

## **The Twig Light: Affordable, Sustainable Lighting for Villagers in Rural Ghana**

Brad Rogers, Mark Henderson, and Michael Pugliese, Arizona State University

### **Abstract**

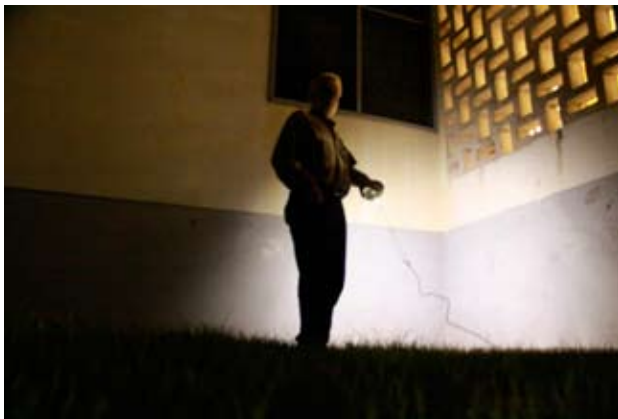
A problem commonly identified by villagers in West Africa is the need for clean, affordable lighting. Villagers who can gain access to an affordable light source will be able to extend the productive portion of their day into the evening. This paper describes the development of a new, low cost, sustainable light source for poor villagers in developing countries. The device, called the Twig Light, generates electricity by imposing a temperature difference across a compact thermoelectric generator. This is accomplished by sandwiching the thermoelectric generator between a combustion chamber (in which small amounts of a combustible material are burned) and a water-cooled heat sink. Enough power is created to light a bank of Light Emitting Diodes (LEDs) sufficient to illuminate a small room or to recharge portable electronic devices. After conducting interviews with villagers to consider issues they faced, a prototype was developed. Subsequently, the technology was tested in the rural Ghanaian village of Domeabra in the summer of 2009. The performance and effectiveness of the light will be evaluated during a return visit.

### **Introduction**

The Twig Light project was catalyzed by the GlobalResolve initiative at Arizona State University (ASU), and is being supported by an Advanced E-Team grant (6371-09) from the National Collegiate Inventors and Innovators Alliance (NCIIA). The GlobalResolve program was established in 2006 as a social entrepreneurship initiative with the goal of improving the lives of underprivileged people through economic development based around the establishment of village level entrepreneurial ventures, while simultaneously enhancing the educational experience of students at ASU. GlobalResolve emphasizes the importance of using global partnerships to solve local problems. Teams consisting of faculty and students at ASU and local universities in developing countries, rural villagers, local governments and financial institutions, and representatives of NGOs work together to create local solutions to global problems. GlobalResolve employs a compressive development process for project selection. Candidate villages for projects are identified, local needs are surveyed, and collaborative solutions are proposed that form the basis of entrepreneurial ventures within the selected villages. Recent GlobalResolve projects include: water system improvements in the severely impoverished Ghanaian village of Fawomanye and the town

of Gamao Dago; the development of biodiesel crops near the village of Biemso, Ghana; the installation of a gelled ethanol production facility in the village of Domeabra, Ghana, coupled with the development of very low cost stoves to support this fuel; the development of a neurosurgical medical device for healthcare in areas of rural poverty in South Africa; and the assessment of wind power on the Hopi Reservation in Arizona.

The Twig Light project was initiated to provide safe, affordable, and efficient electric lighting to rural villages in the developing world. An estimated that 1.6 billion people in the world do not have access to electricity.<sup>1</sup> The consequences of this problem become evident when underprivileged people are interviewed about their lives. During recent visits to Ghana, Arizona State University Engineering Professors and GlobalResolve founders Mark Henderson and Brad Rogers spent substantial time and effort coaching and supervising teams of students who interviewed impoverished rural villagers and urban dwellers, many of whom earn less than one dollar per day, about their needs and aspirations. During these conversations, one of the most commonly identified problems was the need for affordable, clean lighting. The lighting was desired so that the days can be extended into the evening hours, providing much needed time for beneficial activities in the home such as income generating pursuits, homework, reading, and social interaction. Existing electrical lighting products for this market involve batteries that are often too expensive and have limited product life, even if they are rechargeable. Even those with access to electricity often cannot afford the price, and therefore go without. Current technologies that address this problem rely on light given off by combustion processes, which results in high levels of pollution inside homes, uncomfortably high temperatures, potential for disastrous fires, and the use fuels such as kerosene that are too expensive for very poor families.



*Figure 1. Demonstration of Twig Light System in Kumasi*

The experiences gained during these visits have been brought back to the classroom at ASU. A course, called Village Energy Systems, is currently offered and is based on the principles articulated by Dr. Paul Polak in his seminal book, *Out of Poverty* (2008). The course, designed for seniors and graduate students in Engineering at the Polytechnic Campus of Arizona State University, is taught in a project-based format. Using the problem-based learning approach, students work in cooperative groups to solve a large, class-wide project. In addition, students are required to complete an individual project in which they conceive and develop a product based on the principles of extreme affordability that also meets an identified need of people living in poverty. In Spring 2009, a graduate student class embraced the challenge of creating an ultra cheap, safe, and affordable lighting system that utilized a thermoelectric generator and LED

technology. The light was initially powered by combustion of twigs gathered off the ground. Figure 1 shows a demonstration of the system in Africa in the summer of 2009, and illustrates the magnitude of the light that is produced. The performance of these prototypes and current state of development of the Twig Light will be described in the following sections.

### Project Description and Current Status

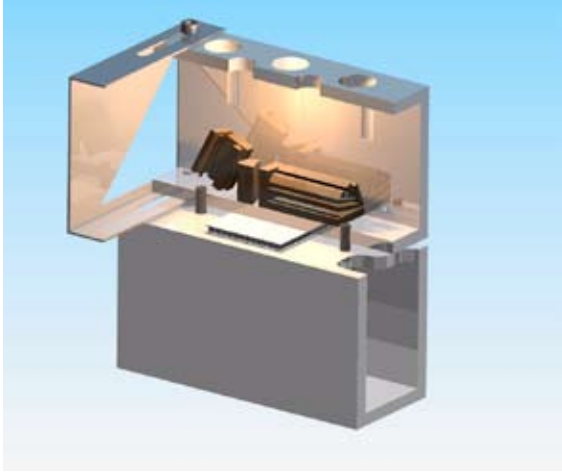


Figure 2: Twig Light Power Module, Illustrating Combustion Chamber

The Twig Light is built around two core technologies. The first is a compact, wafer style thermoelectric generator, which produces electrical power when a temperature difference is imposed across the surfaces of the unit. The second is ultra-low power light emitting diodes (LEDs) that convert electrical energy to light very efficiently. The assembly surrounding the thermoelectric generator is called the power module, a rendering of which is shown in Figure 2. It is constructed of two pieces of 3-inch by 2-inch aluminum channel, each 4 inches in axial length, with the thermoelectric generator sandwiched between the upper and lower sections. The upper section is a small combustion chamber in which any combustible material, including small pieces of wood (as illustrated), can be burned. The lower section can sit on the ground, or, preferably, in a pan with a few centimeters of water in the bottom. The combustion process heats the upper chamber, establishing a temperature difference between the heated upper and cooled lower sections. (The use of aluminum, which has a very high thermal conductivity, results in a more uniform temperature in each of the separate sections.) The temperature difference between the sections powers the thermoelectric generator, establishing an emf through the circuit with sufficient power to illuminate a bank of LEDs, recharge portable electronic devices, and potentially perform other tasks as well. The LED/recharge unit is called the application module. To keep the combustion process outside of the home, the power module is connected to the application module by several meters of wire.



Figure 3: Rural Village Assessment Meeting in Domeabra

Thermoelectric generators have been used for indoor lighting by utilizing waste heat from cooking stoves (Mastbergen et al. 2007), but with this design the motive temperature difference is generated by the outdoor combustion of small amounts of wood, charcoal, or leftover coals from cooking fires. During testing it was found that the combustion of 20 small pieces of wood approximately 0.5 cm in diameter and 10 cm long kept the light illuminated for more than 30 minutes, leading to the name “Twig Light.”

During the summer of 2009, GlobalResolve personnel traveled to Ghana and conducted a comprehensive rural village appraisal of the village of Domeabra in the Asante region, as shown on Figure 3. In this figure, the villagers are shown producing a map of the village and surrounding areas for the purpose of teaching members of GlobalResolve about their village and lifestyles. Domeabra is the location of the gelfuel production facility that was installed during September of 2008 (Rogers and Henderson 2008), and supporting technologies developed at ASU, including a stove specifically designed to take advantage of the properties of the fuel, were delivered to the chief of the village, Nana Frempong Afaokwa. After completing the two-day appraisal process, both the stoves and the Twig Lights were demonstrated for the villagers. Several Twig Light prototypes have been placed in homes in Domeabra. The villagers’ comments were positive concerning the stoves, but the Twig Lights generated a great deal of excitement. Because of this enthusiasm, interviews were conducted specifically addressing the Twig Light and desirable attributes, and the results of the GlobalResolve interpretation of the comments are shown below in Table 1.

<b>Product Attribute</b>	<b>Importance (Scale is 1 to 5, 5 = very important, 1 = not important at all)</b>
Cost	5
Flexibility of Use, including charging cell phones	5
Simplicity	5
Manufactured in Ghana	5
Durability	4
Flexibility of Fuels	3
Safety	3
Efficiency	2
Green (Ecologically Friendly)	1

Table 1. Results of Village Survey

As expected, cost is a critical issue, and the cost breakdown is discussed in more detail in the next section of this paper. Virtually all of the people interviewed wanted a unit and were willing to pay, but they had limited means. (Surprisingly, when asked if they would pay 20 Cedis (about \$14) for a unit, most of those interviewed said that they would.) Simplicity of use and ease of cleaning were also noted as very important. In addition, all interviewed were very enthusiastic about the opportunities that could be created if the units were manufactured, or assembled, locally. Durability was also a major issue, and the villagers responded very favorably to the suggestion that the units could be made to last much longer than competing technologies. All of those interviewed indicated that they would simply use leftover coals from cooking fires to power the system, and they were not overly interested in flexibility of fuel choices. (This question was asked specifically because of the desire to expand the market for the gelfuel manufactured in Domeabra.) Efficiency was not a large concern, as long as it the light was efficient enough to operate with the mass of leftover coals that are typically available, and ecological properties were of no concern at all to the villagers.

Perhaps the most important information from this exercise, however, was when villagers were asked about their needs not only with respect to lighting, but the use of electricity in general. It was discovered that even though electricity is available in Domeabra, few families could afford it and most homes were not connected to a source of electricity. Most of these same families had at least one cell phone available, but they had no way to recharge it. Villagers were asked if they would be more likely to purchase a Twig Light if a cell phone charging feature was added, and they responded very enthusiastically, even if they were told they would have to pay extra for the attachment. Consequently, subsequent developments will include the capability for recharging cell phones and other portable electronic devices, resulting in a multi-function platform.

Villagers were also asked about existing technologies. Lighting in Domeabra consists mostly of combustion, flashlights, or other battery-operated lights. The villagers are very critical of combustion-based lighting because it is expensive, hot, results in poor quality, and is dangerous. With respect to battery-powered lights, the batteries wear out quickly, replacements are difficult to obtain and are not affordable, and most flashlights are not designed for space illumination. Similar comments were made about systems with rechargeable batteries: although rechargeable batteries may last longer, they eventually wear out. And villagers rarely have the means to recharge the batteries.

The villagers in Domeabra were anxious to obtain a prototype of the Twig Light system, and rather intense competition followed for one of the seven units that had been given to the chief for distribution to households. These units, which included a 24 light LED array, were distributed on July 29th, 2009 and are currently in use in Domeabra.

Testing at ASU in the summer of 2009 indicated several problems with the initial prototypes that led to product failures. These problems involved control and initiation of the combustion process, which caused melting of the solder used to attach wires on the thermoelectric module. The prototypes that were delivered to Africa did address these issues, although additional testing and evaluation is still needed. GlobalResolve remains in regular contact with the chief, Nana Afaokwa, who reported that, as of September 19th 2009, all units were still functioning with no failures. GlobalResolve personnel will be returning to Ghana in May of 2010 to further evaluate the performance of these prototypes, and to deliver the next generation for further use and field-testing.

### **Next Steps**

The GlobalResolve program seeks to help establish village-level entrepreneurial ventures. Consequently, the ultimate goal of the Twig Light project is to profitably manufacture and sell the units in Africa, with as much manufacturing as possible occurring in villages. The final design of the product may involve machining operations. If that proves to be the case, it may be necessary to develop some of the component parts in metropolitan cities. However, the goal is to produce and assemble the products in the rural villages as much as possible.

The success of the initial prototypes distributed in Ghana is encouraging, but several challenges, both technical and business-related, remain before the Twig Light can become viably manufactured in Africa. Technical challenges include the development of a cell phone charging circuit, a manufacturing plan for Africa, and applying the principles of design for extreme affordability to the system. Business development challenges include a careful identification of customer needs for other Twig Light capabilities, cost reduction strategies including economy of scale, securing the location of component manufacturers, and development of supply chains. In addition, competing technologies in the marketplace, such as solar lanterns, must be critically compared to those of the Twig Light, both technologically and economically.

The initial goal of the Twig Light project was to produce a product that could be profitably sold for \$10. Further analysis shows that this is likely not possible. Thermoelectric generators can be bought for less than \$5 internationally. The cost of individual LEDs is very low, but the cost of a single assembled array of twenty-five lights is about \$5. This cost can also be expected to decrease if the arrays are purchased in large quantities, and foreign manufacturers also sell these products at lower cost. The cost of the additional materials—the aluminum and electrical wiring—is less than \$1 per unit, but machining operations on the material, as well as the final assembly, lead to labor costs. Therefore, while costs can be reduced substantially, the \$10 benchmark will need to be revised.

The development of a cell phone charging circuit for the Twig Light application unit is currently underway at ASU, with a scheduled completion date of March 2010. Options investigated included modification of commercially available units or the development of a circuit and assembly to be manufactured with the units in Ghana. Because of the desire to get the product to the market as quickly as possible, and potential difficulties with detailed electronic manufacturing in Africa, it was decided to modify existing charging systems to accept input from the Twig Light. That project is currently underway.

In Ghana, telecommunication companies, such as MTN and Vodafone, have extensive distribution networks that reach even into remote rural villages. This leads to the possibility of marketing and selling the Twig Light by offering it through the existing cell phone vendor network. Discussions have been initiated with representatives from these companies.

Additional teams have been formed, consisting of faculty, graduate and undergraduate students at ASU and KNUST, and partners in Ghana, to enhance and improve the engineering development, the product design, and the business plan for the village venture. In addition, a separate team is creating a portfolio of products around the TEG concept. Prototyping and testing are critical, as is adapting the product to the particular country's culture. In order to accomplish this, a second multi-disciplinary, multi-campus capstone course has been created. In the spring of 2010, students in that course will explore business plans, engineering, product design, and village needs assessment to address the triple needs of economic, social, and environmental sustainability.

The past, present and future project timeline is noted in Figure 1.



Figure 1. Twig Light Timeline

## Conclusions

The ongoing Twig Light project is a result of a unique and innovative educational experience that was offered to seniors and graduate students in Engineering at the Polytechnic Campus of Arizona State University. The experiences of Professors Rogers and Henderson in working with poor villagers in rural Ghana were brought to the classroom, serving as a segue for teaching the principles of affordable design through the pedagogy of problem-based learning. The classroom environment exposed talented and enthusiastic students to previously unexposed problems and gave them an opportunity to work on solutions. The Twig Light is an example of an idea that has expanded out of this classroom environment, and has the potential to make a significant impact. The technology is currently being field-tested in Africa, improvements in the design are underway, and the business development opportunities in Ghana are being explored. The Village Energy Systems class will be again offered for engineering students in the spring semester of 2010. In addition, a three-semester GlobalResolve sponsored interdisciplinary capstone sequence will be initiated in Spring 2010, with the goal of allowing selected students from multi-disciplinary backgrounds to form teams and focus their talents on positively addressing the difficult problems that face impoverished people.

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