Building a Solar-Powered Pump to Deliver Clean Water to Villagers in Ngomano, Kenya

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Abstract

In pursuit of the goals of environmental, economic, and social sustainability, the Engineers for a Sustainable World (ESW) chapter at Harvey Mudd College is planning a service project trip to Ngomano, Kenya for the summer of 2010.[1] The purpose of the trip is to implement a solar-powered pump to deliver clean water to the Clay International Secondary School in Ngomano. Students will design a means of converting a diesel water pump to solar power. They will then travel to Kenya to execute the design as well as build upon relationships established between Harvey Mudd students and Ngomano villagers during a water quality assessment trip to the village last winter. Upon completion of the trip, the students will share their design and the knowledge gained while abroad with the Harvey Mudd community through written documentation of their experiences and public presentations.

Research and initial designing of the pump will take place throughout the 2009-2010 school-year. The project will then continue for ten weeks into the summer of 2010. The first two weeks will be spent at Harvey Mudd finalizing the design before departure. Part of the team will then travel to Ngomano, Kenya for six weeks to build the solar-powered pump system. The last two weeks of the project will be spent documenting the experience and evaluating further project options at Harvey Mudd after the team returns from Ngomano.

Project Background and Previous Work

In 2006, Andy Leebron-Clay, a trustee of Harvey Mudd College, asked members of ESW if they were interested in doing a service project in Ngomano, Kenya. Clay and her husband Jim had been doing work in the village of Ngomano for about a year prior to this time. They had previously founded the Clay International Secondary School in Ngomano, purchased chickens and vegetable seeds for the school, and funded the digging of two wells on the school's campus.

Subsequent water tests showed that the water in these two wells is heavily contaminated with calcium and magnesium ions, among other minerals, making it unsuitable for drinking and irrigation. The alternative is water from the subsoil of a dry stream bed located 850 meters from the school grounds, but this water is also prone to high mineral concentrations. Moreover, because reaching water requires digging through the surface of the dry river bed, it is impossible for any individual to collect enough water to irrigate farmland, which is critical for the school and village to become financially independent and sustainable. The Clays posed this water problem to ESW as one which might be solved through a demineralization and disinfection solution.

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ESW is a national organization that strives to address issues relating to sustainable development. By educating, training, and mobilizing a network of professional engineers, students, and professors, ESW endeavors to promote environmental, economic, and social sustainability in developing communities around the world.

ESW formed a small team of about four students to tackle the problem of water demineralization. Working throughout the 2007-2008 and 2008-2009 school years, the group compiled a list of possible solutions ranging from reverse osmosis to slow sand filtration to solar stills. Four students were chosen to travel to Ngomano in the winter of 2008 to implement the final solution. However, due to violence following the presidential election in Kenya in December, the trip was postponed to January of 2009.

Research into disinfection methods continued and after prototyping a couple disinfection design options, the team decided the best solution for Ngomano would be large-scale solar purification.

In January, 2009 three ESW student members and a faculty advisor traveled to Kenya to explore the feasibility and effectiveness of their design. While in Kenya, they spent several days at the school getting acquainted with project possibilities and people. The students built a prototype of a solar still at the school to demonstrate the principle of solar disinfection to the school's students and faculty and led a science lesson with those students about the water cycle and solar distillation. With limited resources, the prototype was more of a logistical challenge than expected, but the students were innovative and decided to build their solar still out of an old wood glue drum. The prototype was a success, and students of the Clay School verified that the previously brackish water from the campus well now tasted pure.

While such solar stills could be effective for small-scale use, the question still remains of how to provide a large supply of drinking and irrigation water to the school. Because the water from the river is less brackish than the water from the campus wells, the best alternative appears to be to pump river water uphill 45 meters from 2,800 feet away to the school grounds, where it can be stored in a large tank and used for drinking and irrigation.

At the time of ESW's visit last January, a pump from the river to the storage tank in the village had been purchased but was not operational because it lacked sufficient power to pump the water uphill. Since the trip, a new 16 hp diesel pump has been purchased by the school and is operated once per week to fill the tank. However, fuel for the pump is expensive and harmful for human health and the environment.

Proposed Project

Because sun is plentiful in Ngomano, it is the ESW team's goal to convert the diesel pump to operate on solar power by installing a solar array at the Clay International School, running cable over the 2,800 foot length to the pump, and replacing the diesel engine with an electric motor. Since Ngomano, Kenya is located near the equator and receives 6.5 -7 kWh/m^2 of direct sunlight per day with only a short rainy season (by comparison Los Angeles receives 5-5.5 $kWh/m^2/day$), the team determined that solar power would be the most feasible and sustainable alternative power source for the water pump. The team has begun research into the best design for a solar-powered pump. A bank of batteries purchased in Nairobi, Kenya, will be installed near the panels on the school grounds to store energy generated throughout the week between pumping times. An electric motor has been identified which will operate the existing pump and which can be serviced in Nairobi should problems arise.

The team plans to continue the research and solar pump design process throughout this school-year. During summer 2010, the team is planning a service project trip to Ngomano, Kenya to install the pump. In addition the trip will be an opportunity to enhance connections between Harvey Mudd students and the Ngomano villagers.

Four students and one faculty advisor will spend ten weeks during summer 2010 working on this project. The first two weeks will be spent on Harvey Mudd's campus in order to complete the design and prepare for the trip (see Appendix A for a detailed project schedule). Then, the team will travel to Kenya where they will spend six weeks in Ngomano. While there, the team will spend most of their time implementing the new power system for the pump, troubleshooting the inevitable difficulties, and training a member of the school's faculty in the operation and maintenance of the pump. In addition to building the solar-powered water pump, the students hope to spend time at the school, teaching classes as well as learning about Kenyan culture from the students. Living on the campus, the students will be immersed in the Kenyan lifestyle. This opportunity will allow the students to experience the culture and get a sense of the impact of their solar pump. Moreover, they will build new engineering skills as they try to navigate an engineering project in a developing country. Upon returning to Harvey Mudd, the students will spend another two weeks documenting their research, final design, and experiences in Kenya.

Educational Value

During this project, students will gain an experience abroad while participating in hands-on engineering and international development in order to help the community of Ngomano. The students will apply their classroom-based knowledge to a real-world situation. The students will learn about the limitations of solar power and the difficulties of construction and power-generation in an underdeveloped country, which will require them to leverage their knowledge in creative ways. The post-trip documentation of the design process and implementation difficulties will be useful to other engineers who are interested in developing solutions for communities with similar situations to that of Ngomano. In addition to the technical knowledge the students will gain through this project, the students will gain a deeper understanding and appreciation of Kenyan culture. When the students return to the U.S., they will share their experience with the Harvey Mudd College community through public presentations.

Significance for Environmental Quality

Replacing the diesel pump with a solar electric system will save the school money and reduce dependence on fossil fuels. This will also give the school and village access to the water table underneath the river, which contains cleaner water than the muddy water they are currently digging up, and less brackish water than what is contained in the campus well, reducing the risk of disease among students and villagers. It will also drastically reduce the time spent daily by the women and children of the village gathering water, as a tank in the village could store water pumped from the river 2,800 feet away. If a more economically and environmentally sustainable power source can be implemented, the pump can operate frequently and ensure the villagers are supplied with sufficient clean water. The water can then be tested and the team can determine if purification is still necessary. If so, this could provide the basis for a future project.

Feasibility

A trip to Kenya will require extensive funding and preparation, but there are several factors that make this project feasible. First, through the Clays, the team already has contacts to members of the village. Second, team member Rob Best and advisor Susan Martonosi traveled to the village in January, 2009, and thus have a sense of the current situation and have relationships with the Clay School faculty.

The team has also performed extensive background research and begun preliminary design. Throughout summer 2009, the students worked in teams to research prior solar pump installations in undeveloped nations. The team also looked into the cost and availability of different components both in America and Kenya. During the school year, the team has thus far developed several potential designs which are described in more detail in Appendix B.

Other factors that contribute to project feasibility are the two-week design period prior to departure and the two-week summary period after return (see Appendix A for a detailed project schedule). These two-week periods will provide a focused environment to both plan for and analyze the team's time spent in Kenya. In the first session, students will be able to finish their design and finalize their schedule in order to be productive while in Kenya. In the second session, the students will analyze their experiences and produce a concise and detailed final report of the project.

Budget

Appendix C shows the proposed budget for the project, with a corresponding list of funding sources we will be approaching to support certain components of the project. From the Center for Environmental Studies, we are requesting $10,000 to cover the stipends of $3\frac{1}{3}$ students for their work this summer. We have outlined several other donors we intend to approach to cover the remaining expenses of the project. Moreover, we may shorten the duration of the trip to four weeks if our fundraising falls short of our target of $83,930.

Appendix A – Project Schedule

October - January

- Finalize calculations for the pump

February – May

- Begin prototyping a solar-pump system at Harvey Mudd
- Research Kenyan culture and customs

Week of May 17

- Students begin Research Project: prepare prototype and notes for departure.

Week of May 24

- Design survey methods, outline the information we need to obtain, and continue research started during the first week.

Week of May 31: Travel

- Fly to Nairobi, spend two days there. Drive to Wote, spend two days there. Arrive at Ngomano. Set up research base, prepare for next week.
- Meet with VGD representative and Clay School. Get accustomed to local culture and identify key leaders.

Week of June 7

- Begin implementation of the prototype. Appoint a Chief Engineer to take care of the pump. Allow the person to participate in the design, and train him/her in the use and maintenance of the pump.

Week of June 14

- Continue work on implementation.
- Meet with local leaders and Clay School representatives.

Week of June 21

- Midterm: evaluate the progress and make changes accordingly.

Week of June 28

- Finish implementation.

Week of July 5

- Finish up and present final result to community.
- Complete training of the Chief Engineer of the pump.

Week of July 12: Travel

- Students depart Ngomano, drive to Wote (two days) and then Nairobi (two days). Fly to LAX.
- Unpack, prepare for next week.

Week of July 19

- Document the trip findings, contacts and experiences. Identify problems encountered and solutions presented.

- Evaluate the success of the pump.

Week of July 26

- Make final recommendations based on the triple-bottom line of economic, social, and environmental sustainability. Prepare preliminary guidelines for future work.

Appendix B: Design Recommendations

The 75,000 L tank in which the pumped water is stored is located at the top of a 45 m hill near the school, whereas the pump is located at the river in the valley below. In the past, villagers have had problems moving the water to the tank from the pump. The water must move approximately 850 m in distance to the tank as well as gain the 45 m elevation.

Currently a 16 hp above-ground diesel pump is used to transport water to the tank. It is the team's goal to operate either the existing pump or a more efficient pump using solar power. Should the pump be replaced, the team is considering an efficient centrifugal pump. Preliminary calculations show that the tank can be filled in approximately 4 hours, at 5 L/second, using a 3 kW solar array with batteries. These estimations can be made based on calculations that show only a 4 hp requirement at steady state, plus a larger transient power requirement, to carry the water to the tank.

Because the team is planning to install expensive equipment in the village, much thought has been and will be given to vandalism and theft. One suggested solution is to keep the solar panels on the school grounds as shown. This will ensure that the panels will be watched constantly and are less likely to be stolen. The team is also considering various mounting and locking options to increase security.

In the interest of economic and social sustainability, one major goal of the project is to ensure the system will last for at least 30 years. To reach this goal, the team will engineer a flexible design by performing sensitivity calculations and tests. Students will also educate and train a member of the community for the position of Chief Engineer to ensure that the pump will be maintained after installation.

Appendix C – Budget

Item	Cost Per Each	# People	Total Cost	Target Donor
Pump Supplies	$35,000		$35,000	Manufacturer Donation Rotary Club Shanahan Funds (prototype development)
Van rental (in-country transportation)	$150/day		$6,300	Clay Foundation
Stipends	$3,000	4 Students 1 Faculty	$15,000.00	Center for Environmental Studies Strauss Fellowship Club funds from Jenzabar HMC Clark Funds
Airfare	$2,400	5	$12,000.00	Clay Foundation
Medical Preparation				Shanahan Funds
- Study Abroad Physical	$45 per student	4	$180	
- Faculty Physical	$100 co-pay (?)	1	$100	
- Vaccinations	$200	5	$1000	
- Malaria prophylaxis	$250	5	$1,250	
Insurance				
- AIG TravelGuard Trip Insurance	$140	5	$700	Clay Foundation
- SOS International	$135	5	$675	Shanahan Funds
Accommodations				Clay Foundation
- Nairobi (4 nights)	$215/room/night = $860	3	$2,580	
- Wote (4 nights)	$50/room/night = $200	3	$600	
- Ngomano	In-Kind?			
Food				Clay Foundation
- While in-transit	$120 (6 meals per person)	5	$600	
- In country	$630 ($15/day/person)	5	$3,150	
Visas (at airport)	$50	5	$250.00	Shanahan Funds
Airport Transportation				Shanahan Funds
- Super Shuttle	$112 + $18/addl person	5	$184	
- Airport Lockers	$6/person	5	$30	
- Layover transportation	$6/person	5	$30	
In-country supplies				Shanahan Funds
- Water	$168 ($4/person/day)	5	$840	
- First Aid and group travel supplies	$130 $90	Fixed Fixed	$130 $90	
- SIM cards, minutes (for emergency communication)	$32 (once/wk)	Fixed	$32	
- Internet (for communicating with HMC and parents)	$25/each	5 new ones	$125	
- Money belts				
Subtotal			$80,846.00	
Unplanned and Emergency Expenses (10% of non-stipend expenses)			$3,084.00	
Total			**$83,930.00**	

Fixed Costs: $45,430 (pump + van rental)
Additional Costs per Person: $5,500 (approximately)

Target funding:

Clay Foundation: $37,000

- Van rental and in-country transportation
- Airfare and travel insurance
- Accommodations in-country
- Food in-country

Manufacturer Donation: $27,500

- Prototype development and supplies for final installation

Shanahan Funds: $10,000

- Prototype development and supplies for final installation
- Medical Preparation
- Evacuation insurance
- Visas
- Airport transportation
- In-country supplies

Center for Environmental Studies: $10,000

- 3 1/3 student stipends

Rotary International: $8,250

- Prototype development and supplies for final installation

HMC ESW/MOSS club funds from Jenzabar: $5,000

- 1 2/3 student stipends

Strauss Fellowship: $3,000

- 1 Student stipend

HMC President's Clark Funds: $3,000

- Faculty stipend