MECS-TRIID Draft Project Report (public/confidential version)

Insert Project Name: *Thermal Storage with Phase Change Materials*

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Logos of UK Aid, Loughborough and ESMAP to be added once the report is finalised

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Executive Summary

We received notice of the MECS award a week before leaving on a trip to Ghana (PI Pete Schwartz and 4 research students). In three weeks, we visited the Energy Commission of Ghana, SNV, and the universities of Ashesi and KNUST. We spent two weeks in a small village on Lake Volta without electricity. We established an agreement to use the grant money to start a business, SolarElectricCook (SEC LLC) in Kumasi, Ghana, to build and disseminate ISEC (Insulated Solar Electric Cookers) for a pilot study. SNV expressed interest to help support (fund) pilot studies as soon as we have a mass produced (~100 units) cookers. In September, classes at Cal Poly started and the activities in Ghana were supported by Cal Poly research groups and student groups in Schwartz's class. Additionally, we are partnering with Nexleaf (who provided us with temperature data loggers) to assess the ISEC adoption process.

We experienced many difficulties and setbacks in in establishing SEC LLC including:
- disagreements with Ghanaian collaborators in financial routing,
- difficulties and delays routing money from the UK to Cal Poly to SEC LLC in Ghana,
- lack of time of PI Pete Schwartz in coordinating activities and communication
- sourcing materials from China to Ghana (sometimes through Cal Poly),
- lack of communication between community dissemination and manufacturing, and
- changes in personnel and lack of needed skills in electronics.

In January, Martin who was running SEC LLC came to the USA to start a master's program in mechanical engineering and hired Emmanuel to take his place leading the company. Additionally, Owen graduated with a Cal Poly BSc in physics and was hired full time to manage the project at Cal Poly and support communication between research groups at Cal Poly and SEC LLC in Ghana. Communication/coordination is more difficult than we anticipated. Thus, we are spending more time communicating via the web and have also reduced the number of collaborators actively communicating on a daily basis.

As we close the funded project, we report:
- we are manufacturing ISECs of good, reproducible quality,
- we can source all needed materials to Ghana for a reasonable cost,
- we established a dissemination mechanism directly from SEC LLC to nearby communities,
- we have established 30 ISECs in two communities each, one community has electricity,
- we are working with Nexleaf to assess community adoption of ISEC,
- Martin and Emmanuel are competent, responsible partners dedicated to continue work.

We identify two needs/opportunities.:
- Martin has a one-year scholarship to study in the USA and wishes to continue the project and return to Ghana. We would like to bring him to Cal Poly over the summer, 2020 (costing about $6000) to co-develop ISEC technology for his master's thesis. The result would be a local business/technical leader to manage SEC LLC, filling the leadership void so badly needed in Ghana.
- SNV has expressed interest to promote ISEC technology and provide support for additional studies. We would like to provide continued support for Ghanaian salaries for the next year for about $1000 / month.

In retrospect, when we received the MECS award we were not ready to start a business. However, in prematurely moving forward with a business model, involving about 40 Cal

Poly students, we learned many valuable principles and skills toward establishing ISEC as a sustainable solution to the cooking/electrification challenge experienced by the global poor.

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1. Introduction

1.1 We developed Insulated Solar Electric Cooking (ISEC) whereby a solar panel is directly connected to an insulated, electrically-heated cookpot. In 2018, we explored using diode heaters rather than resistive heaters because diode heaters more effectively couple power from a solar panel under a wide range of solar intensities. Typically, we use a 100 W solar panel, capable of heating 5 kg of food to boiling in the course of the day. If people want more power and/or want to cook in the evening after the sun has set, we developed phase-change thermal storage capability using Erythritol, with a melting point of 118°C that is capable of storing about ½ kWh over the course of the day. The cookers can deposit much of this energy in a short period of time after external power has been disconnected, providing many times more power than 100 W. The simple phase change thermal storage unit could be used with applications other than ISEC, and is a simple design built from less than $20 in materials.

1.2 *References are provided at the end of this document*

Aims of the project

1.3 The aims of the project are to improve the design, share knowledge with African partners, collaboratively disseminate the technology, and study the technology adoption process. Our dissemination model is to support local enterprises in constructing and innovating ISEC products for local sale.

Objectives of the project

1.4 Objectives:

- Establish connections in Ghana
- Study the use of the cookers by Ghanaians
- Set up a business in Ghana to manufacture the cookers
- Disseminate the cookers for a pilot test
- Study the adoption
- Present results for future sustainable companies or NGO or government production.

2. Methodology

2.1 The project develops through the coordinated effort of business and technology work at a designated company in Kumasi, Ghana, research groups at Cal Poly, and service-learning classes directed by Pete Schwartz.

Outline of the concept

2.2 Using existing technologies in a novel way, ISEC (Insulated Solar Electric Cooking) is a fundamental disruption of the use of solar electricity (Watkins 2016), providing a radically inexpensive and simple way to extract heat and electricity from a solar panel at near optimum efficiency (Gius 2019). The innovation we sought funding for is to improve, refine, and disseminate Phase Change Thermal Storage (PCTS) with a Phase Change Material (PCM), allowing the user to cook after electrical power is disconnected, and to have access to greater power by discharging the stored heat over a shorter period of time. This PCTS capacity can be used with grid electricity and other energy sources as well as with solar electricity.

2.3 We develop this phase change thermal storage (PCTS) in tandem with Insulated Solar Electric Cooking, which we recently introduced (Watkins 2016) and continue to develop (Gius 2019). We developed the nested heater (Fig. 1, 2) in spring 2019 with a student group in the Appropriate Technology Class.

http://appropriatetechnology.peteschwartz.net/design-spring-2019

Figure 1. Image of the nested heater design.

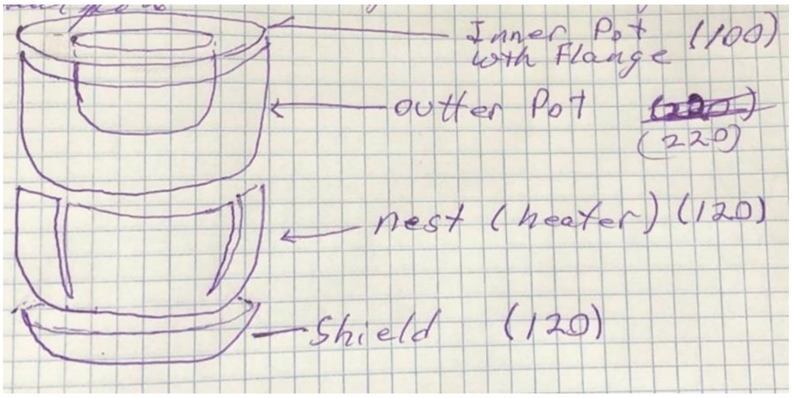

Figure 2. Schematic of the nested heater design.

Intellectual Property Rights

We wish to keep any innovations we are responsible for as open source, in the public domain.

Assumptions made

We assume that maintaining open access to the IP we develop will optimize the speed of development and dissemination of the technology. Additionally, it will allow us to dedicate our creative energy to further product development rather than engaging in the competitive process of intellectual property defence.

3. Implementation

We visited Ghana August 2019 (days after learning that we received the MECS award) with the intention of developing university and government collaborations. There we spent time in the community of Agbokpa where we cooked with local people using ISEC and studied its compatibility with their cooking methods. We established local connections and agreed to build a business dedicated to manufacturing and disseminating ISEC cookers, both the direct slow-cooker model of ISEC as well as models with PCTS. Cookers are currently being produced and a pilot test at target communities in Ghana will begin within the next 3 weeks.

The work conducted

3.1 We spent Aug 7- Aug 27 in Ghana visiting the rural, off-grid community of Agbokpa and developing connections with skilled technical workers, government organizations, NGOs, and companies with the intention of establishing a sustainable company in Ghana, which is now located in Kumasi. Martin Osei (with a Mechanical Engineering BSc from KNUST, Kumasi, Ghana) founded SolarElectricCook, LLC with the help of Dr. Schwartz and Cal Poly students. We met with Domod Aluminium Company (link below), a cookpot factory in Accra who agreed to make pots to our specifications. A considerable amount of work has gone into sourcing parts and materials to SEC, LLC. Some materials such as the pots (produced in Accra at Domod Aluminium Company) are produced locally, to erythritol (the phase change material) is easily imported from South Africa, to some electronics that are still purchased online in California and sent via air mail to Accra, Ghana.

http://domod.com/da/aboutus.html

3.2 The idea of local manufacturing of the technology comes from student research in Dr. Schwartz's development class.

As described in the application, local manufacture achieves the following goals:
- Decreases dependence on foreign supply lines.
- Employs local people improving local standard of living, and providing labor at a reduced cost.
- Brings the industry closer to the people, making the technology more adaptable to local needs and wants. The feedback loop formed by the user giving input to what changes they want in the product and the producer making those changes is shorter. A local business can adapt to consumer demands quicker and with more insight than a foreign business
- Provides a model for other countries to establish their own production and dissemination.

3.3 *Liberation of funds so we could get started building the project.*

Settling the contract to make funding available took about two months. After this approval process, university funding would not front the money for larger purchases requiring the Ghanaian workers to go into debt to pay for supplies, and also limiting the size of purchases to that which the Ghanaian workers could borrow enough money for.

Martins departure, expertise of Emmanuel

In October, Martin was granted a scholarship to a graduate school program at Eastern Illinois University in the United States. At this point, he was the sole director of operations in Ghana and we had invested a significant amount of our time in Ghana to teaching him about ISEC.

Before he left Ghana, Martin found a replacement for himself named Emmanuel and trained him to make cookers. Emmanuel has been very aptly communicating with us, however he lacks the technical experience with the cookers that Martin has. He is still producing operational ISECs, but we are currently finding an electrical expert to hire to assist him.

Sourcing supplies

Many supplies are hard to find in Ghana. Electrical supplies are scarce and many specific parts cannot be found and must be imported. Erythritol has been very difficult to find and will likely need to be imported.

Technological Problems

Corrosion

The leads between the wires and the diode chains seem to corrode over time in some cases. We have a student at Cal Poly that is dedicating their senior project to studying this.

Diode Failure

The diodes can break if they overheat, which can occur if they are not properly attached the base pot or if too much current is run through them.

Charging/Lighting Systems

The charging circuit and LED lighting strip both need housing as they are somewhat delicate. It is possible that we may want to buy these things instead of making them ourselves. These statements apply more to the lighting system than the charging circuit.

Pete teaching classes and running the project simultaneously

By the time the grant was awarded to us, Pete was already committed to teach a full load of classes for the fall quarter, and he was not able to dedicate the attention to this project that it deserved/required. We had initially hoped to find a dedicated professor in Ghana, but were not able to find a committed partner. This was partly mitigated in winter quarter by hiring Owen, who has experience on the project and had just graduated, making him available. Moving forward, we propose a natural solution to this challenge is to help Martin continue his education in the USA with ISEC research so he can direct SEC, LLC locally in Ghana on firm technological understanding. Such an innovation would provide long-term sustainability to the continued development of the technology in country.

3.4 In many cultures it is the job for the women to manage all cooking. Women are freer from the burden of collecting firewood with ISEC as it requires no fuel source. This saves women time they would have spent collecting firewood, money they would have spent on it, and protects them from violence that they may be exposed to while out obtaining it. Cooking with ISEC does not require as much attention as cooking with and tending to a fire, so this is another way in which it saves women time.

The liaisons hired in the communities will also be all women, as they are more involved in the cooking process in these communities.

The project findings

3.5 The most obvious finding is that it would have been better to build a strong collaboration with university and industrial partners in one place, consolidating communication to a very small number of key players. We recognize that we didn't have this luxury, as we didn't know anyone until we arrived in Ghana. Moving forward, we will seek to continue to strengthen the connections we have.

3.6 We have established a strong relationship of trust and common goals with Martin and Emmanuel, which will likely be beneficial toward long term success of this project.

Limitations of the innovation/approach/design/system

Are there any limitations on how, when, where, why, by whom this solution can be used?

The use of diodes and local production provide limitations.

Describe what these limitations are

Diodes

The diode heater technology is able to directly take power from solar panels more effectively than a directly-connected resistive heater. However, diodes have their drawbacks: they have a maximum operating temperature and can thus be destroyed if run above 275 C. Additionally, the voltage across a diode, while largely constant, depends slightly on current and temperature. Additionally, the maximum power point voltage from a solar panel also varies with temperature. Thus it is not possible to precisely optimize power drawn from a solar panel with diodes, nor be able to take power from the diode chain optimally to power a USB port.

We will continue to develop diode technology, but we will also continue to support development of active control measures to power a resistive heater ISEC and a USB charger from a solar panel. Presently, we will do this through collaborations at Cal Poly in Electrical Engineering as well as with universities elsewhere.

Local Production

Producing the cookers locally results in challenges regarding sourcing parts, as certain technical components cannot be found in Ghana. This can be overcome by importing parts from China, possibly all at once via shipping container to obtain the best price.

4. Practical applications of the concept to the national cooking energy system (including costs)

4.1 We plan to be producing ISECs through SEC LLC in the next month. We will provide SNV with a prototype and seek their support for continued field tests. We will also continue working with Nexleaf to study the adoption process. Lastly, we may ask MECS for continued funding. Once SEC LLC has a customer base and well-established supply lines, the need for external support should diminish considerably, and the Ghanaian Energy Commission may become interested. Ultimately, the continued decrease of the cost of solar panels such that the company should be financially self supporting. We anticipate that this could happen within the next two years. The open-sourced availability and active publications should help make this transformation spread globally.

5. Next steps (e.g. beta or field testing and implementation; more development etc)

5.1 Emmanuel has enough supplies to continue producing cookers, but we will need to order more to finish the 100 required for the pilot test. We haven't ordered everything yet because we are still exploring options for sourcing materials to find the best prices. Here is a list of the supplies and where we are at with them:

· *Solar Panels* – Emmanuel has two solar panels that he uses for testing the cookers he makes. He and Martin established connection with two sources in Ghana that can supply 150W solar panels for approximately $80 each. As discussed elsewhere, we have to buy them 10 at a time due to limited funding.

· *Pots* – We have received 20 pairs of pots (each cooker requires a pair) to our specifications from the factory in Accra. They are ready to produce the remaining 80 for the pilot test at any time.

· *Insulation* – Material for insulation will depend on what is available in the target community that is settled upon. We will look into inexpensive fiberglass insulation.

· *Diodes* – Currently Emmanuel has enough diodes for 50 ISEC. We will be ordering more to be delivered to Cal Poly and then sent to Ghana, but we are still exploring means to have them shipped directly to Ghana.

· *Erythritol* – Erythritol has been hard to source in Ghana, but we are planning to order 50kg from South Africa for $390 which should arrive this week.

· *Thermal switches* – Emmanuel has recently run out of thermal switches (turn off the heating circuit when the temperature exceeds a set point) and we are exploring the cheapest options to get more to him. The rest of the cooker can be manufactured without the switch and then the switch can be added at the end.

· *USB power sources, charging circuit* – Emmanuel has made operational charging circuits and has components remaining to make several more. We will order more parts to him this week.

· *Nexleaf sensors* – Emmanuel has received 20 sensors from Nexleaf for the pilot test. We plan to use these 20 sensors to verify self reported use of distributed ISEC.

5.2 Funding for Martin this summer. Continued support for Owen (way cheaper than released time for Pete… and also builds more capacity by bringing in recent graduates). Continued funding for Emmanuel and community representatives. Continued funding for components. However, this may be minimal as it is reasonable to expect that recipients of a well-tested ISEC will pay for the cost of parts.

5.3 Nexleaf has provided temperature sensors.

SOWTech is pursuing a resistor version of ISEC and is informing us of their progress. http://www.sowtech.com/

SNV has agreed to help with further dissemination as well as subsidization of the cookers once we demonstrate the effectiveness of the cookers through a pilot test.

We can potentially expand and disseminate cookers into Sierra Leone through Project Peanut Butter and into Uganda through AidAfrica and Beacon of Hope Secondary School.

Dissemination Plan

5.4 The dissemination plan is to locally produce and disseminate the cookers. Initially, we find 2 communities for a pilot test: one off-grid and one on-grid. The communities should be close enough to where Emmanuel lives and manufactures the cookers so that he can remain in contact with them easily. Contact will be through a liaison in the community who is paid to report on the cookers' usage. If problems arise with the cookers, the liaison will report it to Emmanuel, who will assist them in person or virtually.

We have different ideas for the method of dissemination within the target community. We may use a buy-in lottery system. A student at Cal Poly is currently investigating the advantages of different methods.

The larger dissemination strategy is to establish a model of a business that is financially sustainable and publicize it. Additionally, we are working in several different regions with different partners: Sierra Leone through Project Peanut Butter and into Uganda through AidAfrica and Beacon of Hope Secondary School.

Explain what dissemination you have done already or what you plan to do if you haven't done any yet. Who are you focusing on? (who is your main audience e.g. customers, politicians, standards agency etc.). What are you telling them (e.g. are you focusing on the technical benefits of the solution, the price point, how well your solution works compared to a different solution).

We have identified target communities. Within the next two weeks, SEC LLC will establish and hire liaisons in these communities. Within three weeks, we will have people in these communities using ISEC and we will be tracking the use, value, difficulties.

The main selling point to the consumer will be that they will no longer have to purchase firewood.

Is your audience responding to what you are telling them? – how do you know? (e.g. have you done any customer feedback? Have you been invited back for follow up conversations on your approach/product?)

We haven't done any customer feedback yet. Our collaboration with Nexleaf allows us to monitor how often the cookers are being used. Our liaisons in the community will communicate with us how the adoption of the cookers is going and Emmanuel can see for himself and discuss with the users how things are going when he visits the communities.

6. Conclusion

6.1 In establishing a financially sustainable ISEC company in Ghana with well-tested cookers and a well-studied adoption process we are way behind our timeline. We have established a company with reliable collaborators. We are making ISECs and we will have them in the hands of families in the next few weeks. At the close of the grant, we will have numbers of delivered ISECs and an initial analysis of adoption success.

7. Appendix

7.1

Appendix A

Appendix B

References

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