MECS-TRIID April 2019 Competition Reporting Template

Reporting Period	**Jan. 21 2020 - Mar. 13 2020**
Reporting Author/s	**Owen Staveland, Pete Schwartz, Olivia Hansel**
Institution/Organization	**Cal Poly Corporation, San Luis Obispo**
Project Code/Project Title	**16-541/Thermal Storage with Phase Change Materials**

Key Activities

We have been continuing our operations in Kumasi, Ghana of producing ISECs, disseminating them, and getting user feedback, as well as continuing development and testing of the Phase Change Thermal Storage (PCTS) cooker at Cal Poly.

During the February 11th Skype call with MECS, we were tasked with three questions:

- Erythritol/Water mass ratio for boiling water: less than 1.7, future work will explore lower values.
- Can we cook beans after 3 hours of no power: not yet, but the effort has lead to redesigns that we are confident will yield a positive result.
- Can we cook beans: we cooked 1.3 kg of beans/water after power was disconnected. Boiling was sustained for several hours.

Greater detail is given on these developments in this report and our final report will include improvements in both the performance and precision of our results.

Figure 1. Emmanuel and Kojo-Nkwanta resident installing a solar panel for an ISEC cooker.

Ghana operations

The manufacturing and dissemination of cookers in Ghana has been continuing through our local employee Emmanuel. 10 ISEC cookers have been disseminated in the on-grid community of Kojo-Nkwanta. We have continued to source and test materials to be sent to Ghana. We have adjusted our plan and deadlines based on expected arrival of certain materials.

Figure 2. Emmanuel and Kojo-Nkwanta family with ISEC cooker and complimentary bag of rice.

Dissemination Plan

The new plan can be split into 3 Phases.

Phase 1: We have disseminated the 10 already-made cookers to a community. These and bags of rice were given away for free with the help of the community's pastor and will be used for 2 weeks. Emmanuel will call by phone the users halfway through to check in on the experience. A survey that we have developed with the help of NexLeaf will be given at the end in person when Emmanuel collects the cookers and panels.

The dissemination of cookers for Phase 1 has been completed and we are underway with the user experience data collection of Phase 1.

Phase 2: Dissemination of 40 more cookers. 20 will be disseminated in an on-grid community, and 20 more will be disseminated in an off-grid community, to be chosen between a few communities. These cookers will feature improvements to (hopefully) all the things listed in the "improvements to be made" section below. The "dissemination plan" section has more info on how we will disseminate cookers for this phase. We plan to have these disseminated by April 7th.

Figure 3. ISEC cooker (inside blue bucket) inside a home in Kojo-Nkwanta. It is wired to a rooftop solar panel.

Phase 3: When our shipment of erythritol has arrived in Ghana and we have settled on a design for the (PCTS) cooker, Emmanuel will begin manufacturing these cookers and conducting a pilot test at the established communities.

Improvements to be made

We already recognize ways in which Phase 1 could have been improved. Some of these shortcomings were:

- Dissemination only took place in one community, Kojo-Nkwanta (on-grid), instead of one on-grid and one off-grid community.
- Kojo-Nkwanta is a few hours drive away from Kumasi, making it harder for him to come if something breaks or if any assistance is needed.
- There was less time to plan a grander dissemination "event" or party, to spur interest in the cookers, although bags of rice were given away with each one.
- Cooker shortcomings, all of which we plan to address by Phase 2:
- Not all have chargers and the chargers are lower quality than the incoming ones.
- None have lighting systems.
- Exterior design/insulation could be improved. Emmanuel has successfully cooked rice and noodles with the current design he is using (shown in Fig. 5, 6 below). Better insulation would improve cook time/capacity to cook in reduced sunlight.
- The diode nests (Fig. 4 below) don't come up far enough on the sides, limiting thermal connection.
- There is no brochure or any instruction manual, although Emmanuel spent time with each user teaching them how to use it.
- There are no Trek sensors from NexLeaf on these cookers for data collection on cooker usage.

Figure 4. ISEC cooker with diode nest and metal cement-filled shield to protect diode chain.

Figure 5. ISEC cooker in bucket with blankets epoxied to the inside.

Figure 6. Side view of closed bucket containing ISEC cooker.

Notes on Supplies and Materials

Only unexpected developments are listed here. "Business as usual" inventory notes are omitted.

- Erythritol
  - We have been communicating with sellers in China to negotiate a purchase of at least 100kg of erythritol to be shipped to Ghana. Some erythritol we have purchased in the past (in small test quantities) has turned out to not actually be erythritol, so we ordered a sample from our potential supplier to the US, which arrived this week. Our tests show that it is indeed erythritol, so we will be ordering at least 100 kgs to be sent to Ghana at a rate of $3.80/kg. We will choose to ship by sea due to lower carbon emissions than by air, so it is estimated to arrive in 30 days.
- Charging circuits
  - Initially, we were building our own charging circuits that can be attached to the diode chain on the cooker and charge any male USB input. However, we have learned that while we could maybe save some money by making these ourselves, it is a better use of our time to just buy them. After buying a test sample, we have purchased 50 buck converters with female USB outputs to be sent to Ghana, which can be easily attached to the diode chain. They cost $3.50 each and are from China. As of the evening of Mar. 12th, they are at a sorting facility in Ghana, so they should arrive on the 13th.

- Lighting System
  - We ordered a sample of a lighting system (Fig. 7) that would be chargeable from the USB charging circuit that will soon arrive in Ghana. We are satisfied with the product after first use and examination; however, we will be conducting some tests to verify battery life and charging capacity before making a larger order to be sent to Ghana.
- Thermal Switches
  - The thermal switches we ordered to prevent fires and protect the diodes are still delayed in China due to COVID-19. As an alternative, we are presently buying thermostats in Ghana that can be locked onto one temperature, thus acting as a thermal switch, however they are more expensive ($8 each) than the switches we ordered ($0.16-$0.36 each).

Figure 7. USB rechargeable LED light with hook for hanging.

Dissemination Plan

We have developed a dissemination plan for Phase 2 with the help of NexLeaf and Cal Poly students, one of whom attended the ETHOS conference in Washington this January and the World Sustainable Energy Days conference in Austria last week to learn about cookstove adoption.

Step 1: Choosing the Community and Liaison

1. Choose target community
   a. The community must speak the same language as Emmanuel or at least the liaison must be able to translate for both of them.
   b. Should be within reasonable traveling distance from Emmanuel, making it easier to respond to a broken ISEC, collecting data, and making check-ins routine. For this reason, we may not disseminate in Kojo-Nkwanta again.
   c. We will have two communities: one on-grid and one off-grid.
2. Choosing a Liaison
   a. The liaison will be a woman from within the community, recommended by the pastor, chief, or other connection through Emmanuel.
   b. The liaison will preferably speak English or at least a language Emmanuel speaks.
   c. She will preferably have some exposure to smartphones since they will be used in the data collection process.
3. Expectations for the Liaison
   a. She should be able to participate in at least one day of paid training with Emmanuel on how to use the ISEC, give the qualitative survey, and collect data from the Trek sensors. We should pay for her transportation and childcare if it is needed for her to attend this training. This will take place before dissemination.

   b. She will be expected to check in with ISEC participants a minimum of 1 time a week, preferably 2 or 3.
      i. She will organize activities and help build a community around ISEC use.
      ii. She will give people a shorter version of our full survey every time she visits. She will fill out the survey with pen and paper.
      iii. She is also expected to collect data from the Trek sensors with a smartphone at every visit.

Step 2: Community Event

1. The liaison should have had an ISEC for at least one week prior to the event to get familiar with how to use an ISEC and how to cook specific foods with ISEC and she should have completed the training with Emmanuel.
2. After the liaison has finished her training and time with the ISEC she will host a community event to gain excitement around the technology.
   a. This event could be a soccer game, a movie showing, or anything else she wants; it should be the liaison's choice on what to do for the community.
   b. She will cook with ISEC for the community at the event.
   c. Emmanuel will be there to talk more about the ISEC and gauge community excitement.
3. After the community event we will write down the names of women who are interested in using ISECs in their homes.

Step 3: Distribution

1. We are considering two ways of distributing the ISECs to homes:
   a. Letting the liaison choose who gets an ISEC.
   b. Create a raffle.
      i. The raffle makes more sense if there are more people interested in ISECs than ISECs available.

Step 4: ISECs in the Community

1. The liaison will be checking in with users regularly, assisting and answering questions.
2. The participants should have the ISECs for a minimum of 3 weeks:
   a. If participants are using the ISECs for longer than 3 weeks they should have breaks. Ex: 4 weeks of data collections, 1 week off of data collection, 4 weeks on, etc.
3. Emmanuel should check with the communities as he sees fit.

Step 5: Finishing Data Collection

1. Once we are done collecting data from a community, we will give them the option of purchasing their ISEC.
   a. For the poorer, off-grid community, we may explore other options if they wish to keep using ISEC but cannot afford it, such as discounts, financing, or buy-in lotteries.

2. After ISECs are collected or purchased, liaison/Emmanuel should do a group close out interview.
    a. All participants the liaison supervised will be together.
    b. The survey will be given.
    c. People are given the opportunity to give feedback outside of the survey questions.
3. If ISECs are purchased/kept, Emmanuel should do a post data collection follow up 3 months later.
    a. Give qualitative survey again to some or all who bought ISECs.
    b. The purpose of this is to see if there is a drop off in ISEC usage after the data collection.

Survey

Below is the survey for ISEC users we have developed with NexLeaf:

<u>Follow-up for ISEC households</u>

Respondent name: ____________________________

What is your general opinion about the ISEC?

1. What do you like about it?
2. What do you dislike about it?
3. Since you've had this stove, have you had to have any repairs done?
4. What challenges did you have in using this stove?
5. Did the Trek device cause any inconveniences to you or your cooking habits? Please describe.
6. How likely would you be to buy or take out a loan to buy your own ISEC?

____ yes, likely   ____ not very likely   ____ not likely at all

    a. Why?

2. Do you have any other stoves or cooking appliances in your home other than the ISEC we gave you?

____ yes   ____ no

    a. If yes, what are they?_______________________________________

2. Do any other members of your household cook?
    a. If yes, who? *Write response in table below*
    b. how often? *Write response in table below*
    c. Which stove do they generally use? *Write response in table*

Other cook	Often (2+ per week)	Sometimes (1 per week or less)	Rarely (special occasions)	Preferred stove

Section 4: Food preference

1. In the last 3 days, what foods did you prepare with your ISEC?
2. In the last 3 days, what foods did you prepare other ways?
3. Are there any foods that you only cook on your ISEC?
    a. What are they?
    b. Why?
4. Are there any foods that you only cook another way?
    a. What are they?
    b. Why?
5. Are there any meals where you use both stoves at the same time?
    a. What are they?
    b. Why?
6. Do any of the following things affect whether you use your ISEC or another way? If yes describe.
    a. Weather
    b. Ease of acquiring fuel
    c. Holidays or festivals
    d. Using your stove for something other than cooking, such as heating your house
    e. Any other reasons?
7. How important is it to you that your ISEC reduces smoke?
    a. Why?

Phase Change Thermal Storage Cooker Developments

We are continuing to develop our Phase Change Thermal Storage (PCTS) cooker using erythritol as a Phase Change Material (PCM). Test results have motivated continued product design improvements.

Figure 8. Initial design of PCTS cooker. The sides of the pot are filled with PCM.

Design Progression

These are the major changes in the design of the Phase Change Assembly (PCA) we have made, although many other adjustments have been made along the way.

Initial Design: Two pots of different diameters are attached at the rims. The cavity that is left between them is filled with PCM (see Fig. 8). The PCM is melted by placing the PCA inside a diode heater nest.

1st Redesign: The nest is placed in an erythritol bath, which is placed inside an insulating container (see Fig. 9, 10). Then a normal cookpot filled with food is added/removed for cooking.

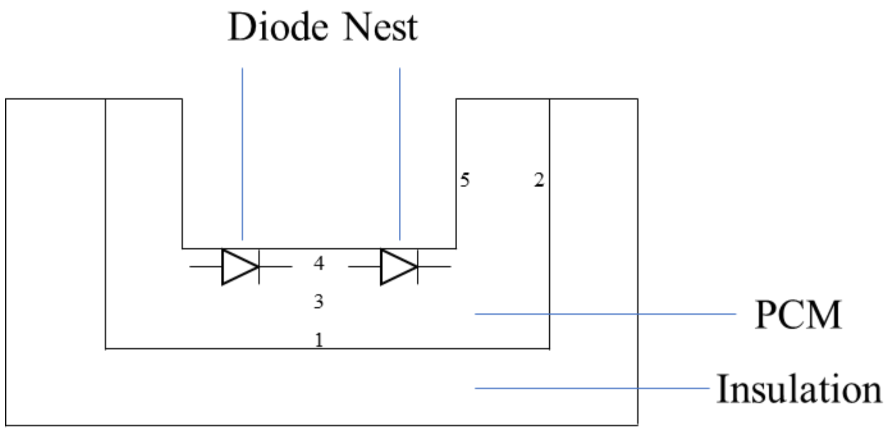

Figure 9. PCA for the 1st redesign (upheld for the future designs with minor adjustments). The numbers correspond to the locations of different thermocouples used for testing.

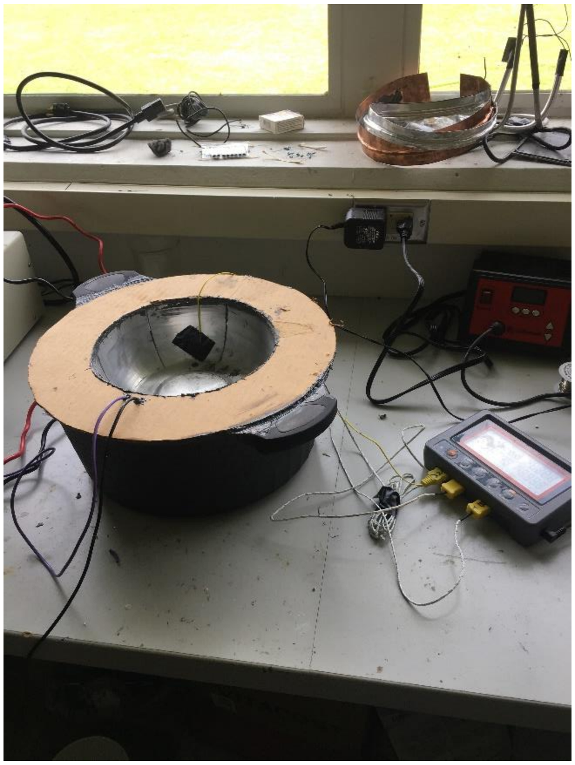

Figure 10. PCA for the 1st redesign. This prototype had less thermocouples than the prototype depicted in Fig. 9. The lid covering the containers of PCM and insulation was made of cardboard here, but most are sealed with wood or spray foam.

<ins>2nd Redesign:</ins> Aluminum shavings are added to the erythritol in an attempt to increase thermal conductivity of the erythritol (see Fig. 11).

Figure 11. Diode nest inside container of molten erythritol with Aluminum shavings. Weights are added on top of the diode nest to keep it from floating too high while the erythritol solidifies. No insulation container is present in this photo.

<ins>Exterior Design/Insulation</ins>

The current exterior design being used for ISECs in Ghana is a bucket lined with blankets (shown in Fig. 5, 6). Emmanuel reports that he has been able to successfully cook noodles and rice with this design with a 150W panel. He can also build this ISEC cheaply with local materials.

However, as we begin adding PCTS to the ISECs in Ghana, this design may not be adequately insulated to retain PCTS heat after sunset. While running tests like leaving the cooker disconnected from power for a few hours and then cooking, we recognize the importance of an exterior design that is cheap, manufacturable in Ghana, and can store the heat effectively. We have been experimenting with different overall designs that allow for more insulation, as well as with different insulated materials such as high temperature spray foam insulation, and we will continue to do so.

Experiments

Experiments include testing the PCTS cooker heat retention, water boiling capability per unit of molten erythritol, ability to have temperature gradient within erythritol reduced by aluminum shavings, and ability to cook certain foods such as beans.

<u>Questions from mid-February Skype call with MECS</u>

1) What is the water to erythritol ratio that can achieve boiling?

We have achieved sustained boiling of 1.5 L of water for a few hours several times with 2.5 kg to 3.0 kg of melted erythritol. We chose this amount of erythritol because it was the amount required to appropriately fill the containers we use. Including the energy required to heat up the erythritol to the melting point as well as the energy stored in the latent heat, this requires approximately 1250 kJ of energy to melt this amount of erythritol. This is achievable within about 4 hours with a 100 W panel, although it may take about an hour longer depending on insulation.

2) Can it be left for a few hours without power before cooking?

Initially this was not successful. As shown in Fig. 12 below, the temperature of the PCM dropped to the melting point and began solidifying over the course of the 3+ hours. When water was added, the temperature of the PCM closest to the nest dropped below 100 ºC and thus was not able to bring water to a boil.

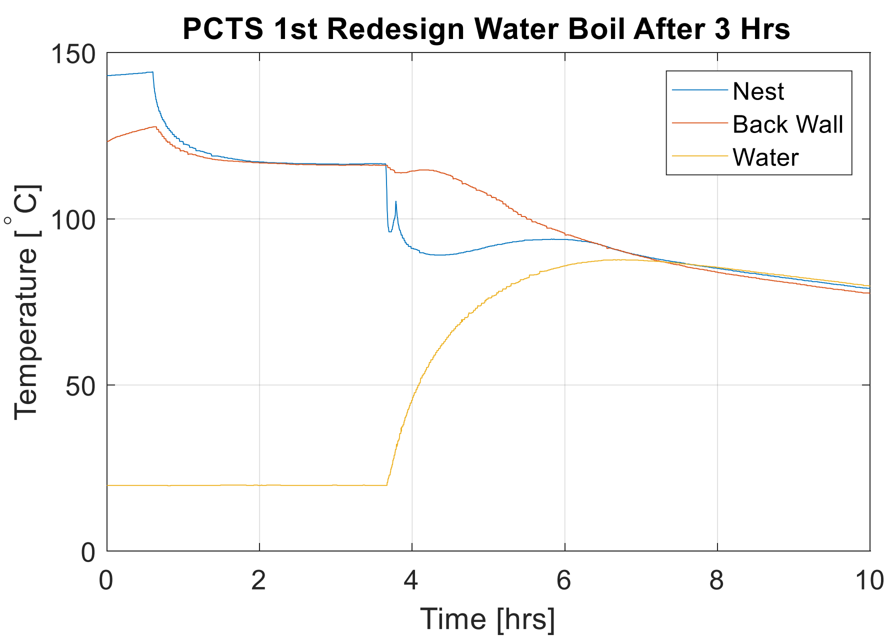

Figure 12. Thermocouple data for water boil attempt after melted PCM had been left without power for 3+ hrs. Thermocouples were placed in the PCM against the nest, in the PCM against the back wall of the PCM container, and in the water. This cooker had 2.6 kg of erythritol.

However, the PCM that was closer to the back wall of the erythritol container was still melted. This graph demonstrates the problem we have of the non-uniform cooling of the erythritol reducing our power into the food. The erythritol closest to the food solidifies first, acting as a thermal barrier for heat from the still-molten erythritol. This is what lead us to mixing aluminum shavings into our erythritol container to increase thermal conductivity in the erythritol.

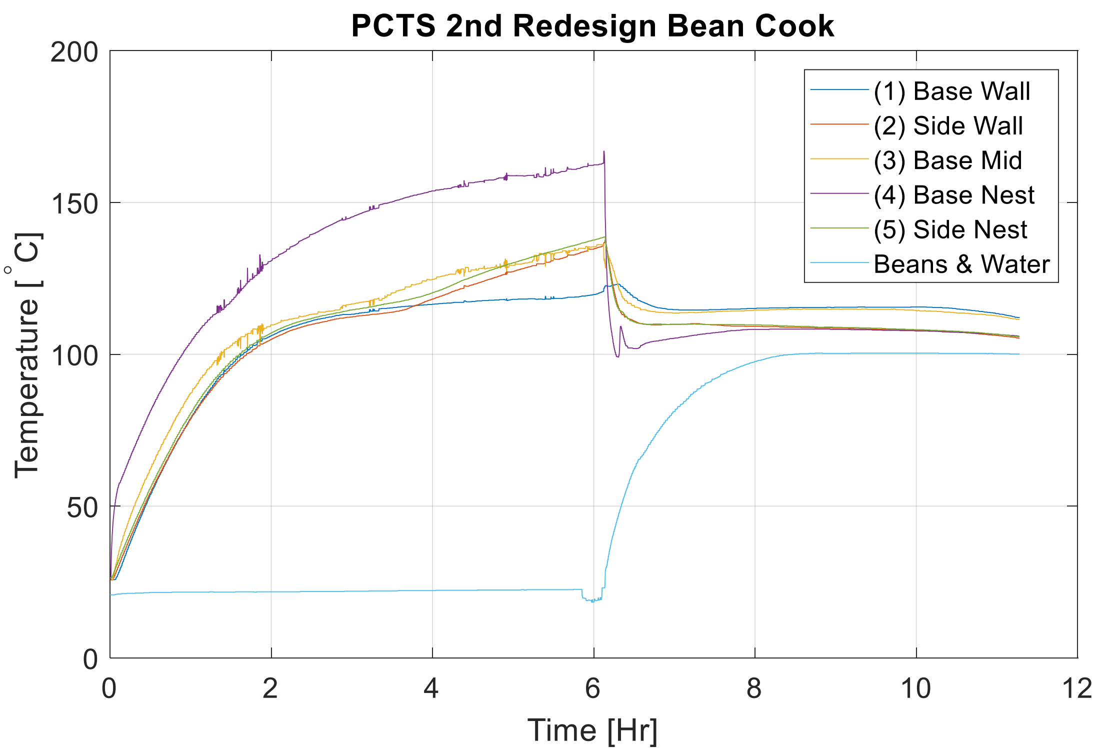

Figure 13. Thermocouple data for kidney bean cook attempt with the 2nd redesign of the PCA. The numbers in the legend refer to thermocouple locations depicted in Fig. 9. The cooker had 2.6 kg of erythritol and 0.5 kg of aluminum shavings. Power to the cooker was turned off as the beans were placed in the cooker.

Fig. 13 shows an attempt at cooking beans with aluminum shavings added to the PCM in the PCA (2nd redesign). We have run several tests with and without shavings. Preliminary results indicate that adding about .5 kg of aluminum shavings to about 2.6 kg of PCM reduces the temperature difference across the PCM from about 30 ºC to about 15 ºC.

While we have not demonstrated successful cooking after power has been off for a few hours, we are confident that the addition of Aluminum and the insulation improvements we've made will allow this.

3) Can it successfully cook beans?

Fig. 13 shows our attempt to cook about 1.3 kg of kidney beans and water. This cooker has 2.6 kg of erythritol. Power to the cooker was turned off as the beans were placed in the cooker. The boiling sustained for multiple hours and continued after the experiment ended. The beans were quite overcooked, as we wanted to see how long it would continue.

Design challenges

There are several different challenges we've encountered while designing the PCTS cookers:

- Ease of use – the initial design was difficult to use because the erythritol (which was inside the walls of the cookpot) was being added/removed from the diode nest. This made it heavy, difficult to remove food from, more likely to burn people, and would cause heat to be lost each time the pot was removed. This was successfully improved by our switch from the initial design to the first redesign, where now a normal cookpot filled with food is added/removed for each use and the erythritol stays in the PCA.
- Thermal conductivity was improved with aluminum shavings.
- Erythritol leaks – the molten erythritol will often leak out of its container into the nest, sometimes in significant amounts. We will need to achieve a consistent seal for the final design.
- Insulation – We are experimenting with different insulation strategies including spray foam. Many of our designs have been adequate, but we are not yet poised to make recommendations on optimal designs.

Resistive Heating

While moving forward with improvements in diode heating and voltage control, one present senior project at Cal Poly explores our original design using resistive heating. We are collaborating with Paul Routley in the UK. He is working on resistive solar heating and has sent us his Power Optimization Device to begin working with, which optimizes power out of the solar panel and has a female USB port for charging.

Planned Activities

- Successfully cook when power to the cooker has been off for a few hours.
- Test limits of food cooking. What is the maximum amount of beans we can cook with how much molten erythritol, for instance?
- More cooking with actual solar panels. Due to lack of sun, we have been using power sources to mimic solar panel output. We want to do more cooking with panels to establish operation expectations under real circumstances.
- Exterior design testing. We will continue developing designs for the cooker and insulation that are effective and realistic for Ghana.
- Implementing a temperature display in order to determine when a cooker is ready to cook with. We presently use thermocouples, but we plan to deploy a visual display.