Title: Solar-Thermal Powered Autoclave for Rural Health Services

Background
This is the final report of the Shell Center for Sustainability (SCS) Funded Project “Solar-Thermal Powered Autoclave for Rural Health Services” that was submitted to the SCS in October of 2011 and approved later in 2011. The PIs are Dr. Douglas Schuler and Dr. Marcia O’Malley, of Rice University’s business and engineering schools, respectively. This final report is an account of the activities that have been funded by SCS under this proposal.

1. Objectives
The primary objective is to deploy a sustainable energy technology into the off-grid medical services space in developing countries. Specifically, we first propose to perfect the engineering behind a solar-thermal concentrator, dubbed the “capteur soleil,” coupled to an autoclave via a hotplate heat transfer device. Second, we propose to place this device into an off-grid medical services clinic and/or hospital in a developing country. Third, we propose to chronicle its use, measure its performance, and learn more about the characteristics of user communities. This project targets SCS focus areas #10 Health and Well Being, Rural Impacts and #5 Energy Conservation.

Background: Many global health problems can be related to the lack of access to reliable electricity. The International Energy Agency estimates are that about 1.4 billion people do not have access to electricity (IEA, 2010). Certain regions are particularly affected. For example, the IEA reports that about 585 million people or about 70% of those living in sub-Saharan Africa do not have electricity, and nearly 85% of those living in rural areas lack an electricity connection. South Asia has 612 million people living off grid (IEA, 2009). The United Nations’ Millennium Development Goals (2005) has identified the lack of energy services, including electricity, for activities such as lighting, cooking, and motive power as a major deterrent to socio-economic development.

Of particular importance for the study, the lack of access to electricity is associated with negative public health outcomes. Without electricity, there are significant hindrances to effectively provide many health services, such as properly refrigerating vaccines, conducting certain medical tests, and medical instrument sterilization, the focus of this project. Medical instrument sterilization using autoclaves (called “wet sterilization” – the gold standard of sterilization) is compromised due to poor electricity access. The WHO (2002) reports that nosocomial (within the health facility) infections for patients and health-care workers are linked to contaminated equipment and poor infection control practices including inadequately sterilized medical instruments.

2. Approach
Our approach overcomes current limitations associated with the sterilization of medical instruments in rural, off-grid settings. We had two phases: [1] Engineering, especially with reference to join the solar-thermal concentrator with the autoclave; and [2] application of such devices into the field.

2.1 Engineering. The approach is to utilize a solar-thermal concentrator, a device that was earlier supported by SCS funds (and later by other sources). In 2008–2009, we built at Rice
University a solar-thermal concentrator which we deployed into northeastern Haiti in June of 2009 for the purposes of cooking. Based upon that field work experience, we shifted the focus of our application to medical instrument sterilization using an autoclave ("wet sterilization") using solar energy as the power source. Since late 2009, we have developed and tested a device that allows the solar-thermal concentrator to provide power to a commercially-available, non-electric autoclave. We have done this work in conjunction with an undergraduate course at Rice, Mechanical Engineering 407/408, Senior Design, taught by Dr. O’Malley, with a four person student team supervised by Dr. Schuler. In academic year 2010–11, this student team worked on perfecting a design of a steam-powered (using steam from the capteur soleil) hotplate that could provide a safe, efficient, and easy to use interface between the capteur soleil and a commercially available autoclave (similar to those used by international health organizations such as Médecins Sans Frontières). The student team performed superbly, winning the student award for “Best Sustainable Energy Prize” at the engineering Elevator Speech competition held in fall of 2011. The team was featured in Rice publicity that was later picked up by about 20 external outlets (e.g., Science Daily, May 5, 2011: http://www.sciencedaily.com/releases/2011/05/110503133205.htm) and one of the students was featured on Canadian Broadcast Corporation Radio’s national show “As it Happens” http://www.cbc.ca/video/news/audioplayer.html?clid=1910980763.

The hotplate device was subject to further testing during the summer of 2011 by Rice undergraduate engineering student Tremayne Kaseman, under supervision of Dr. Schuler and Mr. Boubour. The results were stupendous – the device was able to power the autoclave in such a manner that in over 27 runs it was always able to achieve its performance objectives related to efficacious sterilization per the standards of the U.S. Centers for Disease Control. This study was published in a peer-reviewed global health journal in October, 2012 (see References). Subsequently, in November of 2012, The New York Times wrote a short article about our project in their Health section (References).

2.2 Field work in Sierra Leone in May 2013. Our next step was to ready the solar-thermal system for the rigors of the field. We concentrated upon optimizing thermal efficiency, maximizing safety features, improving reliability, and making user interface more accommodating. These steps are seen as critically important to gain user acceptance, a necessary condition to widespread adoption.

For the field test, we found a suitable partner to pilot this system for off-grid medical services, WellBody Alliance (www.wellbodyalliance.org), a U.S.-based NGO that runs a clinic, the WellBody Clinic, in Dorma Village, Kono District, Sierra Leone. WellBody has a close relationship with the Koidu Government Hospital (KGH), a public hospital in Koidu-town, because it is part of the public health network in the Kono District. Both the WellBody Clinic and the KGH are off the electrical grid, although the government is slowly bringing electrical power to Koidu-town (but not to Dorma Village or any of the surrounding areas). We describe our field work in Sierra Leone below (see Appendix, Figs 1-4 for map and general photos of the area).
Dr. Schuler and Mr. Boubour travelled to Sierra Leone from May 6 through May 26, 2013. The purposes were the following:

1) To install a solar-thermal powered autoclave system at the KGH.
2) To train local persons to install, maintain, and operate this system. Maintenance and operation also included the non-electric sterilizers, the autoclaves.
3) To meet with various leaders interested in public health in Sierra Leone. Meetings were with Dr. Musa P. Kamara, the person in charge of public health facilities (Health Facility Planning Unit, Department of Planning and Policy) for the Ministry of Health and Sanitation for Sierra Leone; Dr. Ekundayo J. D. Thompson and several other university professors from the Institute for Public Administration and Management and other departments, University of Sierra Leone; Dr. Abdulai D. F. Barbu, the Medical Superintendent for the Koidu Governmental Hospital; the surgical theater staff of KGH (these people are charged with the sterilization of medical instruments within the health care facility at KGH); Dr. Bailor Barrie and Dr. Dan Kelly, the founders and co-heads of the WellBody Alliance and the WellBody Clinic in Kono District (note that Dr. Barrie will be a Fulbright Fellow at Harvard School of Public Health beginning July 1, 2013. Dr. Kelly is formerly Fellow at the Baylor College of Medicine and will be a Fellow at UC San Francisco beginning July 1, 2013); Mr. Michael Owen, the U.S. Ambassador to Sierra Leone; Mr. Todd Unterseher, the Economic and Commercial Officer of the U.S. Embassy of Sierra Leone;

Here, we comment on the outcomes of each of these three activities.

**Installation of the Solar Thermal Autoclave System**

After touring the hospital grounds with Dr. Barbu, the Medical Superintendent, we settled on a site to place the solar thermal concentrator just besides the building that hosts the surgical theater and sterile processing (Figs. 5 and 6). Advantages are that it is close to the existing sterile processing site (they use a non-electric sterilizer and a burner with a tank of propane gas. See Figs. 11 and 12), it is on the hospital grounds (with a secured perimeter), there is a decent amount of medical instrument throughput per week (outside of childbirth, the hospital performs about 15-20 surgeries per week without electricity), and the location is sunny.

**Training: Installation, Maintenance, and Operations**

In partnership with WellBody Clinic, Dr. Barrie identified two persons we trained to install, maintain, and operate the solar concentrator as well as the autoclave. We installed the solar thermal concentrator over about a four day window. We did training about maintenance and operations over a five day period. We have identified two individuals working for WellBody, Ahlaji and Sasko, who will be charged with operating and maintaining the solar thermal concentrator and doing autoclave sterilization (Figs. 7–8). These two individuals will also be charged with recording usage.

We also gave many tours of the solar device to the hospital staff from the surgical theater. These individuals are already familiar with using the autoclaves (Fig. 9).

Additionally, we helped to develop a sterile processing protocol and to train users at the WellBody Clinic. Currently, WellBody uses about 60 dental tools per week and a small number
of medical tools (of which none are sterilized. Fig. 10). We worked with the dentist and Wellbody’s staff to improve their cleaning and sterilization protocol.

Meetings with Leaders interested in Public Health
We had seven meetings with individuals interested in public health in Sierra Leone (listed above) in Freetown and Kono.

We had another a dozen or so informal meetings at the hospital with several medical doctors, surgical theater staff, pathology lab staff, patients, and visitors.

3. Outcomes and Future Steps
In our proposal submitted in October of 2011, we identified Engineering and Field Work as areas in which we needed to make accomplishments. With regards to Engineering, as stated above in Approach, we made significant strides in adapting the solar-thermal concentrator for use with an autoclave by developing the hotplate. While we do not doubt that additional engineering work can be done on the hotplate in terms of its design (i.e., the types of gaskets used; the size of the steam pathways; materials), we are satisfied that we have created several highly functional and well-performing prototypes. These prototypes have performed well both at Rice and in the field. We also made minor changes to the solar-thermal concentrator, such adding a hand-held water pump and incorporating several new types of valves, in order to better adapt the device for the task at hand (running the autoclave) and to improve its ease of use and safety for the operator. Our field work validated these engineering improvements such that we were able to train two novices to set up and operate the device after only a few days of training.

Our field work produced several important revelations. First, as stated above, we learned that our device has been engineered in such a way that novices can be trained to use it. Second, the field work revealed that there are settings such as the KGH where sterile instruments are demanded by doctors and nurses (there are two surgery theaters in the surgery building and another two surgery theaters in the maternity building) but are inadequately supplied due to equipment (broken or non-existent), energy sources (expensive or non-existent), organizational processes, and other factors. Third, the field work revealed that sterilization, i.e., running the autoclave, is only one of the necessary steps of sterile processing. For presentation to a doctor or nurse for safe use on a patient, medical instruments first must be collected, cleaned (washed), inspected, sterilized, and stored properly. These are all critical links in a medical instrument sterilization protocol. It was apparent from our time in the field at the KGH that many of these steps were improperly performed. Fourth, and related, we realized from the field that the sterile processing of instruments is but one important step in assuring a sterile field for medical procedures. Other elements of the hospital environment, such as clean hands and gloves, masks, a clean operating room (i.e., swept, washed, etc.) are necessary. Many of these were also absent at KGH. One person told us that the post-operation infection rate from the surgical theater was 100%. While we were not presented with data to verify this statement, our observation was that many patients had poor post-surgery outcomes in part due to the lack of sterility in the hospital environment.
Our future research is directed precisely at our third and fourth revelations above: improving the entire chain of sterile processing and introducing a more hygienic protocol to the operating room environment. For sterile processing, we envision creating a sterile processing “space” and protocol that can be done inside a standard 20’ shipping container. The container would have a gathering and cleaning stage (with at least three sinks, a water source, and brushes), a non-electric autoclave (such as the one we use) with two power sources (solar, via the capteur soleil and hotplate, and gas, via a burner), a drying rack, and a sealed storage cabinet. We would aim to eliminate “consumables” such as autoclave paper and replace them with re-usable such as muslin cloth, because consumables are both expensive and difficult to obtain in these rural locations. The container would also have a small space for other supplies and tools that could be used for the cleaning and sterilization of an operating or examination room. We believe that the market for this is very large and that it is aimed at an important problem in global health.

4. References


5. Team
*Dr. Doug Schuler, Associate Professor of Business & Public Policy. PI.
Dr. Marcia O’Malley, Associate Professor of Mechanical Engineering. Co-PI.
Mr. Tremayne Kaseman, Mechanical Engineering (former undergraduate student, Class of 2012)
Mr. Jean Boubour, Inventor and Complementary Employee, Mechanical Engineering.

*Contact: Doug Schuler, Associate Professor of Business and Public Policy, Jones School of Business, Rice University. Houston, TX 77005. Tel. 713 348-5472 Email. schuler@rice.edu
APPENDIX
Field Work, Sierra Leone, May 2013

Fig 1. Map of Sierra Leone. Our field work was in Koidu-town, Kono Province, in the eastern portion of the country.

Fig 2. Street scene in Koidu-town. The Government of India is working with the Government of Sierra Leone to bring solar PV lighting to some of the public areas of the city. Currently, there is not electricity grid access into Koidu-town.
Fig. 3. Street scene. Sina Town Village. Near the hospital.

Fig. 4. Street scene. Sina Town Village. Off of the electricity grid.
Fig. 5. Koidu Government Hospital (KGH), Koidu-town, Sierra Leone. Front gate.

Fig. 6. This is the surgery theater building at the KGH. It has two surgery theaters, plus three consultation rooms, two rooms for decontamination, a bathroom, and a foyer. Our solar-thermal powered autoclave is located in the space in the foreground (to the left of the pole), directly adjacent to this building.
Fig. 7. Training Ahlaji to use the solar-thermal concentrator, May 2013

Fig. 8. Ahlaji and Sasko moving the mirrors, May 2013
Figure 9. Giving a short tour of the solar-thermal concentrator at KGH.

Fig. 10. Dental tools at the WellBody Clinic.
Fig. 11. One of surgical theater staff, Koidu Government Hospital (KGH), is preparing instruments for sterilization. These instruments are set into the round stainless steel drums in the background.

Fig 12. Present method used for sterilization at KGH. The All-American non-electric sterilizer 1941X (autoclave) is powered by a tank of propane gas. Our device has successfully powered All-American models 1915X and 1925X using solar-thermal energy, as reported in our 2012 article in the American Journal of Tropical Medicine and Hygiene.