the business structure for distributing and charging the units.

**Relationship of Challenge to Sustainability**

As mentioned above, replacing kerosene lighting with small LED based units in Haiti and other developing countries will result in significant reductions in greenhouse gases. Replacing 10% of the world’s kerosene lights will be equivalent to removing well over four million U.S. passenger cars from our highways. In addition to the environmental benefits, there are considerable
economic benefits to the impoverished rural populations of Haiti and other developing countries. The proposed inexpensive lighting units will have simple paybacks of less than few months with the added benefit of significantly reduced ongoing operating costs. With the exception of the need to replace the NiMH batteries every three to five years depending on use, the lighting units should last well over 10 years. The small fee paid for central charging will support a local microenterprise and thereby keep wealth within the local community, unlike what happens with kerosene lighting systems. Although the environmental impacts and costs are reduced, the light quality will be significantly improved opening the door for reading and indoor/night income generating activities. The LED lighting units will not only improve the quality of life for the current generation but will have a positive impact on future generations.

**Measurable Results, Evaluation Method, and Demonstration/Implementation Strategy**

At the conclusion of Phase II, the project team and partners will have developed two improved LED lighting units and power generation systems, done extensive field testing, developed a plan for the best way to introduce the technology at both a local and regional level sustainably, and conducted up to three community pilot projects in Northern Haiti.

The prototypes will be developed over a two year period by up to four multidisciplinary senior design teams as part of RIT’s Kate Gleason College of Engineering’s two-quarter “Multidisciplinary Design Experience” (MDE). During this experience students from Industrial and Systems Engineering, Mechanical Engineering, and Electrical Engineering will form teams to work on projects for a wide variety of clients, thus providing real-world business interactions. The teams may also attract students from disciplines beyond the College of Engineering. Our students consistently blend excellence and entrepreneurship into this experience with over forty teams participating per year. More details of this multidisciplinary experience can be found at the following URL: [http://edge.rit.edu](http://edge.rit.edu). As the teams move forward with their MDE projects, our proposed student teams will evaluate their designs against the cost and productivity criteria which will include appropriate environmental and social externalities.

During the MDE, which is approximately 22 weeks long, student teams adhere to the following multi-faceted methodology to solve a design problem:

- Need Recognition and Quantification
- Concept Development
- Feasibility Assessment
- Design Objectives and Criteria Establishment
- Analysis of Problems & Synthesis into the Design
- Preliminary Design
- Engineering Models - Simulation and/or Hardware
- Detailed Design
- Transition to Commercial Production

Twice during the overall MDE, each student team presents its progress to a technical panel of professional engineers from academia and industry. The panel then scrutinizes the design and gives feedback. In addition, for this project the student team will be in direct communication with our technical partners H.O.P.E. and S.O.I.L.
During the second half of the MDE, the students will build the LED lighting unit or power generation system and complete preliminary testing. A testing protocol will be developed in cooperation with partners to ensure that the systems meet the specifications developed during the early stage of the design. Prototypes will be sent to Haiti at least twice during the course of the project for field testing by H.O.P.E. and SOIL. Units will be operated and critiqued by the technical staff of the H.O.P.E. and SOIL tech centers as well as distributed to the end users. Surveys will be conducted to assess the appropriateness of the design and document future design improvement needs. Faculty and student teams will visit Haiti at least twice during the course of the project to assist with the field testing and to better understand the needs and issues. Failed lighting and power generation units will be either inspected by the tech centers or the RIT student teams to improve fabrication processes or future designs.

Ultimately the project team will initiate three community pilot projects to deploy and maintain 100-200 lighting units and 3-6 communal charging systems. The pilot projects will be set up using the microenterprise business plan developed during the first year of Phase II. Surveys of the communities will be conducted a month or more after initial introduction of the systems to document any technical problems as well as assess the success of the business plan.

Integration of P3 Concepts as an Educational Tool
During the MDE, students from Mechanical Engineering, Industrial and Systems Engineering, and Electrical Engineering will form teams to work on projects for a wide variety of industrial, government, and academic clients. In the past, teams have also included interested students from other colleges within RIT, including students majoring in business, industrial design, and various science departments. Recently there has been a growing interest in sustainable technology projects, so much so that now RIT’s Engineering College has a track of projects dedicated to sustainable technology. There are typically six to eight sustainability projects done each year, one or two of which focus on developing world applications. It is expected that over the course of Phase II projects 15-25 students will work directly on the LED design projects and be exposed to P3 concepts.

There will also be exposure to P3 concepts in RIT’s College of Business and innovation programs through the development of the microenterprise and regional initiative business plans, highlighted earlier. The project will be an excellent addition to the new Social Entrepreneurship Initiative at RIT’s Simone Center for Innovation and Entrepreneurship.

The project will also be highlighted in RIT’s annual Innovation and Creativity Festival which has drawn approximately 20,000 visitors annually from the Rochester community and upstate New York. Each project team will also develop a poster that will be displayed for one to two years in the college and seen by numerous visitors, faculty, and students.

2. PROJECT SCHEDULE
Phase II activities will build upon the completion of the LED system prototypes developed during Phase I of this project. Nine key tasks with the proposed schedule for the Phase II are listed below. The lead for each task is noted. Kate Gleason College of Engineering (KGCOE) efforts will be lead by faculty, Rob Stevens and Brian Thorn, and undergraduate student teams. Jim Myers will coordinate many of the business development activities in partnership with RIT’s
Simone Center for Innovation and Entrepreneurship (SCIE). Both H.O.P.E. and SOIL will be key partners for the field testing and pilot projects.

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<td>Microenterprise business plan development</td>
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<td>Field testing of 2nd generation prototype</td>
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<td>Field testing of 3rd generation prototype</td>
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REFERENCES

[7] W. Floor and R. Masse, "Peri-urban electricity consumers, a forgotten but important group: What can we do to electrify them?," Joint UNDP/World Bank World Bank Energy Sector Management Assistance Programme (ESMAP), Washington D.C.
3. PARTNERSHIPS
There are two partnerships in Haiti that will provide local support for travel, field testing, design critique, and community demonstrations. RIT’s business program and Center for Innovation will be vital in developing the proposed business plans. The partners are listed below.

H.O.P.E.
www.hopehaiti.org/
Rose-Marie Chierici, Ph.D., Executive Director
228 S. Plymouth Ave.
Rochester, NY 14608
585-672-5852

H.O.P.E. has been working in Haiti for over 13 years with a focus on health, education, economic development, and sanitation & clean water. H.O.P.E. operates a Tech Center in Borgne as well as a permanent and mobile health clinic that serves 80,000 people in 200 villages. H.O.P.E. will initially help the students understand lighting needs by collecting field data from prototype units in Borgne and the surrounding rural areas. As the student team works towards a solution, H.O.P.E. will provide critical feedback for multiple reviews during the design stage of the project. H.O.P.E. will be invaluable in assessing the manufacturability of the proposed design. H.O.P.E. will also conduct field testing and demonstrate the prototypes, providing feedback for improved design. In addition, H.O.P.E. will assist in the development of the community pilot projects. A letter of support from H.O.P.E. can be found in the next section.

SOIL (Sustainable Organic Integrated Livelihoods)
www.oursoil.org/
Sarah Brownell, Co-founder
124 Church Rd.
Sherburne, NY 13460

SOIL is a non-profit organization dedicated to protecting soil resources, empowering communities and transforming wastes into resources in Haiti. SOIL believes that the path to sustainability is through transformation, of both disempowered people and discarded materials, turning apathy and pollution into valuable resources. SOIL promotes integrated approaches to the problems of poverty, poor public health, agricultural productivity, and environmental destruction. SOIL attempts to nurture collective creativity through developing collaborative relationships between community organizations in Haiti and academics and activists internationally. A letter of support from SOIL can be found in the next section.

RIT Albert J. Simone Center for Innovation and Entrepreneurship
http://entrepreneurship.rit.edu/
Richard DeMartino, Director (475-5646, rdemartino@saunders.rit.edu)
Rochester Institute of Technology
105 Lomb Memorial Drive
Rochester, NY 14623
The Simone Center promotes and enhances entrepreneurship and commercialization activities throughout the RIT community. In addition to the curriculum and other educational events, the Center, in partnership with the RIT Venture Creations Incubator, assists students and faculty in advancing their innovative business concepts.
VI. SUPPORTING LETTERS

March 18, 2009

Rob Stevens, PhD
Assistant Professor
Mechanical Engineering
Rochester Institute of Technology
76 Lomb Memorial Drive
Rochester, NY 14623

Dear Professor Stevens,

Haiti Outreach-Pwoje Espwa (H.O.P.E.), is pleased to support your proposal to develop and test an environmentally and people friendly lighting systems with your students from RIT. The proposed project offers several benefits for the 80,000 people who live in the Commune of Borgne, and potentially for people in other areas of Haiti. It offers H.O.P.E. the opportunity to expand one of its main objectives, to introduce and implement inexpensive, simple, technologies in this resource poor yet vibrant area. Introducing improved lighting technologies as you propose will have tremendous economic, social, and economic benefits for Borgne where kerosene lamps are currently the dominant means of lighting. Kerosene is imported and consumes a significant portion of Borgne families’ incomes while providing low quality light and creating poor indoor air quality. The LED lighting systems you are proposing will provide superior lighting for nighttime studying, reading, and possibly income generating activities while immediately reducing costs and keeping financial resources local. We are especially interested in how your lighting systems could be used to create microenterprises, which are critical for economic development in Borgne. The LED project will be critical to working towards a more self-sustainable region.

H.O.P.E. is also glad to offer our own resources on site for this project. Over the past thirteen years we have developed good working relationships with grassroots organizations and community groups. Our Tech Center staff already has a good deal of experience testing, demonstrating and disseminating sanitation and clean water technologies; they will be good allies as you field test and pilot your new technology. The Center is centrally located and has ties to outlying villages.

We really look forward to working with you on this initiative and to the lighting systems your students will develop. Please do not hesitate to contact us, we stand ready to offer our full collaboration.

Sincerely,

Rose-Marie Chierici

Rose-Marie Chierici, PhD
Executive Director, H.O.P.E.

Haiti Outreach-Pwoje Espwa (H.O.P.E.)  A 501 (c)(3) Charitable Corporation
228 South Plymouth Avenue.
Rochester, NY 14608
Tel./Fax: 585-672-5852

www.hopehaiti.org
info@hopehaiti.org

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Dear friends,

I am writing to express the intention of Sustainable Organic Integrated Livelihoods, a US 501(c)3 non-profit working in Haiti, to collaborate with the LED lighting team at the Rochester Institute of Technology (RIT). We can offer logistical and technical support for student teams working in Haiti to field test lighting systems.

We support three “Technology Centers” (the first in collaboration with H.O.P.E.) designed to build the confidence of local Haitians for tackling technological projects. Two centers are located in rural areas and one is in an urban slum. Each technology center has a core group of employees and volunteers who conduct community educational sessions and experiment with new technologies. These volunteers and employees would work directly with student visitors to improve and test their designs in the field and can collect data over long term field trials.

SOIL is well equipped to receive student groups and interns in Haiti. We already hold 10-day service learning courses through the International Studies Department of the University of Miami and Alternative Spring Break programs with the University of California at Santa Cruz for groups of up to 10 students. Last year, we hosted individual interns and visitors from 10 US universities who stayed anywhere from a few days up to 3 months with us in Haiti. We have three American citizens who spend most of the year in Haiti and can help with student projects and support: myself (environmental engineer), Dr. Sasha Kramer (ecologist), and Kevin Foos (hospitality expert and community organizer). We have housing for 10 in Cap Haitien, 2 in Borgne, and 4 in Milot, where our tech centers are located, and can easily set up housing for larger groups either with local churches or in individuals’ homes.

A brief summary of SOIL’s work follows this letter and more information can be found at www.oursoil.org.

We look forward to expanding our collaboration with the Rochester Institute of Technology and ask that you strongly consider funding this important project.

Thank you,

Sarah Brownell
SOIL Co-founder and Project Co-coordinator

The following section is an overview of SOIL’s mission in Haiti:

SOIL promotes the concept that there is “no such thing as garbage.” Our projects focus on transforming things once considered wastes into valuable resources. For example:

- We build ecological toilets that both protect health and transform human wastes into much needed fertilizer. We have built more than 44 public dry toilets, we recently developed a hurricane resistant arborloo called the TwaletSOL for rural households, and we are working on indoor dry toilets with a collection system and a municipal
composting site that will receive human and organic wastes from city neighborhoods. Organic compost will increase agricultural production by building the soil—a local solution to the problem of high food costs.

- We encourage youth to see the trash around their neighborhoods in a new way. In our Garbage Doesn’t Exist Contest, we ask youth to find something that someone has thrown away and turn it into something useful or beautiful. We hope to turn some of the contest entries—sandals made from discarded plastic and beaded window shades made from bottle caps, for example—into products for sale.

- We encourage those who have for centuries been called “garbage” or “incapable of learning” by the elite in their country, that they can be leaders and decision makers. They can start businesses, build water reservoirs, construct toilets, hold conferences, etc. We operate three rural technology/idea exchange centers where new ideas are birthed, shared, and tested by community members and US interns. Two of the centers are planning compost and small garden programs.

- We work to transform attitudes about Haiti by inviting interns and visitors to Cap Haitien to build relationships with local organizations, and by speaking in the US about Haitian culture and positive change that is taking place.

See www.oursoil.org for more information.