



## Full Proposal Example “Light From Below”

### Light from Below: Using earth energy to bring free light to the poor

Light from Below provides light from efficient LEDs which is produced from used bottles and cans and powered by our mix of soil, bacteria and waste. Unlike costly and difficult-to-obtain energy alternatives such as solar powered lighting, these lights provide inexpensive illumination for households in locations where electrical lighting is not available, thereby allowing people to continue their activities after sundown.

#### Proposal and Impact

##### Ethical, cultural, and legal considerations

Panama City could be considered almost a first world city after all the technological and infrastructural advances of the past 10 years. However, the socio-cultural characteristics in Panama vary across the country. Wealthy neighborhoods and designer shopping malls stand next to large communities in extreme poverty. As citizens of Panama, the Light from Below team members aim to alleviate the problems of these impoverished communities. The Light from Below project will mainly target areas in Panama with no access to electricity in order to bring the education and development of the city to help poor communities across Panama.

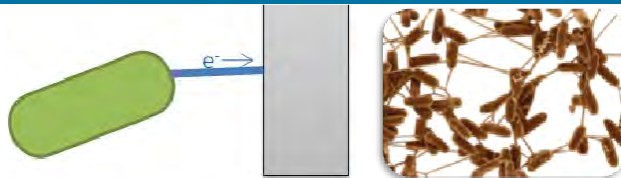
Ultimately, Light from Below is intended to work as a project that would contribute to the electrical needs of many countries that face similar conditions as Panama. Initially, the project will target communities with no access to the power grid, based on information given by governmental organizations. Among these communities are Tormenta, Nuevo Azuero, Chungal, and Altos Pedregal which were studied for the purpose of this Proposal. Since the main goal of the Light from Below project is to construct an inexpensive energy source using materials readily found within these communities, using a microbial fuel cell is one of the best options.

##### How does it work?

Microbial fuel cells (MFCs) are devices that use the natural metabolism of microbes to produce electrical power. Within the MFC, microbes use sugars and other nutrients in the surrounding environment to release a portion of the energy contained within that food in the form of electricity. Microbes thrive in virtually all soils, sediments, and streams on the planet. Among the most electrochemically active bacteria populations are Geobacteraceae Azoarcus and Azospirillum. All of these can be found in soil, mud, and decomposed organic material. Within a sealed vessel (oxygen-free environment), bacteria are forced to use anaerobic (no-oxygen) reactions that oxidize organic compounds such as glucose and acetate. During these chemical reactions, MFCs collect free protons and electrons using metal plates (Fig. 1). Similar to what happens in a battery, the MFC collects and transfers electrons using an anode compartment (one of the two metal plates required in the MFC) to an external circuit.

Electron Transfer Mechanisms:

○ Nanowires



**Figure 1. Biofilm formed at the surface of the anode. KeegoTech.**

In a 70- to 90-degree Fahrenheit environment, an MFC can produce energy with over 50% efficiency. “For each kilogram of incoming organic contamination, microbial fuel cells net 1 kilowatt-hour of electricity” (Sanford, 2010). Recently, a group of Harvard students experimented with microbial fuel cells and produced enough electricity to power a small LED bulb for up to a year (Justa, 2010). This technology is not only cheap but also reusable. Additional soil nutrients, such as acid found in lemons and vinegar, or even a simple change of soil will “recharge” the MFC battery.

### Similar projects

Even though microbial fuel cells research is still in an early stage, several organizations, universities, and individuals are currently experimenting with and building their own MFC prototypes in order to improve the power delivered. A few examples of these projects are:

- **MudWatt by KeegoTech:** The MudWatt is a very simple MFC design that is normally used for educational purposes. KeegoTech is possibly the only company that sells this educational kit. However, materials used by this kit such as titanium wires and graphite fiber felt for the anode and cathode make the MudWatt expensive for the purposes of Light from Below.
- **Home-made MFCs:** Several videos on YouTube show people making their own MFCs using common materials. However, even though these MFCs produce power, there is still no record of a home-made MFC that produces enough energy to power a light bulb.
- **Lebone by Harvard:** A group of Harvard students developed an MFC that was made up of a graphite-cloth anode, chicken-wire cathode, mud with manure, a layer of sand which acted as an ion barrier and salt water which acted as an electrolyte. Their main goal was to use their materials to provide light for African families. Last summer as part of a pilot program they distributed 100 MFC lamps in Namibia. The World Bank provided funding for this project to start trials of MFCs that run on waste and provide electricity to and charge batteries in rural areas of Tanzania and Namibia (Franks, 2010). There is no detail about the process, current stage, or results of this research.

Light from Below is very similar to this last project since both have the same goal of bringing light to rural areas. However, they differ in the following points:

1. **Location:** Light from Below aims to aid Panamanians without electricity as soon as possible. It intends to provide a temporary lighting solution until the government extends the power grid to these communities, which could take several years.
2. **Method:** The lamps in the Lebone project were delivered, meaning that they were made

of materials obtained outside the communities. In contrast, Light from Below not only focuses on creating a light source but also using recyclable materials from within the community that are commonly discarded as waste. This allows the Light from Below project to expand and grow without the need for expensive manufacturing and material waste.

3. Energy source: The mud mix from the Lebone project of 2009 uses manure as a source of organic material and bacteria. In contrast to the commonly use manure, our project uses the innovative fish compost as a better source of energy for the soils.

Our project takes this existing technology to the undeveloped areas in Panama. Light from Below will use the simplicity of these discoveries and maximize the usage of local materials to make MFC lamps for household use. The goal is to prepare a design that will facilitate the manufacture and maintenance of MFC lamps in the community while minimizing the amount of external materials required. The project will finance supplies that will generate free electricity for the community for about one year at an estimated initial cost of about \$10.00 per lamp. When lamp materials need to be replaced, the maintenance cost will be small: mud mix with fish compost, plastic bottles, and cans can all be obtained for a small cost; copper wires are inexpensive; and LED bulbs can be reused.

The Panamanian government has already made some efforts to install photovoltaic panels in these communities. International organizations such as the Global Environmental Brigades from UCSD are also making an effort to deliver solar panels to poor areas (Harding, 2011). However, lighting is only provided in public areas like basketball courts, parks, and schools, but not houses. Additionally, the initial cost and transportation of this technology to areas of restricted access present an economic challenge to the Panamanian government. As mentioned before, the company Keego Technologies has started to commercialize their version of earth energy, the "MudWatt" battery kit, for \$44.95. But our proposed project, Light from Below, offers a cheaper, more portable, an easier to manufacture option for restricted access areas. By using mainly local materials, the project will reduce waste and greenhouse gases, and it will provide free lighting in areas in need of light.

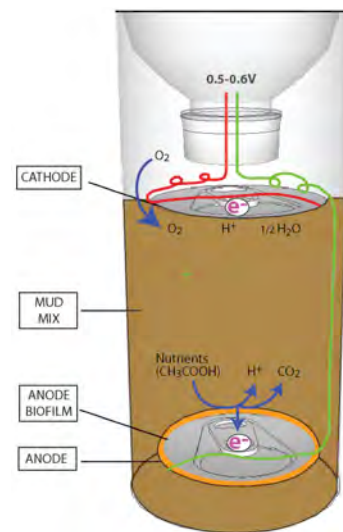


Figure 2. Light from Below basic prototype lamp.

### Initial prototypes and potential obstacles

It takes on average 4 to 10 days for an MFC to create a biofilm around the anode and start producing electricity. The Light from Below team members started several prototypes in January. Team members are still experimenting with different soils, materials, circuitry, and designs. All of the designs made follow the simple schematics of an MFC: an anode buried within the mud to develop a biofilm on its surface, a cathode resting on top in contact with air,

and two wires (one from the anode, and one from the cathode) that bring electricity to a light bulb (Fig. 2).

We can group our prototypes into three different categories:

1. Single MFC: These prototypes were the team’s first attempt to use recyclable materials to make an MFC. It is the simplest and most inexpensive design. There were two prototypes made:
  - Prototype 1.A: Plastic bottle casing, aluminum can ends anode and cathode, and 8 awg copper wire (Fig 3). Max voltage: 0.5V.
  - Prototype 1.B: Glass jar casing, tin/steel can ends anode and cathode, and 12 awg wire. Max voltage: 0.2V.



Figure 3. Prototype 1.A. Plastic Bottle lamp.

The main progress of this design compared to everything previously seen was that the prototypes produced energy out of recyclable materials that are usually seen as waste. The results were promising although higher voltage is required to light an LED.

2. Multiple MFC: These prototypes were an attempt to increase the power delivered by connecting several MFCs in series. Two prototypes were made:
  - Prototype 2.A: Four McDonald’s plastic coffee cups for casing, aluminum foil for anode and cathode, and 22 awg copper wire. Max voltage: 0.2V.
  - Prototype 2.B: 40 plastic test tubes for casing, zinc screws for anode and cathode, and 22 awg copper wire (Fig. 4). Max Voltage: 0.6V.

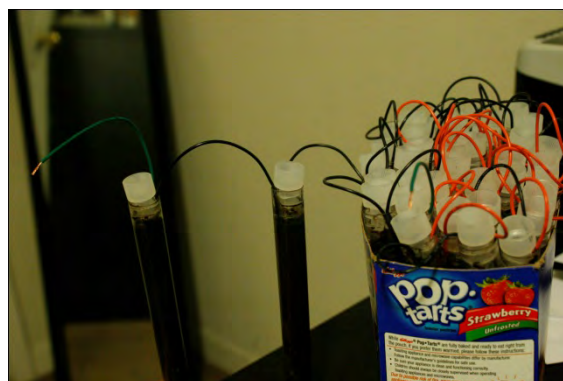


Figure 4. Prototype 2.B. 40 test tubes connected in series.

One of the main disadvantages of connecting MFCs in series is that if one MFC fails, the entire combination will not deliver any power because it will “open the circuit”. Another disadvantage is the weight and space that the multiple MFC takes. Even though our results did not produce the amount of electric energy expected, both prototypes started producing energy in about three days.

3. MudWatt: The Light from Below team members decided to purchase the KeegoTech’s MudWatt and test it. It was purchased and assembled before making the first prototypes



in order to compare results. Due to the team members' flight schedules, the MudWatt had to be disassembled and reassembled in the U.S.:

- First try at Panama City, Panama: The type of soil used was dry, combined with lime, salt, and water. The MudWatt did not produce more than 0.2V in 7 days and did not light the LED.
- Second try at College Station, Texas: Mud was collected a day after it rained. This mud was not combined with any additional components. After 6 days the MudWatt produced 0.4V and the LED started blinking slowly (Fig. 5). The LED kept blinking faster afterwards indicating more power. The MudWatt has been producing 0.7V for about 2 weeks and the LED has been



Figure 5. MudWatt results after a second try .

steadily blinking at the faster pace. Specific measurements can be found in Appendix 1.

One of the main issues affecting energy production is the type of mud used. For instance, the fact that the mud used in the second try of the MudWatt was extracted after a rainy day could have helped to the bacteria production. Similarly, manure-rich mud could be another good candidate for an energy source since it is the type of mud used by the Harvard group Lebone. Finally, our project's newest candidate is a compost made of residual parts of fish (Fig. 6). Already used in Arizona to grow crops at a faster rate, this new compost is attractive for the project because of its high concentration of bacteria and the high availability of fish materials in Panama.

Our research shows other ways to increase power beyond changing the type of mud. As noted above, our current design and mix are successfully converting chemical energy into electrical energy, but the power output is still too low to light electric lamps. Our project will invest three to four months on researching and improving these two aspects of our current findings:

1. Drawing from existing research and recent discoveries, we will study and create designs that will more efficiently produce energy out of the soil mix. For example, we would like to experiment with the dimensions and shape of our anode. Professor Bruce Logan explains that a "three-dimensional structure provides a large



Figure 6. Fish compost used for agriculture in Arizona.

surface area for the bacteria to grow.”

2. We are in the process of improving our soil mix to increase its efficiency by using existing agriculture organic composting. From our research on different techniques and compost types, we find that fish composting is likely to be efficient and appropriate for our purposes. According to Dale Snyder with Sweetgrass Garden Co-op in South Carolina, fish waste composting is more efficient than most existing composting techniques and yields better results than other composting on a number of fronts. Snyder’s research compared neutral compost, vegetable compost, and fish compost. He found that the cucumbers planted with the fish compost not only yielded fruits first, but it also yielded bigger and more fruits than the other compost, with the fish compost yielding about 30% more cucumbers (Snyder, 2011). One member of our team visited the Singh Farms in Arizona and found an example of this fish compost. This compost is used in agriculture to increase organic material in the soil and make it more fertile. Given a correlation between the efficacy of compost and its internal bacterial activity, our project is interested in exploring this new fish compost as a way to boost our soil mix with organic material and bacteria to improve its efficiency. Even though we are familiar with the process of processing fish compost, for our project we will initially buy the compost to experiment and produce the lamps. In the future we would like to do our own compost. We see using fish compost in our project as an opportunity to obtain revenues from fish farms and restaurants around Panama by offering to remove large amounts of fish waste for use in Light from Below.

Ashley Franks, in her article “Bacterial biofilms: the powerhouse of a microbial fuel cell” explains, “It is feasible that in marine environments such as fish farms, natural reserves, harbors and isolated communities, sediment MFC could provide small amounts of power for light or monitoring devices. To meet higher demand the sediment MFC could be replenished through the addition of chitin or other waste organics into the sediments” (Franks, 2010).

“If the sediment MFC were to be enclosed and adapted, it is conceivable that electrons could be harvested as part of the composting waste organic or vegetable matter to power electronics in remote locations or third-world countries” (Franks, 2010).

### **Introducing lamps to communities**

The Light from Below team has been in contact with several organizations in Panama and the United States that have shown interest in our Proposal:

- EWB, Engineers Without Borders at Berkeley, are willing to advertise our project
- BERCC, Berkeley Energy & Resources Collaborative, is interested in including the project in a Science Fair
- Ministerio la Pena de Horeb, a ministry in Panama that helps poor communities in rural areas has shown a desire to use the lamps as a product to distribute to the communities where they have worked

- OER, Oficina de Electrificación Rural (Office of Rural Electrification), is a governmental office in Panama whose primary goal is to bring light to the rural areas in Panama by electric lines and solar panels. Communities with no lighting submit a claim to OER; in turn, OER has collaborated with us and provided information on some of these communities. OER hopes to see Light from Below lamps used in the communities that are difficult for them to access and help.

Additionally, Light from Below is pleased to announce that Global Brigades Panama has offered to work with our Project. Global Brigades is the world’s largest student-led global health and sustainable development organization. Since 2004, Global Brigades has mobilized thousands of university students and professionals through nine skills-based service programs to improve quality of life in under-resourced communities. This organization works with students from the United States to bring needed services to selected communities in Panama. Global Brigades Panama’s vision runs parallel to ours, by improving the quality of life in our country.

Our team has been in contact with the organization and they have agreed to provide us with transportation to the communities where they work. Michelle Menclewicz from Global Brigades tells us that “most of the houses in our communities do not have electricity or do not have it consistently.” Global Brigades is also introducing us to other organization working in these communities, such as the Peace Corps, Ministry of Health, ANAM, and ProNiños de Darien. Michelle also mentions that they expect about 800 to 900 students this year. We plan to work with them from the start of the project in June 2012 to the end June 2013, during which time they will provide transportation and community contacts so that we can continue our research and advance our technology. Global Brigades Panama will also help with the second phase of the project, during which we will transport materials to the communities for the student volunteers to create and distribute the portable lamps.

Global Brigades’ access to rural areas and their established relationships with these communities in need of electric light are essential and valuable to the success of our project. This relationship with Global Brigades will maximize our impact on the communities.

Our initial target communities have been chosen based on the information provided by OER about the communities in need of electric light and the communities with which Global Brigades Panama is currently working. Based on this information, we are interested in communities within Torti, Panama and Chepigana, Darien.

## Growth of the Project

### Research & Development – Initial Phase

Light from Below understands the importance of each member to this project. Figure 7 represents the business relationship model for this phase of the project:

1. Big Ideas is currently our main sponsor. It will initiate the project by providing the finances to refine the materials research and produce the first lamps.
2. Light from Below is the heart of the project. The team is in charge of providing the design, technology, and the light to the communities. At this phase of the project, the group will be going to the communities to research, test, fabricate, and deliver the lamps on site.
3. Global Brigades Panama will provide to the project transportation, community contacts and relationships, and volunteers to fabricate the lamps together with Light form Below.
4. The Communities act as the laboratory site, where we will research the materials and quality of resources available and the socio-economic conditions of the communities.

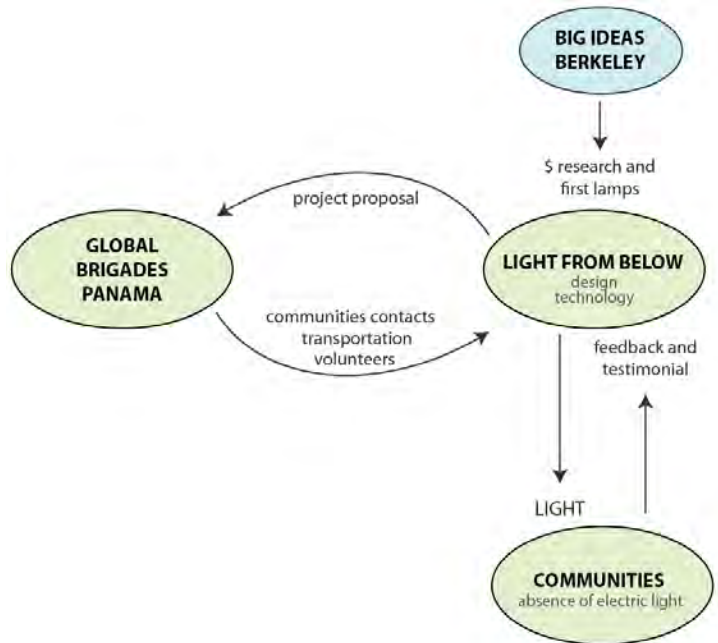


Figure 7. Light from Below business model.

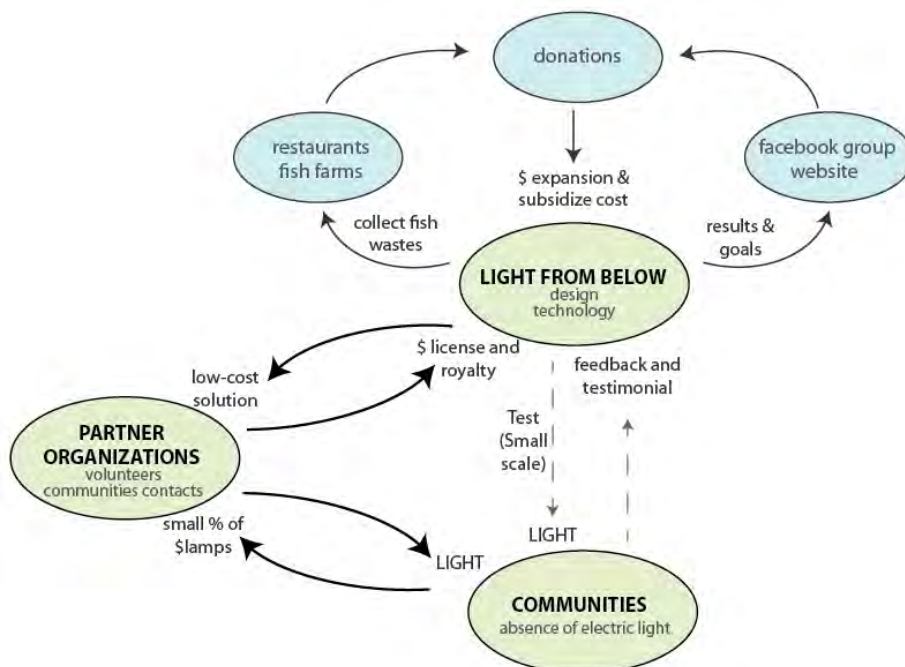


Figure 8. Future business model of Light from Below.

### Sustainable Business Model – Expansion Phase

Ideally, Light from Below will expand to more communities in Panama, South America, and other parts of the world. Figure 8 represents our future goals.

During the expansion phase, our goal will be to finance the



project by selling our lamps to the government and to organizations whose goal is to help the poor communities.

As Light from Below expands and the product becomes more efficient, we see our group as a provider of the design and technology. At this stage the Partner Organizations will be the ones travelling to the communities and providing the light. Also, we believe that the communities will be more appreciative of the product if they pay a very small fee to these organizations. Our goal is to be a research organization that studies the communities with lighting problems and adjusts and improves the design based on the conditions in the various countries and communities. Also, in the future we plan to produce our own fish compost and earn revenues by collecting fish wastes from restaurants and fish farms. In Panama and in many other undeveloped countries, fish are a widely available resource.

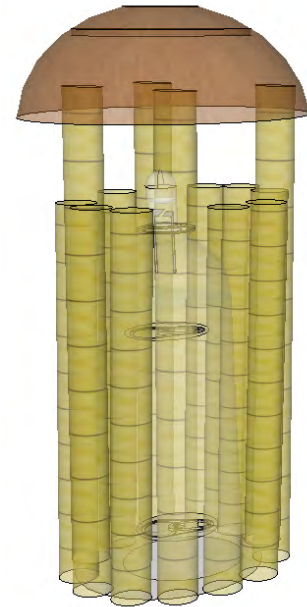


Figure 9. Possible future design.

The portable lamp design will evolve together with the development of the technology and resources in the community (Fig. 9). For instance, a final design would have the following materials:

- 4 bamboo stalks, cut in three parts, one longer than the others. This will provide 12 pieces of bamboo sticks. (Fig. 10)
- 1 water bottle
- 1 aluminum can
- ½ a coconut skin: some communities use the coconut skin to fabricate bowls. This might be an ideal source for a lampshade, if wanted.

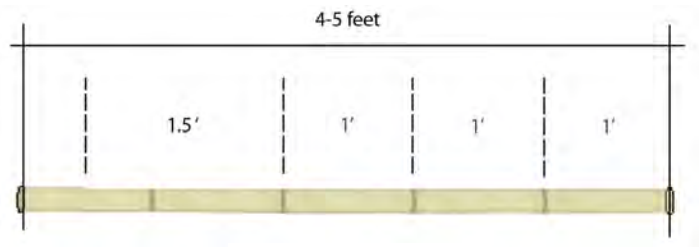


Figure 10. Bamboo cut

It is important to create a prototype flexible enough to be replicated and adapted to several communities, depending on the resources available and their socio-economic conditions.

### Future design considerations:

Will the lamp sit on a surface?

Will it hang from a ceiling?

Will it be portable to carry on a walk?

### **Need Statement**

#### **Community needs**

A poverty study made in 2000 by The World Bank in Panama revealed that 42% of rural areas do not have access to electricity. In addition, about 62% of poor households in rural areas do not

have electric lighting. Similarly, 93% of poor indigenous communities face the same lighting needs (World Bank, pg.19). In the past, our team members have performed social services in remote areas and can testify to the need for light in these communities (Fig. 11). They found that a simple light bulb would dramatically change the living conditions of a community. Nights are unproductive and dangerous. Most poor rural and indigenous areas rely on kerosene and firewood which increase deforestation and cause respiratory illness.



Figure 11. Nuevo Azuero, Chepo Cabezera, Chepo, Panama.

### Surveys

In order to obtain first hand data from the communities in need of electricity, the Lights from Below team made a survey that was conducted on several locations on February 25, 2012 (see Appendix 2). The target communities were chosen based on information provided by OER Panama. Twenty-five families from four different locations were asked a series of questions related to their geography, electrical necessities, resources, waste, and other elements that could be helpful to better understand how the project would impact their lifestyle. All twenty-five families lack electrical energy in their homes, and they all stated that during night times they stop all activities except for talking with their relatives. The only electrical resources available are portable devices as shown in Figure 12:

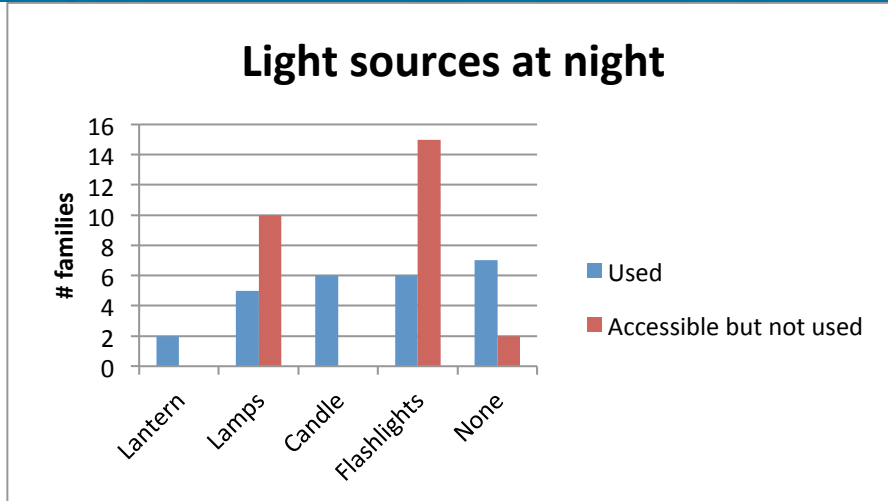


Figure 12. Used and accesible light sources.

Some of these light sources such as battery-powered flashlights are not utilized even though they are physically available because they are expensive to use all the time and require resources such as batteries that must be purchased outside the communities. Additionally, lanterns require fuel, candles need to be replaced constantly and do not illuminate enough for tasks such as reading. For this reason, one of the main objectives of Light from Below is to make lamps out of materials generally found in poor communities. Figure 13a shows the number of families having free access to various resources available in the communities. Some of these resources are seen

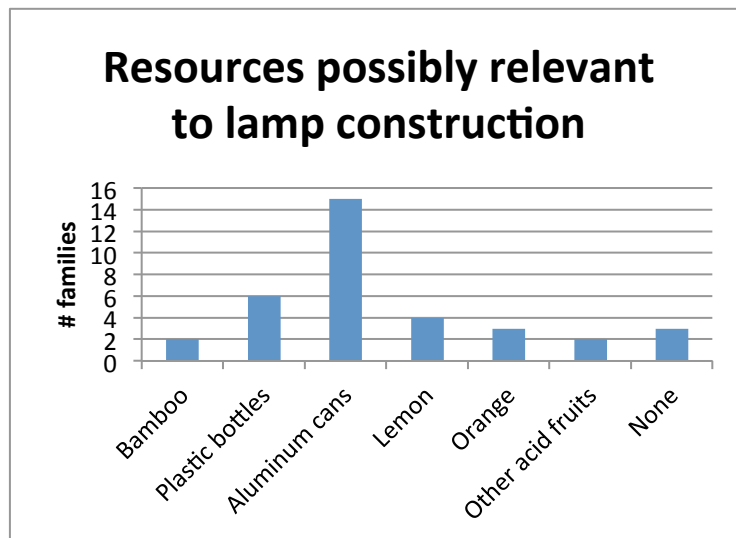


Figure 13a. Community resources

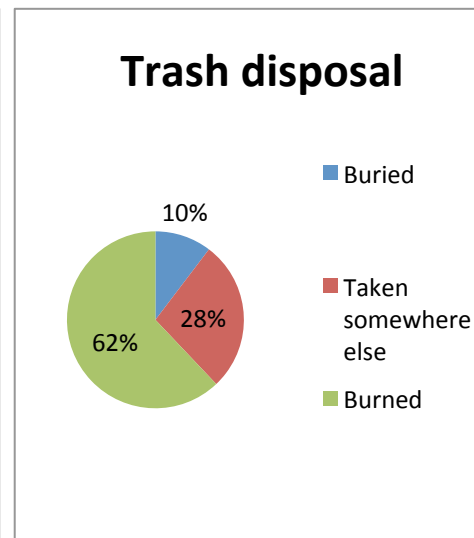


Figure 13b. Trash disposal methods.

waste that is disposed of using different methods (Fig. 13b).

as

Access to water, either through rain or distance to a river or ocean, is a final piece of information important to the project. As mentioned before, rain cycles and waste fish parts could increase the concentration of bacteria in soil. Residents were asked about their perceptions of how often it rained in their community and how far they think the closest river or ocean is (Figs. 14a-b):

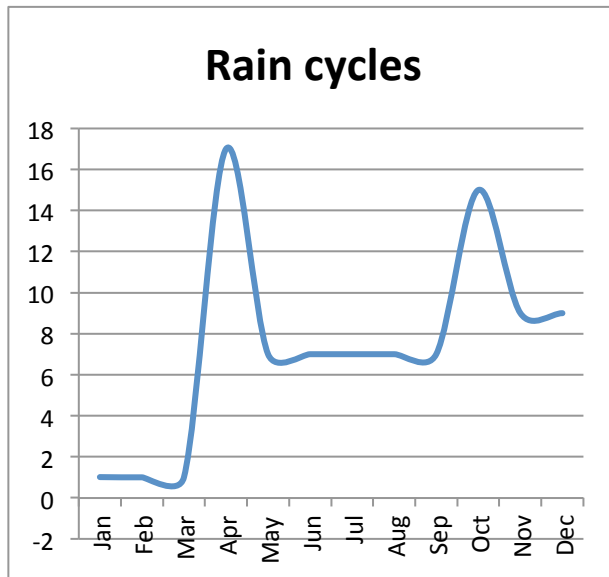


Figure 14a. Rain cycle perceived by residents

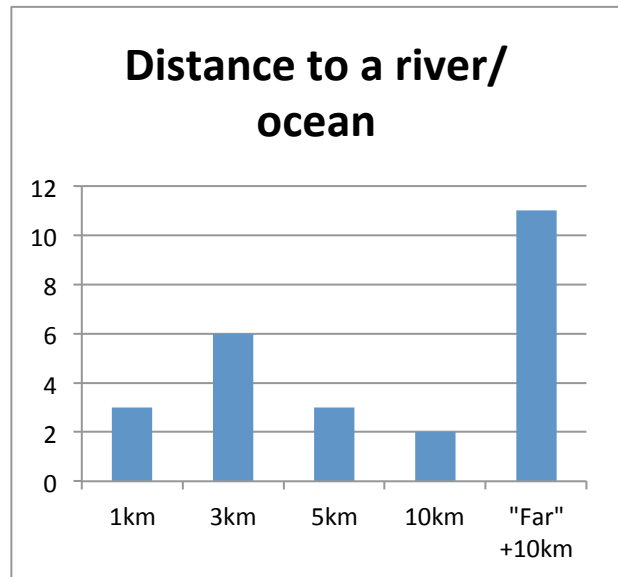


Figure 14b. Closest river/ocean

### Possible challenges

The technological challenges have already been mentioned throughout the Proposal. Consistent materials availability presents another challenge. Some communities have limited access to materials such as bamboo. To maximize the project's impact on different communities, Light from Below will design more than one module to be adjusted depending on the materials available in the community. Another solution to the inconsistency of resources between communities is to bring the bamboo from neighboring areas or to fabricate the lamp casing in communities with bamboo and bring them to others without bamboo.

Language may present another potential challenge. Since many residents of poor communities are illiterate or use only spoken dialects, the project will develop simple illustrated instructions to educate the indigenous on how to maintain their own lamps, using as few words as possible.

### Impact Evaluation

#### How to measure the impact of the project?

At the end of the project, the team will revisit the communities with the lamps to analyze the results and the socio-economic and environmental advantages and disadvantages of the project. Technical studies and surveys will be distributed to gather feedback and testimonials from community members. Light from Below has three main impact levels:

1. On the community: Social and Economical



- Provide free lighting to the poor
  - Explore materials and resources that are seen as waste
  - Increase the possibilities of domestic life/work at night
  - Provide a safe environment for children at night
  - Improve tourism opportunities by renting out cabins with attractive/innovative lighting sources and selling local “Light from Below” souvenirs
2. On the government: Social and Economical
- A temporary and inexpensive solution to the unresolved issue of providing light to undeveloped areas
  - An opportunity to help and serve the communities with the highest economic need
  - Substantial cost savings by shifting away from expensive alternative technologies such as solar panels
  - Smaller technical staff compared to that needed for solar panel maintenance
  - Educate undeveloped areas on creative solutions for their own needs
3. On the environment:
- By using renewable energy, it reduces greenhouse gases and the negative impact of energy production on the environment
  - By using local materials, it reduces the need for transportation of larger equipment
  - By reusing materials such as plastic bottles, the project can minimize the excessive amount of waste that is currently being burned or disposed of in the sea

### **Timeline**

Global Brigades Panama takes students from universities in the United States like Berkeley, to selected communities in Panama. Most of the trips are planned during the summer, winter, and spring breaks. This schedule is also beneficial for our team since we can dedicate more time to the project during these breaks. Figure 15 shows a graphical timeline of the project:

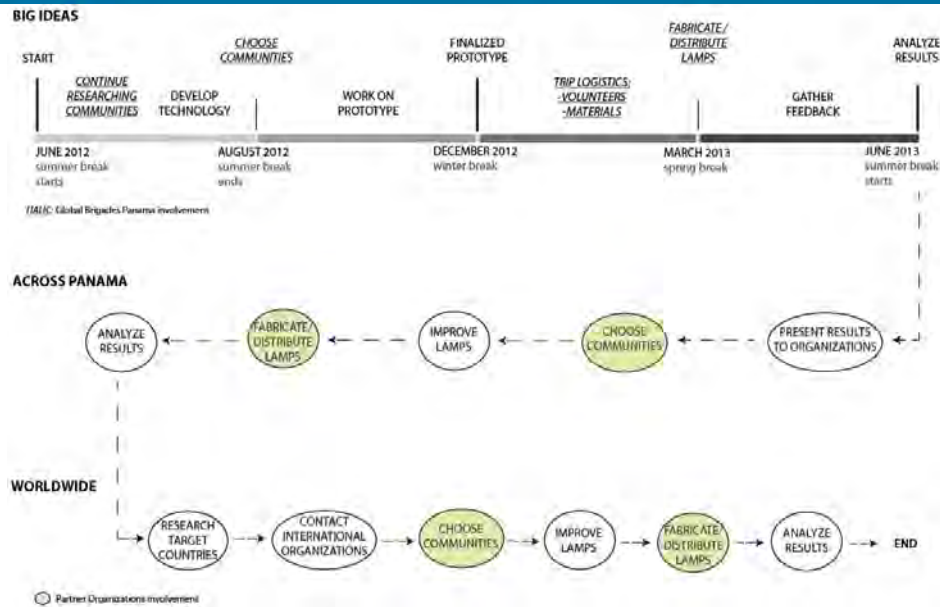


Figure 15. Timeline.

## Team Members

Being natives who speak the language is extremely valuable to our project. We value our multidisciplinary approach, our experience in research, and most importantly our shared desire to help the poor communities of Panama.

[Name excluded for privacy] is pursuing a Masters in Architecture at UC Berkeley. He graduated with a Bachelors in Environmental Design with magna cum laude honors from Texas A&M University. He has worked as a coordinator for Global Architecture Brigades, where he researched accessible materials from the Ngobe Indians. He has worked as translator and researcher with several social services programs along Panama's borders with Costa Rica and Columbia. Professionally, he helped introduce energy-efficient software at BHPD Architecture in Cincinnati. He has worked in a large group research project, "Horizontal Hybrid Solar Light Pip," a hybrid system that integrates natural and artificial lighting, a project that was awarded \$75,000 in an EPA competition.

[Name excluded for privacy] a senior undergraduate Electrical Engineering student is focusing his studies on power systems, power electronics, and renewable energy. He holds a minor in Mathematics, has a GPA of 3.87, expects to graduate magna cum laude in May 2012, and worked at Electro-Tech Industries, a company dedicated to industrial generation and power supply systems. His technical skills and academic achievements make him an essential member



# Full Proposal Example "Light From Below"

## Budget

### Big Ideas@Berkeley 2011-12 Contest Budget Template

Light from Below: Using Earth Energy to bring Free Light to the Poor

SECTION 1. PROJECTED EXPENSES		
I. Supplies Cost	Supplies Cost Details	Total
*LED Bulbs	\$8.00 per bulb, purchased in large quantities to minimized their cost	\$720.00
*Insulated Copper	100ft of copper for \$6.00. We will use 20ft of copper per lamp, \$1.20 per lamp. This is enough copper to make replacements as needed to powered the lamp for one year	\$108.00
*Fish Compost	10lb fish compost. Approx. 1lb per lamp.	\$360.00
Other materials	Bamboo, coconuts, ropes	\$200.00
Materials for research	Include testing of all the materials listed above.	\$500.00
Multimeter	It is necessary to measure the electric current we are generating	\$10.00
Electronic Welding Kit	We expect to borough a kit from the University to avoid this expense	\$25.00
Printing: Instructions to communities and surveys		\$150.00
*Indicates supplies to fabricate 90 lamps		
<b>Subtotal Supplies</b>		<b>\$2,073.00</b>
II. Travel & Transportation Costs	Travel Cost Details	Total
Air flight from U.S. To Panama	2 Flights, round trip. The Average Cost of 1 round trip flight is \$800	\$ 1,600.00
Transportation from the city to the communities. Global Brigades volunteers are not included since they will cover their own expenses	Local transportation (Bus and boats)	\$ 200.00
Cabins in Communities		\$ 300.00
Transportation during research phase		\$ 200.00
<b>Subtotal Travel</b>		<b>\$ 2,300.00</b>
III. Other Project Costs	Other Cost Details	Total
Translator	From Spanish-Dialects	\$ 100.00
Shipping or Transportation of Supplies		\$ 300.00
Labor help in Panama while the team is in the U.S. Distribute surveys and find local costs		\$ 150.00
Unexpected expenses		\$ 77.00
<b>Subtotal Other Costs</b>		<b>\$ 627.00</b>
<b>TOTAL PROJECTED EXPENSES</b>		<b>\$ 5,000.00</b>

### References

- Sanford, Galen. *Make Electricity, Not Sludge*. BlueTechBlog, June 15, 2010. Web. Nov. 19, 2011. <<http://bluetechblog.com/2010/06/15/make-electricity-not-sludge/>>
- The World Bank. *Panama poverty assessment: priorities and strategies for poverty reduction*. Washington: D.C., 2000.
- KeegoTech. *Meet MudWatt*. Keego Technologies, Web. Nov. 6, 2011. <<http://www.keegotech.com/>>
- Justa, Aditi. *Harvard students harness electric power from bacteria in soil*. EcoFriend, June 12, 2010. Web. Nov. 6, 2011. <<http://www.ecofriend.com/entry/harvard-students-harness-electric-power-from-bacteria-in-soil/>>
- Harding, Dan. *Global Environment Brigades Deliver Solar Power to Panama*. CalFinder, Apr. 13, 2010. Web. Nov. 19, 2011. <<http://solar.calfinder.com/blog/news/global-environment-brigades-deliver-solar-power-to-panama/>>
- <http://www.geobacter.org/publication-files/10.4155-bfs.10.25.pdf>
- Sara J. Dunaj, “Relationship between Soil Organic Matter, Nutrients, Bacterial Community Structure, And the Performance of Microbial Fuel Cells. January 6, 2012 URL: <http://pubs.acs.org/doi/abs/10.1021/es2032532?journalCode=esthag>
- Dylan Snyder, *Is Fish Waste Compost Worth the Mess and Effort?* November 1, 2011 URL: <http://www.youtube.com/watch?v=Thk-Jul0ooQ>
- Ashley E Franks, Nikhil Malvankar and Kelly P Nevin, “Bacterial biofilms: the powerhouse of a microbial fuel cell” Future Science Group, 2010.
- Diane Greer, “Harnessing the Power of Microbes” BioCycle, May 2007.



## Appendix 1

### MudWatt Results

-Purchased Keego MudWatt and connected a blinking LED circuitry to the terminals of the battery.

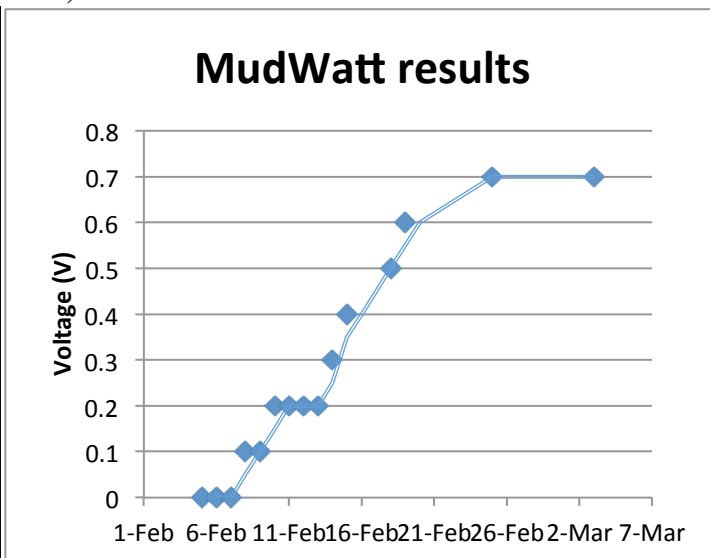
-First try did not produce any results after 2 weeks. Maximum voltage reached: 0.24V.

- Possible cause of failure:
  - o Used dry earth with tap water.
  - o Measured the output of the MudWatt with a cheap multi-miter which could have drained power from the battery every time a measurement was taken.

-Second try produced the following results:

Voltage Measurement (Whole circuit connected)

Date	V	Notes
2/5	0	Rained on 2/4
2/6	0	
2/7	0	
2/8	0.1	
2/9	0.1	
2/10	0.2	
2/11	0.2	
2/12	0.2	
2/13	0.2	
2/14	0.3	LED blinked every 3.45s
2/15	0.4	LED blinked every 1.5s
2/18	0.5	LED blinked every 0.5s
2/19	0.6	LED blinked every 0.3s
2/25	0.7	LED speed <0.3s
3/3	0.7	LED speed <0.3s



Voltage Measurement (Circuit disconnected)

Date	Voltage (V)	Current (mA)	Pavg (mW)	Notes
2/15 Same results 2/18	0.6	~5	3	Measurement made after disconnecting the circuit for 30mins

- Possible cause of success:
  - o Used mud collected after it rained. This could have increased bacteria in the surface providing more energy for the battery.

- Made quick measurements to prevent power being drained. Avoided periodical current measurement for the same reason

## Appendix 2

### Homes without Electric Light

Name: \_\_\_\_\_ Province, District, Community: \_\_\_\_\_  
 Age: \_\_\_\_\_ How many people live in your home: \_\_\_\_\_

**1. Do you have electric light at your home?**

- Yes
- No

**2. What are the activities at night? How do you illuminate during dark hours?**

**3. Do you have physical and financial access to:**

- Batteries
- Flashlights
- Lamps

**4. Do you find any of these wastes/resources in your community?**

- Aluminum cans
- Plastic bottles
- Bamboo

**5. What do you do with the trash?**

- It is disposed of in the sea
- It is buried
- It is transported to another site
- It is burned

**6. Are any of these fruits being cultivated in your community?**

- Lemon
- Maracuya
- Orange
- Tamarind
- Grapefruit
- Other acid fruits

**7. How far away do you live from the sea or river?**

**8. What are the rainy months?**

**9. Would it be helpful to have electric lamps at your home?**

- Yes
- No

**10. How many lamps do you need at your home?**

- 1 to 2
- 3 to 5

## Appendix 3

Homes without Electric Light							
ID#	Location	Name	Age	Residents	Light at night	Electric Light	Activities at night
1	Tormenta, Las Cumbres, Panama	Isaura de Guillermo	26	3	Candle Candle and	No	Talk and Sleep
2	Tormenta, Las Cumbres, Panama	Federico Amador	37	5	Guaricha	No	Talk Talk, very little can be done.
3	Tormenta, Las Cumbres, Panama	Cristina Rodríguez	51	5	Guaricha	No	Almost nothing
4	Tormenta, Las Cumbres, Panama	María Angela Pérez	42	6	Candle	No	Nothing
5	Tormenta, Las Cumbres, Panama	Roberto Duarte	22	2	Candle	No	Talk
6	Nuevo Azuero, Chepo Cabezera, Chepo	Juanita Guerra	32	5	Flashlights	No	Talk Talk, Almost nothing
7	Nuevo Azuero, Chepo Cabezera, Chepo	Maximo González	61	4	Lamps	No	Nothing
8	Nuevo Azuero, Chepo Cabezera, Chepo	Francico Núñez	22	5	None	No	Nothing
9	Nuevo Azuero, Chepo Cabezera, Chepo	Leonarda de García	38	6	None	No	Nothing
10	Nuevo Azuero, Chepo Cabezera, Chepo	Dalvina	23	4	None	No	Nothing
11	Nuevo Azuero, Chepo Cabezera, Chepo	Alejandro Peña	35	5	None	No	Nothing
12	Nuevo Azuero, Chepo Cabezera, Chepo	Desireopoa	23	6	None	No	Nothing
13	Changal, Torti, Chepo	Elisea Ramos Estefani	28	2	Candle	No	Talk
14	Changal, Torti, Chepo	Castro Cesar Manuel	21	3	None	No	Nothing
15	Changal, Torti, Chepo	Maore Magali	53	4	Lamps	No	Nothing
16	Changal, Torti, Chepo	Romero	51	8	Lamps	No	Nothing
17	Changal, Torti, Chepo	Jasuri	26	3	Lamps	No	Nothing

## Full Proposal Example "Light From Below"

18	Changal, Torti, Chepo	Montero Jajaira Marleni	26	3	Flashlights	No	Talk
19	Changal, Torti, Chepo	Ramos Migdalia	43	6	None	No	Nothing
20	Changal, Torti, Chepo Altos Pedregal, Chepo	Barga Gloria	41	3	Flashlights	No	Nothing
21	Cabezera, Chepo Altos Pedregal, Chepo	Rodriguez Rumuerto	32	7	Candle	No	Nothing
22	Cabezera, Chepo Altos Pedregal, Chepo	Cortes	62	2	Lamps	No	Talk
23	Cabezera, Chepo Altos Pedregal, Chepo	Ritalisondro	37	5	Flashlights	No	Nothing
24	Cabezera, Chepo Altos Pedregal, Chepo	María Castillo Faustino	31	3	Flashlights	No	Nothing
25	Cabezera, Chepo	Avilla	27	5	Flashlights	No	Nothing





## Pre-Proposal Example “Light From Below”

### **Light from Below: Using earth energy to bring free light to the poor**

Many undeveloped, dispersed communities in Panama lack essential needs such as lighting. Light from Below will design a lamp that is easy-to-build from accessible materials and powered by “earth energy” electricity generated from mud. The project brings free light to the poorest, darkest, and most remote places of Panama.

#### **The Idea**

Earth energy is a technology that produces electrical energy from the change in the rate of chemical reactions produced by microorganisms. Among the most electrochemically active bacteria populations are *Azoarcus*, *Azospirillum*, and *Geobacteraceae*. All of these can be found in soil, mud, and decomposed organic material. In order to convert chemical energy into electrical energy, earth energy technologies use a microbial fuel cell (MFC). Using a sealed vessel (oxygen-free environment), bacteria oxidize organic compounds such as glucose and acetate. During these anaerobic chemical reactions, the MFC collects free protons and electrons. Similar to what happens in a battery, the MFC collects and transfers electrons using an anode compartment to an external circuit. In a 70- to 90-degree Fahrenheit environment, it can produce energy with over 50% efficiency. “For each kilogram of incoming organic contamination, microbial fuel cells net 1 kilowatt-hour of electricity” (Sanford, 2010).

Recently, a group of Harvard students experimented with microbial fuel cells and showed that the most recent MFC produces enough electricity to power a small LED bulb for up to a year (Justa, 2010). This technology is not only cheap but also reusable. Additional soil nutrients, such as acid found in lemons and vinegar, or a simple change of soil will “recharge” the MFC battery.

Our project takes this existing technology to the undeveloped areas in Panama. Light from Below will use the simplicity of these discoveries and maximize the usage of local materials to make these MFC lamps. The goal is to prepare a design that will facilitate the manufacture and maintenance of MFC lamps in the community. The project will finance supplies that will generate free electricity for the community for about one year at an estimated initial cost of \$10.00 per lamp. When lamp materials need to be replaced, the maintenance cost will be significantly small. Mud, plastic bottles and cans can be obtain for no cost, copper wires are not expensive, and LED bulbs can be reused.

The Light from Below project has three levels of intended impact:



## Pre-Proposal Example “Light From Below”

1. On the community: Social and Economical
  - Provide free lighting to the poor
  - Explore materials and resources that are seen as waste
  - Increase the possibilities of domestic life/work at night
  - Provide a safe environment for children at night
  - Improve tourism opportunities by:
    - o Renting out cabins with attractive/innovative lighting sources
    - o Selling local “Light from Below” souvenirs
2. On the government: Social and Economical
  - A temporary and inexpensive solution to the unresolved issue of providing light to undeveloped areas
  - An opportunity to help and serve the communities with the most economic need
  - Substantial reduction in the capital needed to acquire, distribute, and install expensive alternative technologies such as solar panels
  - Less technical staff as compared to staff size needed for solar panel maintenance
  - Educate undeveloped areas on creative solutions for their own needs
3. On the environment:
  - By using renewable energy, it reduces greenhouse gases and the negative impact of energy production on the environment
  - By using local materials, it reduces the need for transportation of larger equipment
  - By reusing materials such as plastic bottles, the project can minimize the excessive amount of waste that is currently being burned or disposed of in the sea

### **The Problem**

A poverty study made in 2000 by The World Bank reveals that 42% of rural areas do not have access to electricity. In addition, about 62% of poor households in rural areas in Panama do not have electric lighting. Similarly, 93% of poor indigenous communities face the same lighting need (World Bank, pg.19). In the past, our team members have performed social services in remote areas and can testify to the need that these communities face. They found that a simple light bulb could dramatically change the living conditions of a community. Nights are unproductive and dangerous. Most poor rural and indigenous areas rely on kerosene and firewood which increases deforestation and respiratory diseases.

The Panamanian government has made efforts to install photovoltaic panels in these communities. Even international organizations such as Global Environmental Brigades from UCSD are making an effort to deliver solar panels to poor areas (Harding, 2011). However, lighting is only provided in public areas like basketball courts, parks, and schools, but not houses. Additionally, the initial cost and transportation of this technology to areas of restricted access represent an economic challenge for the Panamanian government.

Students from Harvard University have researched “earth energy” and found that Microbial Fuel Cells can provide enough voltage and current to light LED bulbs. Additionally, the company Keego Technologies has started to commercialize their version of earth energy, the



## Pre-Proposal Example “Light From Below”

“MudWatt” battery kit for \$44.95. This project, Light from Below, offers a cheaper, more portable, and easier to manufacture option for restricted access areas. By using mainly local materials, the project will reduce waste and greenhouse gases, and it will provide free lighting in areas in need of light.

Not only is design efficiency important but also design safety. The casing material, exposed copper, heat dissipation, and moisture permeability will be studied and tested for about 3 months to ensure a safe design. Every possibility of danger or damage will be evaluated and discussed and resolved. Since many in the poor communities are illiterate or use only spoken dialects, the project will develop simple illustrated instructions to educate the indigenous on how to build and maintain their own lamps, using as few words as possible.

### Team Members

Being natives who speak the language is extremely valuable to our project. We value our multidisciplinary approach, our experience in research, and most importantly our shared desire to help the poor communities of Panama.

**[Name excluded for privacy]** is a graduate student pursuing a Masters in Architecture at UC Berkeley. X graduated with a Bachelors in Environmental Design with magna cum laude honors from Texas A&M University. He has worked as a coordinator for Global Architecture Brigades, where he researched accessible materials for the Ngöbe Indians. X has worked as a translator and researcher with several social services programs along Panama’s borders with Costa Rica and Colombia. Professionally, X helped introduce energy-efficient software at BHDP Architecture in Cincinnati. He has worked in a large group research project, “Horizontal Hybrid Solar Light Pipe,” a hybrid system that integrates natural and artificial lighting, a project which was awarded \$75,000 in an EPA competition. Last year, X was selected to be a Project CANDLE Ambassador to present the physics and geometry of lighting to high school students in TX. X’s academic and professional experience in environmental design and renewable energy, along with his passion to solve problems for the disadvantaged, make him an ideal member of the team.

**[Name excluded for privacy]** a senior undergraduate Electrical Engineering student at Texas A&M University, is focusing his studies on power systems, power electronics, and renewable energy. Y holds a minor in Mathematics, has a GPA of 3.88, and worked at Electro-Tech Industries, a company dedicated to industrial generation and power supply systems.

Y’s technical skills and academic achievements make him an essential member of the project. His passion to improve the living conditions in the undeveloped areas of Panama, his country of citizenship, is valuable to the success of the project.