

## EVCO: Heating Schools in Lesotho

### 1. Background

#### a) General

The Kingdom of Lesotho is a small mountain country of 1.8 million people, landlocked by South Africa with very limited natural resources. With a per capita income of 2,765 PPP dollars, it is the only country of Southern Africa (which includes Botswana, Namibia, South Africa, Swaziland and Zimbabwe) that is currently classified by the United Nations as a Least Developed Country (LDC)<sup>1</sup>.

More than 80% of Lesotho lies 1,800 meters above sea level, and it is the only country in the world that lies entirely above 1,000 meters. Besides ruling out many forms of economic activity and hampering the development of basic infrastructure, Lesotho's rugged and mountainous topography (over two-thirds of its landscape filled with steep tree-less mountains) makes for a climate that is significantly different to other countries in Southern Africa. Winters, for instance, are bitterly cold: temperatures can fall to -7°C in the lowlands and -18°C in the highlands. Snow falls mainly in winter, but can occur in the mountains at any time of year and frost and hail are frequent hazards<sup>2</sup>.



At almost 82%, the literacy rate in Lesotho is high compared to the average of 64% for Sub-Saharan African countries. In 2004, there were a total of 1476 primary schools, and children of primary school age (6 to 12 years old) accounted for almost 19% of the total population. The average student to teacher ratio was 44, but this number lies higher in the highlands where multigrade teaching is still practiced<sup>3</sup>.

Given Lesotho's limited natural resources, future economic growth is likely to depend heavily on human capital development. The government recognises this; its spending on education is extremely high by international standards, at 12% of GDP (compared to the world average of 4%). The government of Lesotho is working to gradually attain universal primary education by 2015. Most of Lesotho's education expenditure goes to teachers' salaries, food programmes, and classroom construction. While the government is making a significant effort to improve the quality of education, the quality of the school environment leaves a lot to be desired<sup>4</sup>.

<sup>1</sup> UN office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States: <http://www.un.org/special-rep/ohrls/lcdc/list.htm>, April 2007

<sup>2</sup> Encyclopedia of the Nations, <http://www.nationsencyclopedia.com/Africa/Lesotho-CLIMATE.html>, April 2007

<sup>3</sup> World Bank, "Primary and Secondary Education in Lesotho: A Country Status Report for Education". *Africa Region Human Development Working Paper Series No. 101*, December 2005.

<sup>4</sup> Ibid.

## **b) Need**

Space heating within educational environments is absolutely critical to the health and academic success of students. Schools within the United States and other developed countries must adhere to strict regulations dictated by ASHRAE<sup>5</sup> or the World Health Organization that prescribe minimum and maximum climate conditions to preserve student health and promote their education. Should an institution fail to meet these conditions, they are closed until the appropriate renovations can be made to guarantee student health and maximum opportunity for success in their education. According to these regulations, sustainable student health in the classroom prohibits the indoor air temperature of a classroom for any education level to drop below 22°C.

Despite their revolutionary education initiatives, schools in Lesotho struggle with student attendance and sickness during winter months in which the rural classrooms become bitterly cold. Without space heating solutions and located on windy mountains without buffering trees, rural schools are subject to winter temperatures from 0-15°C. The resulting classroom indoor air temperatures range from 5 to 15°C. Students receive vacation in June because it is simply too cold to be at school, but over the last few years winters have begun as early as April and ended as late as October. The country's population is also concentrated heavily in rural areas- over 80 percent of the population lives in the countryside where the schools do not have space heating solution or grid-based electricity. A small number of schools, however, have diesel generators of sufficient size to provide the classroom electricity for lights and computers.

Our team has developed a technology that will capture otherwise wasted heat from these generators and use it provide the classrooms with hot water for space heating, cooking, or cleaning. Moreover, we can provide this service at a fractional sacrifice of electricity output from the generator, and at no additional running cost. One of our community partners in this effort is also engaged in deploying solar-derived electric power equipment in the area, and our technology will be seamlessly integrated with their existing package in order to co-generate electricity and hot water from sunlight. We will travel to Lesotho and install a simple, low cost retro-fit heat exchanger device to existing school diesel generators and solar thermal power devices. Through this effort, we will provide the students and staff in these schools with the heat deserved by an educational institute during the bitter cold seasons in Lesotho.

## **c) Prior art**

For historical reasons, about 90% of schools in Lesotho are owned and managed by churches (the teachers' salaries are paid by the government). Schools therefore have varying levels of infrastructure, with some operating generator sets. The vast majority of rural schools, however, consist of one or more classroom buildings with no running water, electricity, or space heating. There have been no attempts to systematically provide these schools with hot water or space heating, despite the extreme temperatures in which they are forced to operate. Our project targets precisely these schools, and aims to find a way to make widely available the cheap, simple, and reliable technology we have developed to heat water and classrooms.

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<sup>5</sup> ASHRAE (American Society of Heating and Refrigeration Engineers) standard 55

Our community partners in this endeavour are the Solar Turbine Group (STG), Bethel Business Community Development Center (BBCDC), and U.S. Peace Corps, UNESCO and UNICEF contacts in Lesotho. STG is an MIT spin out company, and is deploying solar powered turbine power plants at the Bethel High School. Their technology was also a result of two IDEAS grants, and their current efforts are supported by a development grant from the World Bank. In addition to applications in stand-alone diesel gen-sets, our heat exchanger technology is an enabling component that will permit the STG's existing power package to consistently supply both electricity and hot water at their Bethel High School installation. Before our joining forces with STG and BBCDC, there was no hot water supplied to the high school explicitly for heating or washing. On the other hand, it was anticipated that electricity from the STG energy package could be used for hot water production or electric resistive heating. Based on the existing electricity demands of the school, however, it would be extremely wasteful to direct electrical power towards space or water heating.

Beyond the use of precious electricity for heating purposes, classroom stoves are the only other existing technology to meet the winter heating requirements. Such stoves can burn either biomass or petroleum derived fuels. The lack of brush and thick flora in the mountainous region coupled with the precious value of wood stock, however, precludes the widespread use of biomass heating. Petroleum fuel resources also represent a significant cost, and are generally reserved for transportation or production of electricity. Finally, classroom stoves also force students to stay near the stove in order to stay warm and in a crowded classroom this often makes learning extremely difficult.

## **2. Innovation**

Our innovation was driven by an initial quest to increase the energy use efficiency of distributed electric power generators. Our proto-type device was built, tested, and showcased last year for a contest sponsored by the U.S. Army<sup>6</sup>. At the time, we developed a device that utilized the waste heat from the exhaust of a civilian pick up truck in order to distil and purify water while the vehicle was idling or in use. We were successful in this contest<sup>7</sup> but did not pursue commercialization with the military on account of their existing strong supply chain that consistently delivers clean drinking water to the forward battle theatre. Although the design is simple and effective, there is no such product on the market today for the absorption of waste heat from the exhaust of engines under 100 horse-power (76 kW). The greatest heat loss for an engine occurs through the exhaust system, and our device is the only technology that we have found that can easily adapt to any exhaust manifold to re-claim that waste heat for better purposes. While the original system was initially designed to completely boil water for distillation, it is a simple modification to apply the exact same heat exchanger to produce hot water for space heating, washing or cooking applications.

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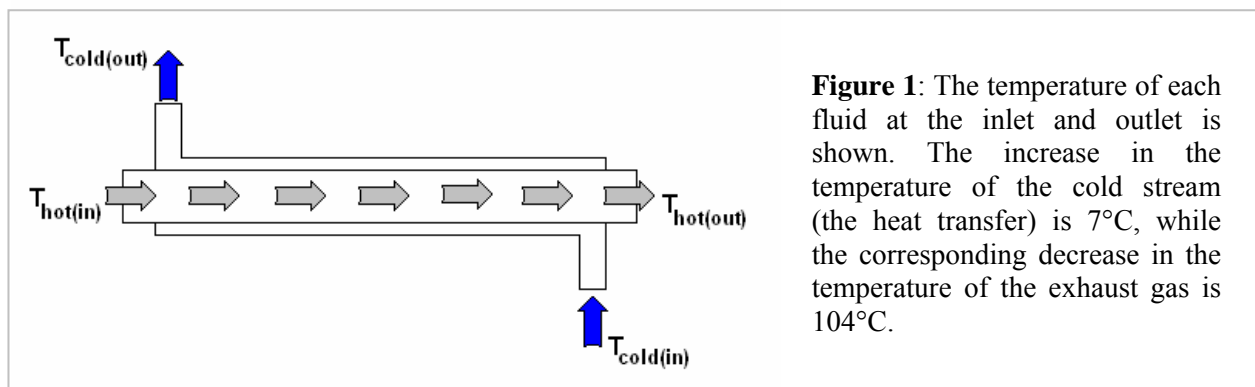
<sup>6</sup> MIT Institute of Soldier Nanotechnology, Soldier Design Contest 2006

<sup>7</sup> Third place out of 15 competing teams

## a) Thermal-Fluid Design

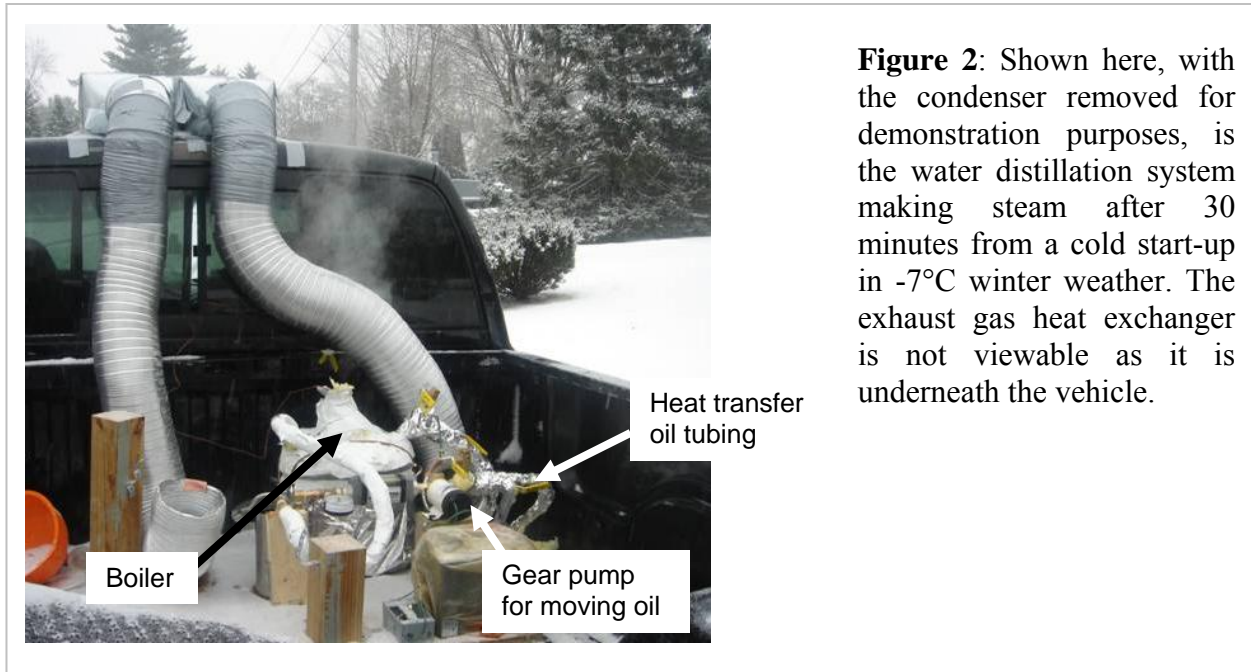
The success of this technology is attributed to the thorough and effective thermal-fluids analysis that supported our design choices. Consistent testing has also proven that our system does not decrease engine performance, but instead effectively make use of an energy source currently being wasted into the atmosphere. The major design work on this project went into developing the exhaust system heat exchanger. As the core of the heating system, it is essential that the heat exchanger deliver enough heat from the exhaust stream to heat water at the desired rate of 40°C per 1.6 l for every minute of operation. At this rate, a regular 230 l hot water tank would completely transition from 15°C to 50°C in about two and a half hours. This is equivalent to a heat delivery rate of 4.6 kW, which is what we have already shown possible with our proto-type system. This particular heat rate is necessary in order to make sure that several students can take consecutive showers before the water in the tank gets too cold for use. On the other end of the scale, space heating is afforded by this technology for a moderately sized classroom space, or multiple occupant bedroom. The precise heating requirements are highly dependent on electrical equipment present in the space, occupancy limits, and building envelope design.

Our existing system pumps heat transfer oil through a 0.61 meter long, cross flow, annulus-type heat exchanger installed over a section of exhaust pipe where the oil experiences a  $\Delta T$  of 7°C. The hot heat transfer oil is then piped to a hot water tank where it releases its heat to the water and returns to the exhaust heat exchanger to be reheated. Testing of our distillation system demonstrated that the system has a heat up time of 30 minutes, and a steady state water distillation rate of 7.5 l per hour. In steady state, the system removes and transfers heat from the exhaust at a rate of 4600 Watts. This distillation system is modified for hot water production simply by executing heat exchange between the existing oil heating device and a larger volume of water.



Measurements show that the temperature of the exhaust going into this section of exhaust piping can be as high as 750°C. With an exhaust stream temperature drop of 104°C, this equates to an exhaust outlet temperature of 646°C. The oil, returning from the hot water tank which is designed such that the oil releases its super-heat to the water, enters the exhaust exchanger at the temperature of the water tank (or in the case of boiling, 100°C). With a temperature rise of 7°C, the outlet temperature of the oil is 107°C from the exhaust exchanger. Starting from these imposed temperature changes, we then worked backwards to determine oil flow rates, pressure

head, and subsequent heat exchanger geometries and materials composition. The system to be deployed in Lesotho will operate at the 100°C oil temperature set point, thereby ensuring rapid heat transfer from the oil to the water within the hot water tank.



## b) Justification

- Efficient: We are utilising existing energy uses that are already in use, and creating value ;from the waste stream that they would normally lose to the ambient atmosphere
- Affordable: The system all together costs roughly 250 USD, the most expensive component being the oil pump, which we can obtain from the U.S. at roughly 150 USD per unit.
- Easy to build and maintain: the only technical component that is rather unique is the heat exchanger itself that consists of the exhaust pipe manifold and the appropriate piping that fits over it. The other components are common place such that any person with moderate training in plumbing or automotive service can perform the installation and maintenance.

## 3. Feasibility

### a) Work to date

As was pointed out before, the technology for this project was proven, presented, and issued a provisional patent last year. Our efforts this term have consisted largely of identifying communities and community partners with whom we could co-develop and deploy this technology for the improvement of quality of human life with developing countries.

## **b) Implementation plan**

Our implementation plan consists of several stages. Each one is necessary to implement and evaluate what we already have and to gather the necessary data to move on to the next phase. In the first stage, we will send two members to Lesotho for two weeks to work with existing STG group in the Bethel Mission. Over the course of this trip we will:

- (1) install our prototype in Bethel high school, which already has an electric generator;
- (2) train one or more locals at the existing STG machine shop on how to maintain and repair the system;
- (3) lend our expertise to STG;
- (4) gather information and forge alliances with local communities, organisations and the government for the purpose of the next stages of the project.

Accordingly, our specific execution strategy for each component of this phase:

(1) Stephen Samouhos and Sarah Edinger will fly to Maseru, Lesotho. Whatever equipment that cannot be transported from the U.S. will be purchased ahead of time in Maseru by our contacts in STG. STG will transport these materials as well as our team mates to the Bethel mission location.

(2) Both team members will work to install the heat exchanger device on the existing diesel gen-set. When this is completed, one of the engineers will focus on the local community to train one or more of the vocational students at Bethel High school on how to maintain and repair the system. They will also be instructed where spare parts for the heat exchanger can be purchased, and at what price. During this period, this team mate will also evaluate the technical operation and community benefit of the heat exchanger.

(3) The other engineer will contribute his expertise to assist the STG with the re-design of the condenser heat exchanger which is currently limiting the performance of the STG's power plant. This will likely lead to a condenser heat exchanger design that uses the knowledge base of our existing heat exchange device, thereby integrating our technology as a turn-key component of STG's power plant.

(4) Both members will spend time in Maseru at the end of trip, meeting with officials from the Ministry of Education, in order to gather further data on schools. They will also meet with some current and potential partner organisations such as the U.S. Peace Corps, UNESCO, UNICEF, and various church associations, in order to obtain practical information, advice, and perhaps partnership for the next stages of our project.

For the purposes of the 2007 IDEAS competition, executing an installation with the STG will be the scope of our proposal and budget outline. Our ultimate goal, however, is to extend this service to other schools in Lesotho and in the long run to possibly have it serve as a model for similar projects in other cold regions in the developing world. This could either be done by working with the STG and their commercial enterprise in the developing world, or pursuing our own contacts and efforts in the region. For now it appears, however, that partnership with STG may offer the most rapid and efficient point of entry and deployment for our technology. Should STG not proceed with its deployment strategies in parallel to our interests, then we will be

prepared to part ways and pursue international development through our own network of contacts in Lesotho and beyond.

How we design the next stages of our implementation plan will depend on our experiences, findings and partnerships developed in the first stage. Our ambition is to combine our water-heating mechanism with the provision of renewable energy, so that electricity and hot water can be provided as a package while avoiding the running- and environmental costs of fuel-powered generators.

### **c) Anticipated challenges**

We anticipate challenges typical to working in developing countries. Transportation and communication will likely be slow and difficult. We will rely on public transportation and logistical support from our community partners in the event of such difficulties arising.

It may be difficult to gather necessary data on a national scale, in which case we will remain in close contact with the Ministry of Education and our community partners upon return, so that we can continue researching the situation in Lesotho for the purpose of the project's next phase.

Based on previous experience of colleagues working on an off the grid energy system in Lesotho, we expect that technical problems may arise during installation. In this case, we will rearrange the timeline to free up one team member who can travel to the capital for spare parts or to resolve other problems.

The language barrier may also be a problem as Sesotho is the other major language in Lesotho other than English and we may encounter various dialects or other languages as we work with different community partners. We plan to have a translator if needed or to work more closely with our English speaking community partners when implementing the project.

We expect that our collaboration with the already established STG will help us avoid and overcome some of these challenges in the event that they arise.

### **d) Support network**

- Clement Lephoto, Director of Education at Peace Corps Lesotho
- Hillard Dunn, Country Director at Peace Corps Lesotho
- Mr Paramente Phamotse, Chief Education Officer, UNESCO, Lesotho
- Mr. Banard, Project Manager for Education, UNICEF
- Reverend Kometsi, Lesotho Evangelical Church (owns a number of schools in Lesotho)
- Chad Gandiya, Coordinator for Africa at USPG, has experience working with St. James Hospital and School, specifically
- Claire Hilger, Friends of Lesotho (recently returned peace Corps volunteer)
- Matt Orosz, lead developer for Solar Turbine Group; primary Lesotho contact for STG and Bethel Mission
- Sam White, director of Solar Turbine Group, primary US based contact for STG and Bethel Mission

#### e) Time line

|                    |  |
|--------------------|--|
| <b>May</b>         | <ul style="list-style-type: none"><li>- Work with STG to redesign condenser heat exchanger, integrate our technology with theirs;</li><li>- Arrange appointments with our current contacts in Maseru;</li><li>- Finalize prototype, finalize trip logistics, purchase materials.</li></ul>   |
| <b>June</b>        | Arrive in Maseru on June 1 <sup>st</sup> , 2007. <ul style="list-style-type: none"><li>- Day 1-2: Arrive in Maseru, meet with STG, gather remaining materials;</li><li>- Day 3-5: Travel to Bethel, install our prototype at the high school;</li><li>- Day 6-9: Install our prototype at STG Power Plant, train vocational students how to maintain and repair prototype, evaluate our prototype;</li><li>- Day 10-13: Gather data on other local schools and meet with current and potential partner organizations to discuss scalability and future impact of project;</li><li>- Day 14: Complete meetings with partner organizations, record contacts for possible future partnerships to scale-up project at other schools, leave Maseru.</li></ul> |
| <b>July/August</b> | <ul style="list-style-type: none"><li>- Follow up on prototype function, address problems as needed;</li><li>- Develop a comprehensive list of partner organizations and begin plans for prototype scalability.</li></ul>  |

#### **4. Community Connection and Impact**

Our main local partner will be the MIT spin out Solar Turbine Group. Working with this group will significantly facilitate our entry point for the initial deployment of our prototype. After the successful completion of the pilot stage, we would also like to work together with STG on the joint provision of electricity and hot water, based on renewable solar-derived energy. This will greatly improve living standards in Lesotho's countryside while avoiding the running- and environmental costs of fuel-powered generators.

However, over the last several weeks and months, our team has been in correspondence with several of our own contacts at various church organizations (Lesotho Evangelical Church, Christian Council Lesotho, United Society for the Propagation of the Gospel) and development organizations (U.S. Peace Corps, UNESCO, UNICEF, Friends of Lesotho). These organizations manage a large number of schools in Lesotho, of which some reportedly have diesel generators. Our project to heat schools (based on existing diesel generators, not STG's solar-powered generators) was in all cases received with great interest, and we have received valuable information and support from these contacts.

The U.S. Peace Corps, in particular, has been most committed to helping us find a school to install our prototype. Mr. Lephoto, the Director of the Education Program, has suggested various schools to us that would greatly benefit from the installation of a heat exchanger and space-heating system onto their generator.



We will work closely together with our contacts at these organisations for the advancement of the combined the solar-electricity and hot water project. However, we have all the necessary contacts and information to pursue the deployment of our technology, independent from the STG.

For the pupils of Bethel High School, or the schools suggested by the Peace Corps, having access to hot water and space heating will be an enormous improvement, especially during the winter months. A hot shower and a warm home during winter are taken for granted by many people in the Global North, but to students in the highlands of Lesotho, it is an unaffordable luxury. Our innovation would bring a change to this, making the heating of water and classrooms a free by-product of the electricity used anyway. Our technology is cheap and simple, and yet could make a great difference to many schoolchildren in Lesotho and eventually perhaps other countries.

## **5. Budget**

Expenses:

|   |                 |
|---|-----------------|
| Airfare (2 people, to Maseru)   | USD 4400        |
| Materials purchased ahead of time by STG:<br>Based on U.S. price estimates of common plumbing supplies, for the construction of the heat exchanger, and back up parts for on-spot repairs or design changes | USD 500         |
| Heat exchanger (imported from U.S.)   | USD 250         |
| <i>Sunk cost (the heat exchanger is already in our possession)</i>  | <i>USD -250</i> |
| Stay in Maseru (2 people, 4-5 days)   | USD 200         |
| Stay in Bethel (2 people, 9-10 days)<br>Based on stay in a homestead-type arrangement   | USD 500         |
| Administrative costs<br>Intra-Lesotho travel, communications during the stay, possible translator fee (ca. 3 USD per hour), follow-up communications (calling cards)  | USD 200         |
| Subtotal  | USD 5800        |
| Contingencies (10%)   | USD 580         |
| <b>Total</b>  | <b>USD 6380</b> |