MECS Final Project Report (public)

Project Name: Thermal Storage with Phase Change Materials

Organization Name: California Polytechnic State University, San Luis Obispo

Produced by: Dr. Pete Schwartz

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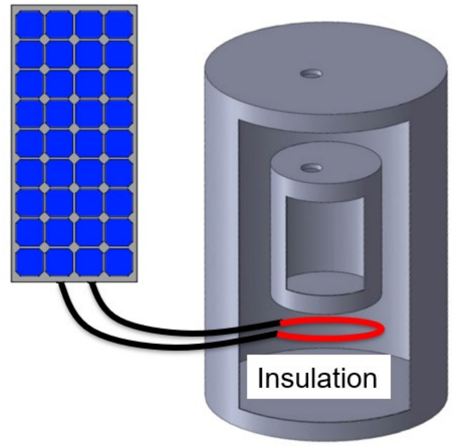
Our research website (http://sharedcurriculum.peteschwartz.net/solar-electric-cooking/) provides links to construction manuals, our published research, and videos.

Acronyms:
ASEI: African STEM Education Initiative, Uganda
ISEC: Insulated Solar Electric Cooking (or Cooker)
LEF: Living Energy Farm: Eco Community in Virginia where they directly use DC solar electricity
MECS: Modern Energy Cooking Services (UK Aid)
NiCr: Nichol Chromium, resistive wire for electric heaters
PCM: Phase Change Material, erythritol or nitrate salts
STS: Solid Thermal Storage, usually aluminium

Executive summary

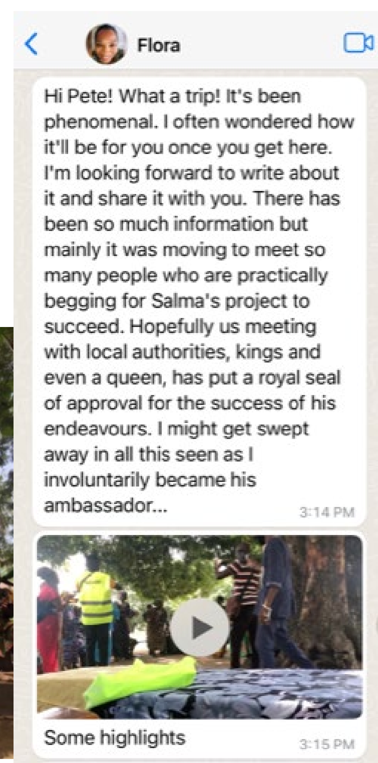


Insulated Solar Electric Cooker (ISEC) is a solar panel directly connected to a heater inside an insulated chamber. ISEC overcomes adoption barriers of traditional solar cooking because it allows cooking in the privacy of the home without reorienting with the shifting sun. ISEC is also inexpensive: 100 W solar panels are sold in Africa and India for $25 - $50. 100 W brings one liter of water to a boil in an hour, so a full day of sun cooks a 5 kg meal. The low-power solar panel is inexpensive but requires insulation for the food to get hot enough to cook.

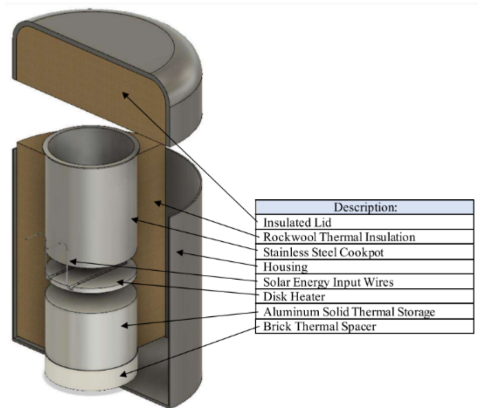
Additional Variations include:
- Ability to connect to grid electricity. The insulation reduces electricity costs.
- Energy storage to provide additional power and the ability to cook after dark.
- Electricity access for other appliances such as cell phone and lights.

Local Production of ISECs by small enterprises stimulates local economy while promoting education and technological innovation. Manufacturing proximity can better provide product support, accommodate local preferences, and take advantage of locally available resources.

Half the MECS funding was used at Cal Poly to innovate technological improvements while the other half subsidized local enterprises (called *collaborators*) mostly in Africa, to build manufacturing capacity. The ~$100,000 MECS grant was matched by more than $100,000 in university research support, and engagement of ~200 students over the 2 ½ year funding period. In the process, we created a living, global learning community of students, collaborators and enthusiasts with weekly online meetings, that continues growing with new opportunities, challenges, and additional members. As an example, while visiting a collaborating EcoVillage in Jamaica, PI Pete Schwartz and his daughter, Tekuru, met Flora, a Nigerian educator. Flora subsequently spent 10 days with collaborator Salma in Togo. Pete will spend the coming year on sabbatical, visiting collaborators.

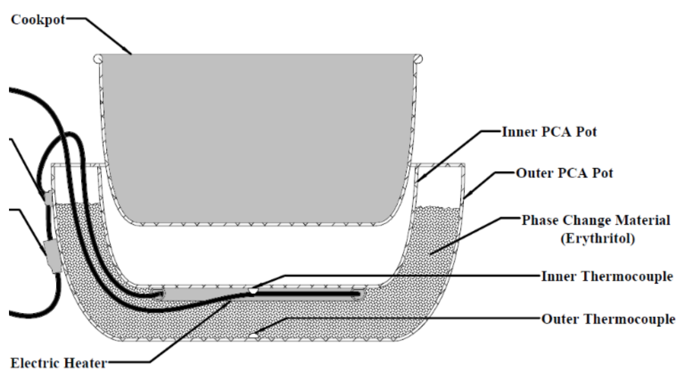


Energy Storage
While 100 W can cook a meal for a family during the day, people want more power and the ability to cook after the sun goes down. Our research focus has been to develop thermal storage capacity by two methods: heating a piece of metal, and by melting a phase change material (PCM). Each innovation is tested extensively, usually in Schwartz's kitchen (for example: https://www.youtube.com/watch?v=Y_5qlXdULQY)



Solid Thermal Storage (STS) A large cylinder of aluminum can store the daily energy output of the solar panel. When placed in contact with a cookpot, the food heats up with about 1000 W of power. The disk heater between the cookpot and STS can be raised so that only the cookpot is being heated.

Phase Change Material (PCM) is confined between two concentric pots, so that food is cooked in the inner pot, see for example: https://www.youtube.com/watch?v=vK-XyyHJaX4 , a video featuring Martin, who met us in Ghana and subsequently came to the USA, wrote his master's thesis on ISEC, and lived two summers with Pete. We have used three different PCMs: two sugar-alcohols (erythritol and xylitol) and a mixture of nitrate salts. The higher melting temperature of the nitrate salts (220°C – 300°C), means they perform better but have more demanding material requirements.



Important Lessons
- Providing freedom and support to collaborators resulted in unexpected diversity of technology innovations, education outreach, development of business models, and community engagement.
- Sourcing materials is challenging, in particular solar panels and inflammable insulation such as fiberglass. What began as a technology project, has shifted to business and societal.
- ISEC inherently involves rural electrification. People are very interested to have access to other electricity applications such as charging batteries and pumping water.
- PCM thermal storage is powerful and convenient because heat is not conducted to the PCM until the cookpot is hotter than the PCM melting point.
- Hot wires and wire junctions often corrode over the course of a few months.
- Heat flow across the solid-solid interface limits power flow. Surface smoothness is crucial

We seek funding for continued support of the Global Learning Community

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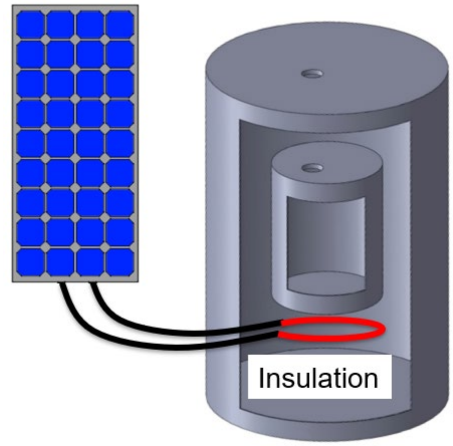
1. Introduction



In 2015, we introduced Insulated Solar Electric Cooking (ISEC) whereby a solar panel is directly connected to an insulated, electrically heated cookpot.[1] In 2018, we explored diode heaters rather than resistive heaters because diode heaters more effectively couple power from a solar panel under a wide range of solar intensities.[2] Typically, we use a 100 W solar panel, capable of heating 5 kg of food to boiling during the course of the day. Answering the demand for more power and/or to cook in the evening after the sun has set, we developed phase-change thermal storage capability using Erythritol,[3] Nitrate Salts, and Xylitol. These materials melt, storing thermal energy throughout the day, allowing the user to cook at night. The cookers can deposit much of this energy in a short period of time after external power has been disconnected, providing power much greater than 100 W. With the decreasing cost trends of solar panels, a 100 W panel can be purchased for as low as $25, making ISEC an affordable and attractive solution for modern clean cooking.

Variations and Options: Since 2015, ISEC has diversified into a family of cooking technologies with many different options that are categorized below.

Power Sources: While the first ISECs were powered by 100W solar panels, any electrical source will work. Many collaborators are using higher power solar panel installations, which is expected with continued decrease of solar panel cost and increased global wealth. Most ISECs are now higher power than 100W and Collaborator LEF has one that is 1400 W. ISEC can also be grid-powered, where insulation simply reduces electricity expenditure. A hybrid solar panel / grid ISEC can be made by adding a used DC computer charger in parallel with the solar panel to use solar electricity when it is available, while paying for grid electricity only in the absence of sunny weather. The voltage of the DC power source must be lower than the MPPT voltage of the solar panel (usually 18 V), otherwise it can drive current backwards through the solar panel. Additionally, care should be taken that the ISEC not exceed the maximum current of the power source.

Configurations: The first cylindrical "pot in an insulated trashcan" ISEC configuration is ideal for cooking stews and frying. LEF has introduced a stainless-steel oven ISEC that costs more and has lower insulation but is more versatile and easier to use. Additionally, ISECs can be installed or moveable, and the cook pot can be removed, or stationary. For instance, the thermal storage ISEC displayed in Fig. 1 has a removeable cookpot for convenience. However, the removeable cookpot was rarely used because directly cooking in the phase change assembly

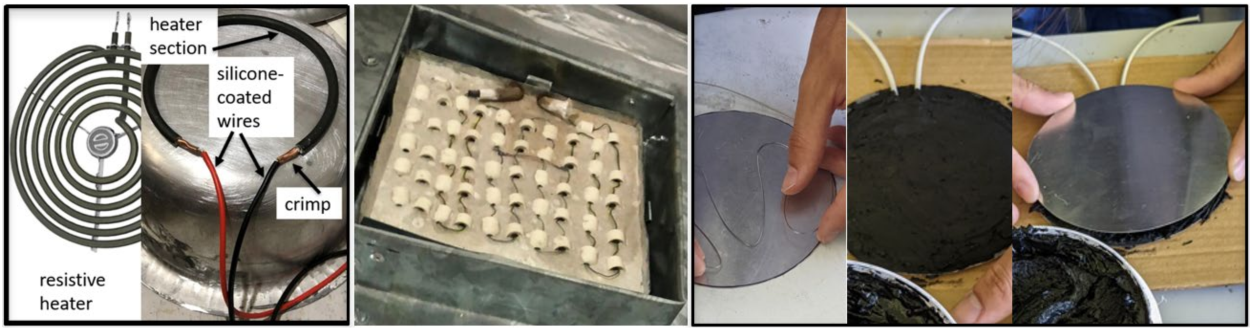
[1] *Development Engineering* 2 (2017) 47–52, https://doi.org/10.1016/j.deveng.2017.01.001
[2] *Development Engineering*, 4 (2019) 100044, https://doi.org/10.1016/j.deveng.2019.100044
[3] *J. Solar Energy*, 220, 2021, 1065-1073, https://doi.org/10.1016/j.solener.2021.03.040

(PCA) provided greater power, even though cooking in the PCA requires the user to clean the stationary PCA inside the ISEC container. Electric pressure cookers (EPC) are an energy efficient way to cook, and low-voltage DC EPCs are being insulated and distributed with solar panels, most notably in Malawi by collaborator Van Buskirk.

(left) Cylindrical ISEC with thermal storage,[3] (middle) Salma's direct connect ISEC, (right) LEF oven ISEC.

Insulation: Inflammable insulation is surprisingly difficult to purchase in Africa. Fiberglass and Rockwool do not seem to be available. We don't recommend cotton because it has a low combustion temperature (~120°C) and can catch fire, although wool (being used by collaborator Bidjanga) has a higher combustion temperature of ~570°C. Perlite and vermiculite are both naturally occurring high temperature insulators that are also uncompressible, so it won't be deformed by the weight of a heavy cookpot. Thus, perlite is often placed under the cookpot. Collaborator ASEI is developing an insulating concrete by mixing vermiculite with a small amount of cement. We have experimented with stainless steel double wall vacuum insulated food containers, and found the inexpensive one (Stanley Camp Crock) with plastic parts to poorly insulate and melt at high temperatures, while an all stainless steel, more expensive container insulated better.

Heaters: We have used three categories of heaters: resistors, diodes, and positive thermal coefficient (PTC) thermistors. The most frequent ISEC failure comes through corrosion where the power cable is attached to the heater wire. LEF is presently exploring spotwelding the NiCr wire to steel, which is the industry standard.
Resistive heaters can be made by connecting commercially available ceramic resistors and can be made from nichrome (NiCr) wire in a variety of ways. LEF makes radiant heaters for their ovens by securing NiCr wire on the surface of a concrete pad, and we have made heaters by cementing NiCr wire in furnace cement between two sheets of aluminum. Heaters can be made from sections of electric range heating elements, and we have also purchased immersion heaters to immerse in PCM.

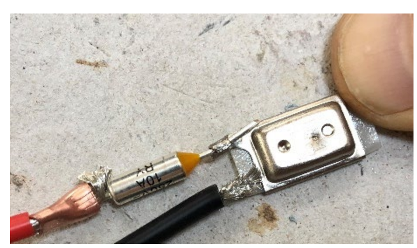


Resistive heaters can be made (from left) by cutting a section of an electrical cooking element and crimping the inner NiCr wire to power leads with copper tubing, threading NiCr wire through ceramic beads, and by sealing NiCr wire in furnace cement between aluminum sheets.

Diode heaters more effectively couple power from the solar panel because diodes, like solar panels, operate at constant voltage.[2] However, this improvement is small, and can also be achieved by means of modulating the voltage with a buck convertor. We have returned to using resistive heaters for several reasons including temperature resistance and ease of assembly.[3] Van Buskirk still uses diodes as well as resistor/diode combinations.
PTCs are temperature-dependent resistors that abruptly increase in resistance at a predicted temperature, essentially cutting off the power obviating the need for temperature control. Low-transition temperature PTCs are typically used to heat batteries and car seats. Our PTCs transition at ~220°C.

Storage allows the user to cook after sundown as well as deliver power flow to the food that is much higher than that provided by the solar panels. Batteries can hold their charge for many days without loss and also deliver high power, making them the most desirable. Batteries are expensive, but continue to decrease in price, making them the clear favorite maybe 10 years in the future. Thermal energy can be stored by heating up a piece of metal (solid thermal storage, STS), or melting a phase change material (PCM). We explored these methods and explain more later.

Temperature control is necessary to prevent overheating that can start fires. Because AC current passes through zero 240 times per second, inductive arcing is short-lived, making AC easier to interrupt than DC current. Most thermostatic switches are made for AC, and DC uses can quickly destroy the contacts, so care must be taken in choosing a thermostatic switch. We usually make use of a DC bimetallic switch that opens at 180°C and a thermal fuse that irreversibly "blows" at a higher temperature. PTC thermistors require no temperature protection, and Alexis uses timers to turn off their ISEC ovens rather than monitor temperature.


From left to right: Red power cable to copper tube clamp to thermal fuse to thermal switch.

Aims of the Project

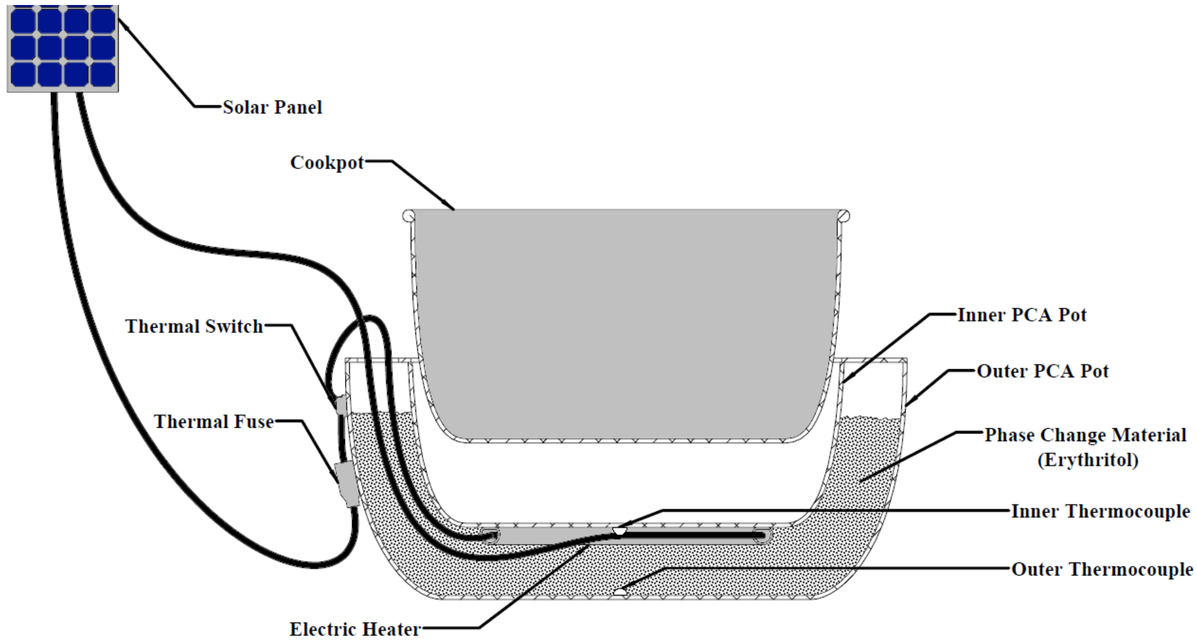
The aims of the project are to improve the design, support creation of manufacturing capacity of collaborators in Low Income Communities (LIC), in Africa, India, and the Caribbean where we anticipate dissemination, collaboratively disseminate the technology, and study the technology adoption process. Our dissemination model is to support local enterprises in constructing and innovating ISEC products for local sale. The MECS grant is leveraged by more than $100,000 in university research support (primarily by the William and Linda Frost Fund) and student participation in service-learning classes,[4] student research, and senior project classes together engaging about 200 students over the 1½ year grant period.

Objectives of the Project

- ➢ Improve design of ISEC with and without thermal storage.
- ➢ Financially and technically support international collaborators to build ISEC manufacturing capacity.
- ➢ Engage with collaborators to develop an ISEC that fits their needs.
- ➢ Study community adoption of the technology

[4] http://appropriatetechnology.peteschwartz.net/about-us/

2. Approach



The ISEC with phase change assembly made from cementing two pots concentrically.[3]

Cal Poly research students worked on technical advancements in a variety of areas including heater design, phase change materials, solid thermal storage, insulation, and overall design. We engage approximately six research students for 10 weeks in summer (2020, 2021, 2022) internally funded with $25,000 - $30,000 annually,[5] and between three and eight year-long capstone senior projects during each academic year. Additionally, our collaborators also make significant technical advancements. The International Learning Community meets for an hour every week (Thursday 10 AM, California time) to share ideas and lessons learned. We also provide information on our research website, the ISEC forum, and through Email and WhatsApp correspondence.

Concept

Using existing technologies, ISEC (Insulated Solar Electric Cooking) provides an inexpensive and simple way to cook with a solar panel at extremely high efficiency. Our MECS funding is to improve, refine, and disseminate thermal storage 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 time. Thermal Storage capacity could be used with grid electricity and other energy sources as well as with solar electricity. Electrical power itself is a

[5] We acknowledge The William and Linda Frost Fund supporting Frost Research Fellows (Students), providing faculty summer salary, and funding some materials.

high-demand feature for many of the global poor, to be used for a variety of purposes including lighting, cell phone charging, and pumping water.

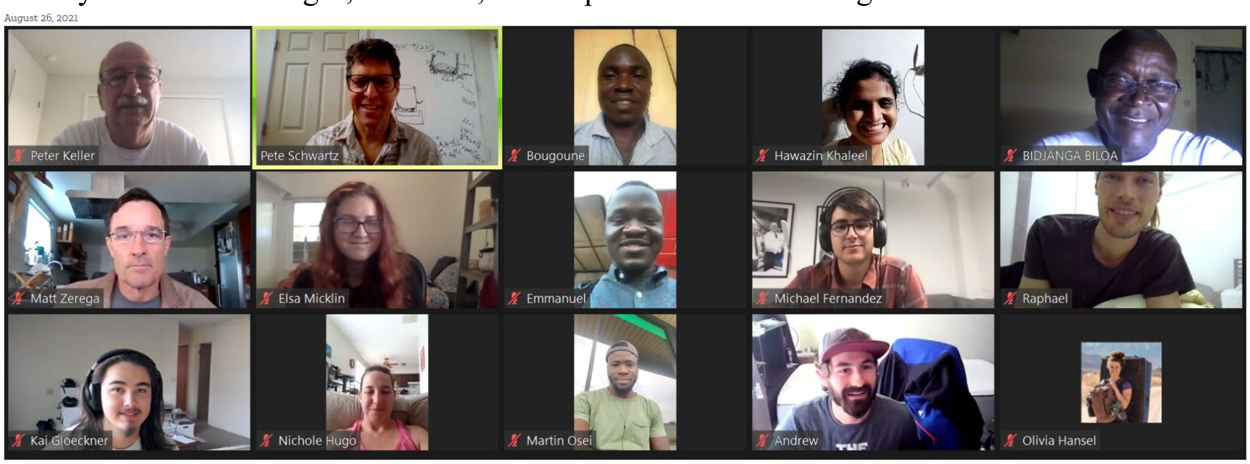
Rather than taking advantage of economies of scale in a large factory, we chose to support small enterprises in the same LIC targeted for distribution, providing the following benefits:

1) Supporting the local economies.
2) Providing motivation and means for local technological innovation.
3) Improving product support.
4) Gaining a diversity of ideas and strategies from enterprises in a variety of cultures, with access to different technologies and materials.

3. Presentation of Results

The Global Learning Community

We welcomed into our project anyone who expressed an interest. Collaborators have been welcomed into the appropriate technology classes[4] (facilitated by the pandemic's necessity of holding classes virtually), often giving presentations about their projects; and we still meet weekly to share challenges, solutions, and inspiration. One meeting is shown below.



Collaborators contacted Pete at one point, having learned about ISEC: from friends, via our website, Facebook, and/or YouTube. Collaborators received Stage I funding ($1000) after filling out an application verifying capability of manufacturing ISECs, and Stage II funding ($4000) after implementing manufactured ISECs and applying to scale up manufacturing.

Two lessons from the learning community mentioned in the executive summary are the diverse growth of projects resulting from the free exchange of ideas and the shift from purely technological to include business and societal topics. A few examples are provided below.

Martin Osei joined the Cal Poly ISEC team in August 2019 and built Ghana's first PCM ISEC. Martin started SolCook Ghana, LLC in October, but turned the company over to Emmanuel in December as Martin prepared to enroll in Eastern Illinois University's (EIU) engineering graduate school, writing his master's thesis on ISEC,[6] with partial support from the MECS grant. Martin's advisor at EIU was Nichole Hugo, specializing in Hospitality and Tourism as well as Sustainability, providing needed cultural insight. Martin lived with Pete in California summers 2020 and 2021. Cal Poly laboratories closed in March of 2020 due to the pandemic and our laboratory moved into Pete's garage. Martin graduated this past spring but continues to conduct experiments and facilitate communication with collaborators.

Martin Osei: (left) creates ISECs in Agbokpa Village, Ghana; (Middle) Father's Day, 2020 Pismo Beach, California; (Right) collecting data in our quarantine garage ISEC laboratory, San Luis Obispo, California.

Hawazin's efforts documented on group website

Hawazin from Kerala India contacted Pete in March 2020 expressing an interest to learn about sustainability and ISEC. She joined nearly all the appropriate technology classes that spring with her toddler on Zoom, and we watch the sun rise behind her twice a week as the class ended at 5:30 PM. Without a shop, the student projects were supported out of Pete's garage. Hawazin joined the ISEC project group (https://gcastr09.wixsite.com/calpolyisec) and together they built ISECs in San Luis Obispo and India. Hawazin has subsequently worked with several Cal Poly student projects. By spring 2021, there were many ISEC collaborators, many of whom worked with one of the eight ISEC project groups in an enormous spring 2021 appropriate technology class (https://canvas.calpoly.edu/courses/49543).

Alexis Zeigler's focus is on directly using solar electricity for all the needs of his community, Living Energy Farm (LEF), as a proof of concept that direct use solar is inexpensive enough to be accessible to all people. Small battery capacity supports only lights and computers at night. He contacted me to inform me that ISEC is great, but that we were building them all wrong. Alexis uses materials and processes that are readily available where he works in Jamaica. His construction manual has also been posted on the research website with links to his videos and increasingly inform other collaborators.

[6] Development of Phase Change Thermal Storage Medium: Cooking with More Power and Versatility, 2022. https://thekeep.eiu.edu/cgi/viewcontent.cgi?article=5932&context=theses

Robert Van Buskirk has become a valued source of technological and business information. He published the 2019 “Hot Diodes” paper[2] with us. Robert has been inexpensively importing materials by the shipping container from China to Malawi. Robert recently joined the Global Learning Community because his interest to support solar electrification with subsidized shipments of solar electric goods perfectly matched collaborator need to receive these items. This past month, collaborator Salma received a shipment of subsidized 100 solar panels each of 200 W, as a proof of concept, stating “words cannot express what I’m feeling”. The next shipment will be solar water pumps for irrigation.

Salma has been particularly active, holding workshops for new potential collaborators from Togo, Ethiopia, Congo, and Nigeria. He hosted Flora from Nigeria, and introduced us to Rismah, a Liberian entrepreneur running Afrik’Energy Connect (https://afrikenergy.org/) with Fatou, who lives in the US.

Alexis Zeigler has been working with communities in Jamaica and the Navajo and Hopi Nations. He has recently received a donation for $80,000 and has begun working with activists and communities in Puerto Rico to build resilient DC solar electric minigrids. Alexis is hosting and funding two direct DC workshops at LEF in July and August, each two weeks long. Fatou is attending one of these workshops, and Pete is attending one as both a student and instructor.

The Source Farm is an EcoVillage in East Jamaica committed to supporting food-growing on the jungle-covered island that still imports 70% of its food, mostly from the USA. Because of the high cost of electricity, they are working with Alexis Zeigler to develop direct DC solar electricity for domestic use and food processing. In December of 2021, The Source Farm received a $5000 shipment of solar panels funded mostly by our grant. Pete and his daughter, Tekuru spent Thanksgiving week of 2021 at the Source farm learning about their goals and lifestyle while helping establish their use of DC electricity, ISEC production and implementation, food processing, and environmental efforts. During this time, Pete constructed and repaired DC appliances including ISECs, studied the use of direct DC electricity, and presented at the University of the West Indies and at a food-processing workshop.

With The Source Farm, Jamaica: (left) Layla innovating a pulley to lift an ISEC that wasn't being used because it was too hard to lift; (middle) presenting at University of the West Indies Engineering; and (right) a meeting of farmers and academics at the GWG food processing center.

Collaborators could be awarded three stages of funding by meeting each stage’s requirements.

Stage I funding (US $1,000) was received by:

- Emmanuel Osei Amoafo from SolCook in Ghana, Africa
- Salma Bougoune from Togo, Africa
- Mark Manary from Project Peanut Butter, Sierra Leone, Africa
- Hawazin Khaleel from Karala, India
- Deepak Ghadia from Gujarat, India
- Chris Musasizi from Uganda, Africa
- Bidjanga Zach from Cameroon, Africa
- Andrew Mayanja and Alicwamu Moses from ASEI Uganda, Africa
- Alexis Zeigler, Living Energy Farms, Virginia, U.S. & Jamaica, Caribbean
- Crosby Menzies from Sunfire in South Africa

Stage II funding (US $4,000) was received by:

- Emmanuel Osei Amoafo from SolCook in Ghana, Africa
- Salma Bougoune from Togo, Africa
- Bidjanga Zach from Cameroon, Africa
- Andrew Mayanja and Alicwamu Moses from ASEI Uganda, Africa
- Alexis Zeigler from Living Energy Farm (LEF) in Virginia, U.S.

We have awarded Stage III funding (US$5,000) to one collaborator, Bidjanga Zach from Cameroon. He has made tremendous strides in ISEC dissemination and education, via weekly workshops among his local community and universities. More of his progress is described in the collaborator progress section below.

Collaborator Progress

In total, we estimate than 241 ISECs have been constructed by collaborators and 83 are in use. More ISECs have been constructed by unsupported collaborators such as Robert Van Buskirk but are not counted in this number.

Total ISECs Constructed: 241
Total ISECs in Use: 83

Cal Poly Research Laboratory and Classes

Number of ISECs made	65	25 class projects, 40 senior projects and lab research
Number of ISECs in use	4-10	Some have been given away and may be in use
Materials	variety	
Type of heater	~40 Resistive NiCr ~20 Diode Chain 3 PTC Thermistor	NiCr radiant on concrete, NiCr in furnace cement between Al sheets, commercial electrical stovetop burners, homemade immersion heaters
Connection of heater	radiant, glue, direct contact, PCM	Difficulty at NiCr/copper power junction.
Size of PV panel	100 W – 425 W	
Insulating material	variety	Fiberglass, Rockwool, Perlite, Vermiculite, double wall SS,
Direct drive	Yes, most of them	
Phase change material	6 Erythritol 3 Nitrate Salts 2 Aluminum STS	
Battery	1	0.120 kWh Lead/Acid
Grid-connected Power	2	DC computer charger draws no current when sunny

Eastern Illinois University
Martin Osei, Nichole Hugo

Number of ISECs made	6	Experimental, but are used to cook meals
Number of ISECs in use	5	Used in homes and lab
Size of Pots	Diameter: 20”-24”	20 cm inner pot can hold up to 3 liters of water
Type of heater	Resistive (NiCr)	
Material of Pot	Aluminium	
Size of PV panel	100 W – 150 W	
Insulating material	Fiberglass	
Direct drive	1	
Phase change material	4 Erythritol 1 Nitrate Salts	
Battery	no	

Alexis Zeigler, Living Energy Farm, Virginia, Jamaica, Puerto Rico
https://livingenergyfarm.org/insulated-solar-electric-cooker/


Number of ISECs made	60	Most are experimental
Number of ISECs in use	18	3 at Living Energy Farm 1 at Little Flower Community 11 in Jamaica
Cost	$40 for bucket ISEC $95 Galvanized oven $143 SS oven	Simple bucket ISEC above left, oven above right
Materials	Sheet Steel, SS	
Type of heater	Resistive NiCr	Exposed NiCr wire on concrete base, or section of commercial electrical stovetop burners
Connection of heater	Free standing	Difficulty at NiCr/copper power junction. May start spotwelding.
Size of PV panel	100 W – 1400 W	Ovens are typically 300 W
Insulating material	Rockwool	Some early models used Perlite
Direct drive	yes	
Phase change material	No	
Battery	No	


Oven ISEC, radiant heater

Living Energy Farm (LEF) is an off-grid community of about a dozen people relying solely on sustainable technologies and cooking mostly with ISEC. They have many different design variations of the ISEC, which they use year-around. They have finalized two designs: the Pearl Cooker (for perlite insulation) and the Roxy Oven (for rockwool insulation). Additionally, LEF is pioneering Direct DC Technologies, or "Daylight Drive" or "Direct Drive," where the majority of solar electricity is used during the day, requiring very small battery capacity for nighttime activities. LEF is teaching about and developing manufacturing capacity around Daylight Drive in nonindustrial communities where the reduction in cost is a game changer. Alexis and other LEF community members have spent a considerable time in Jamaica, at The Source Farm EcoVillage with corresponding nonprofit Living Energy Solutions (LES). Additionally, the Source Farm holds educational programs about the benefits of ISEC and Direct DC Solar technologies, especially for processing locally grown food. Similarly, LEF plans to collaborate with the Navajo and Hopi Nations in Arizona where they have previously established relations as well as with permaculture centers and activists in Puerto Rico. Unique ISEC designs from Alexis are documented in videos and a construction manual available on our research website.[7] In July and August, 2022, Alexis is holding two 2-week workshops at LEF on Direct DC Solar.

LEF has spent their stage II funding on materials for Jamaica, in particular $5000 for a large shipment of solar panels that arrived in Kingston in December of 2021.

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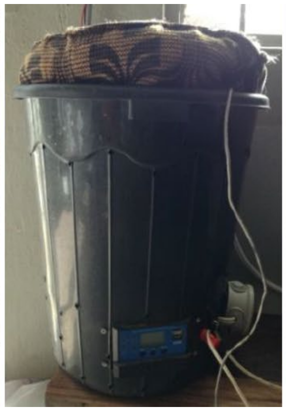
[7] http://sharedcurriculum.peteschwartz.net/solar-electric-cooking/

Salma Bougoune from Togo, Africa

Number of ISECs made	28	12 to be sold now that solar panels have arrived
Number of ISECs in use	9	4 in laboratory, 5 owned by customers
Cost		
Size of pot (liters)	7x2L,11x4.5L,10x7.5L	
Material of pot	Aluminium	Locally produced
Type of heater	Resistive	Locally available
Connection of heater	Glue	Not reliable. Glue peels off.
Size of PV panel	200W	
Insulating material	Fiberglass	
Direct drive	yes	
Phase change material	No	
Battery	yes	Option available for more money, picture above, right

Salma has been working on two new ISEC designs; one using a small cook pot with 200W with 10A/12V-24V charge controller and another using a larger pot with 300W-400W with a 20A/12V-24V charge controller. 15 small pot ISECs and 5 larger pot ISECs were built and have been tested. He is waiting for a $5,000 shipment of 100 subsidized (200 W) solar panels brokered by Robert Van Buskirk (Kuyere!, Kachione LLC), to disseminate the ISEC systems and other DC solar electric technologies.

Hawazin Khaleel, Karala, India

Number of ISECs made	5	
Number of ISECs in use	3	2 have been disseminated to users. However, they don't seem to use that often from latest feedback, as they are looking for options with more power and minimal cost.
Cost	US$ 36	100 W Solar Panel: US$42
Size of pot (liters)	1-2	
Material of pot	Stainless Steel	
Type of heater	Resistive	
Connection of heater	Concrete	
Size of PV panel	100W	

Insulating material	Fiberglass	
Direct drive	yes	With added DC adapter connected for grid use.
Phase change material	Not yet	
Battery	No	

Hawazin constructed and disseminated 5 ISECs to her community. She continues to build an ISEC with thermal storage with erythritol PCM. She has spent her portion of the funding on the equipment and materials and is continuing to build new designs suitable for her community. She is also seeking new collaborations to help with production and dissemination and plans to collaborate with a student group at her local University.

ISEC, resistive heater of NiCr wire through ceramic beads

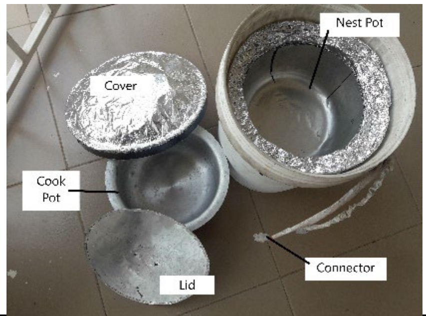
<u>Musasizi Chris, Uganda</u>

Number of ISECs made	5	
Number of ISECs in use	4	
Material of pot	- Aluminium	
Type of heater	- Resistive	
Connection of heater	- Riveting - Glue	
Size of PV panel	- 3 x 125W - 2 x 100W	
Insulating material	- Woollen cloths - Vermiculite	
Directive drive	Yes	
Phase change material	No	
Battery	No	

Fig. 5 Chris meets with Peter and Irene Keller from AID Africa

Africa Stem Education Initiative, Uganda

Model I



Number of ISECs made	4	
Number of ISECs in use	4	Used during 2-month pilot period
Cost	US$ 55	2x100W Solar panel: US$166
Size of pot (liters)	7	
Material of pot	Aluminium	
Type of heater	Resistive	
Connection of heater	Glue	
Size of PV panel	2x100W	
Insulating material	Fiberglass	
Direct drive	yes	
Phase change material	No	
Battery	No	

Model II

From left: recycled plastic housing, cook pot, heater plate, welded heating element under plate

Number of ISECs made	1	
Number of ISECs in use	1	
Size of pot (liters)	5	
Material of pot	Aluminium	Outer housing made with recycled plastic
Type of heater	Resistive	
Connection of heater	Aluminum & Glue	90% of the heater attached with melted aluminum, wire ends connected with JB weld
Size of PV panel	2x100W	
Insulating material	vermiculite	
Direct drive	yes	
Phase change material	No	
Battery	yes	Operates with or without battery

Model III

Number of ISECs made	2	
Number of ISECs in use	2	
Size of pot (liters)	5	
Material of pot	Aluminium	
Type of heater	Resistive	
Connection of heater	Aluminum & Glue	90% of the heater attached with melted aluminum, wire ends connected with JB weld
Size of PV panel	2x100W	
Insulating material	vermiculite	
Direct drive	yes	
Phase change material	No	
Battery	yes	Operates with or without battery

Rigid, insulating vermiculite concrete

Andrew and Moses have made impressive progress in a short amount of time, receiving Stage I funding in January 2022. They work with African STEM Education Initiative (ASEI), a non-profit aimed to increase capacity for innovation in Uganda through STEM projects, involving communities, especially the youth, in project-based learning. ISEC is their newest project to develop and introduce to their community. They have built and disseminated eight working ISECs. They are developing vermiculite concrete, a rigid insulator by mixing locally available vermiculite with cement.

Takataka Plastics, Uganda, produces personalized products from recycled plastics. ASEI has designed a outer housing for the ISEC using recycled HDPE (High Density Polyethylene). ASEI will likely partner with NGO Aid Africa (Gulu, Uganda), who has connections to communities, marketing experience, and access to funds.

Emmanuel, SolCook, Ghana

Number of ISECs made	14	Experimental, but also used for cooking meals
Number of ISECs in use	12	10 in Kojo-Nkwnata, 2 in Kumasi
Size of pot (liters)	3 L	
Material of pot	Aluminium	Locally produced
Type of heater	Resistive & Diodes	
Connection of heater	Glue	Not reliable. Glue peels off.
Size of PV panel	150 W	
Insulating material	Blanket, Cotton Wool	
Direct drive	11	
Phase change material	3 with Erythritol	
Battery	no	

Emmanuel has used his funding in materials and equipment to construct direct-connect, as well as erythritol PCM ISECs, for distribution in local communities. He is working with Fred Akuffo, a professor emeritus at KNUST in Kumasi, who is now dedicated to a solar electric company and is conducting market research with the ISEC. Emmanuel is currently looking for additional partnerships in hopes of expanding manufacturing.

Fig. 9 Two ISECs with phase change material (erythritol) and wool insulation

Bidjanga, Cameroon

Number of ISECs made	56	22 in use now; 34 in stock with regional partners, waiting for potential buyers.
Number of ISECs in use	22	12 in use in the Far North Region; 7 in use in the South Region and 3 in use in our Workshop
Cost	US$ 40	100 W Solar Panel: US$ 61
Size of pot (liters)	3-4 liters	
Material of pot	Aluminium	
Type of heater	Resistive	NiCr wire
Connection of heater	Concrete	
Size of PV panel	100 W – 200 W	Also: 1 experimental prototype 48 V, 800 W
Insulating material	Wool	
Direct drive	Yes	
Phase change material	no	
Battery	2 ISECs	100 AH, $LiFePO_4$, 12.8V, 1.28 kWh, $US 280, charged with 600 W solar, MPPT 30 A controller

Bidjanga has constructed and disseminated over 50 ISECs in his community. He has taken a step further from product development to education, conducting a variety of ISEC training sessions, teaching high school and university students the technical background necessary for ISEC construction and cooking.

Bidjanga has been visiting primary and secondary schools teaching about solar power and ISEC as well as training secondary students. He is gathering new partners and plans to submit a letter to the government to train secondary students for futures in the solar industry. One of his workshops was covered by a university television crew (at right)

Bidjanga's ISEC university workshops, at right including Bidjanga (second from left).

Bidjanga hosts community and school workshops as well as holiday celebration events.

Traditional foods cooked with ISEC at Bidjanga's workshops and holiday events

Kuyere! workshop, Malawi.

<u>Robert Van Buskirk, Kuyere!, Malawi</u>

Robert does not receive collaborator funding from us, but like us, is an MECS funding recipient. He does most of his work in Malawi, Africa where he founded NGO Kuyere!, dedicated to rural distributed solar electrification with home solar electric systems including ISEC. He is importing container shipments of low-cost solar panels and other DC electrical appliances and sells them well below the local retail prices. Recently, he has extended this reduced cost importation opportunity to our collaborators as well, which has so far been taken up by Salma in Togo. Robert has introduced the Lithium-Titanate (LTO) Battery as a storage mechanism. LTO batteries are more expensive but have a longer lifespan, able to cycle close to ten times as much as regular lithium-ion batteries. Robert imports battery cells and has them assembled in Malawi.

Project Peanut Butter from Sierra Leone, Africa

Although the necessary parts were delivered to the Project Peanut Butter office in February 2021, they have not built an ISEC that we know of. Our communication with the people at the office is intermittent at best and we presume they have had difficulties with organization and communication among their team. They continue to stay in contact with us and give updates when they can, however the facility they planned for ISEC construction was repurposed for a food manufacturing facility.

We received no report from Crosby in South Africa, and Deepak in Gujarat, India.

Cal Poly Research

Several student groups work on independent research as well as year-long senior projects. We also have a group of five to six students conduct full-time research over summer through the funded Frost program at Cal Poly representing $25,000 - $30,000 per summer in 2020, 2021, and 2022. Some results are described below, and links to the projects can be found in the appendix.

Thermal Storage with Phase Change Materials (PCM): Sugar-Alcohols and Nitrate Salts

Our success with PCM thermal storage began in 2019 with an engineering group senior project[8] using erythritol a sugar-alcohol with a melting point of 118°C, ultimately resulting in our "Thermal Storage" publication.[3] The prototype was used daily and proved powerful and convenient but the erythritol degraded over the three-month period with daily cycling to 180°C, with a decrease in melting point to ~ 100°C and decrease in thermal storage capacity, although the ISEC was still functional. The longevity of erythritol can be improved by sealing the chamber under an inert atmosphere,[9] or encapsulation.[10] We subsequently made an ISEC using Xylitol as a PCM. While xylitol should not thermally degrade, its performance is less desirable than that of degraded erythritol.


Immersion heater fit to inner cookpot

A mixture of potassium and sodium nitrate salts is being developed as an ISEC PCM, largely informed by the information assembled in the PhD thesis of Matthew Alonso[11] while developing SunBuckets. The nitrate salt mixture should not degrade and the mixture we use (60% sodium, 40% potassium) melts from 220°C - 270°C. Our summer 2021

[8] Justin Unger, Nate Christler, Marcus Strutz, Matthew Weeman, June 2019 https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1542&context=mesp

[9] *Stability Study of Erythritol as Phase Change Material for Medium Temperature Thermal Applications*, 2021, Luna et al. *Appl. Sci.* **2021**, *11*(12), 5448 https://www.mdpi.com/2076-3417/11/12/5448

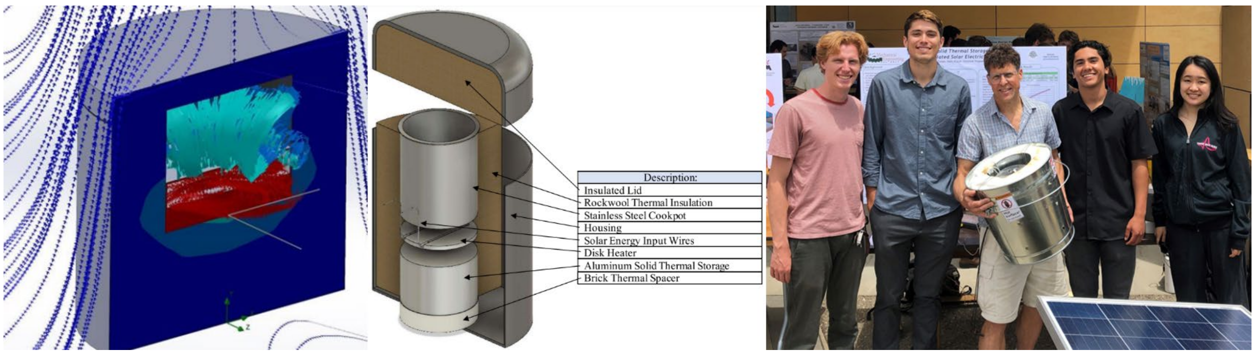
[10] *Supercooling suppression and thermal behavior improvement of erythritol as phase change material for thermal energy storage*, Wang et al., Solar Energy Materials and Solar Cells 171 (2017) 60–71; http://dx.doi.org/10.1016/j.solmat.2017.06.027

[11] *The development of a portable vessel for the collection, storage, and utilization of solar thermal energy for household use*, 2018, https://www.ideals.illinois.edu/items/107251

results indicate that these higher nitrate salts temperatures degraded the materials used for the erythritol ISEC. Subsequently, an engineering senior project group built an ISEC with nitrate PCM using commercially available immersion heaters[12] and we are continuing this research.

Solid Thermal Storage (STS) using Aluminium Puck.

Physics Major Michael Fernandez wrote a computer simulation of heat flows and transfers throughout the ISEC with an aluminium puck STS and tested it against an actual ISEC,[13] while a team of four mechanical engineering students designed and built an ISEC with an engageable aluminium STS.[14]



From left: SolidWorks Model Output,[8] ISEC with engageable aluminum STS,[9] Pete with ISEC and Project Group[9]

Although the thermal model was never sufficiently tuned to reproduce experimental data, its use provided considerable insight including:

- The solid-solid interface between the metal blocks presents great thermal impedance.
- The mass of the metal STS determines the amount of available thermal energy, and must consider the necessary cooking temperatures, insulation, and the amount of available power and charging time.

The ISEC with engageable STS was tested in Pete's house for two weeks with high performance and convenient functionality. It is presently being retrofitted with better insulation and for higher temperature capability.

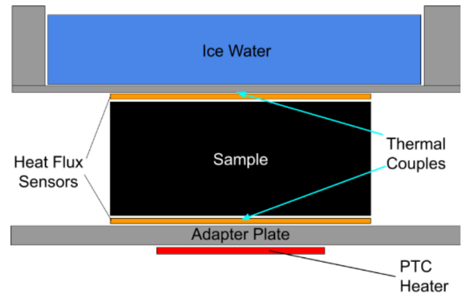
Table 4.8: Candidate thermal energy storage materials ranked by highest total energy density (TED) by weight when heated from 115 °C to the maximum operating temperature (boiling point or 401 °C).

	Operating Point [°C]	TED - Weight (kj/kg)	TED - Volume (MJ/m^3)
$MgCl_2$ KCl NaCl (37/20.5/42.5)	401	685	1232
$NaNO_3$	380	681	1540
$NaNO_3/KNO_3$ (60/40)	401	484	871
KNO_3	400	440	928
Aluminum	401	359	970

Aluminum has volumetric thermal density exceeding that of the nitrate salt mixture, *Alonso*[11]

[12] Weijun Zhao, Owen Chu, Jake Lung, Sarah Melzer, *Insulated Solar Electric Cooker with Phase Change Materials*, https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1739&context=mesp
[13] https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1233&context=physsp
[14] Eric Cortez, Dominick Trageser, Andrew McCombs, Nami Suzuki, June 2022 https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1747&context=mesp

Testing thermal conductivity of different Insulation Material



Measuring thermal conductivity of insulation

Michael Dalsin (funded by the William and Linda Frost Fund) designed and built an inexpensive thermal conductivity meter (<$1500, comparable to $30,000 for a purchased instrument) to investigate insulation materials.[15] The instrument uses a positive thermal coefficient (PTC) thermistor, an ice water bath, and two custom-made heat flux sensors. Insulation samples measured include pyrolyzed bread (carbon foam) as well as fire bricks. Fire bricks are made from a combination of clay and organic material such as sawdust. When the bricks are fired, the organic material burns away, leaving pores behind. We plan to quantify the thermal conductivity of the vermiculite concrete being developed in Uganda by ASEI.

Building and Testing

PTC heaters are being characterized and used as heaters in ISECs. The PTC heater is a self-regulating heater where the resistance of the heater increases with temperature abruptly by about a factor of 100 at a defined temperature (The PTC thermistors we purchased transition at 220ºC). thereby limiting ISEC temperature. To record and track PTC power, a microprocessor-controlled Arduino was built to record the PTC's activity. So far, we have shown that that the behavior of more than 10 PTCs are reproducible and consistent with each other. *work in progress*

Summer 2021, students built 12 Direct ISECs (without thermal storage) with available USB charging to share with anyone who wanted to use an ISEC.

To provide data for Robert Van Buskirk, a Lithium-Titanate (LTO) battery was tested under domestic cooking at Cal Poly's student experimental farm. The LTO battery has proven to have a decade-long lifespan, fast charging performance, and high resistance to a wide range of temperatures. It is currently being tested using two 100 W solar panels on an ISEC otherwise engaged for direct cooking. It is being directly compared to the quality of cooking done using a direct ISEC and 200W, to determine whether the additional battery storage is monetarily worth its investment.

[15] http://sharedcurriculum.peteschwartz.net/wp-content/uploads/sites/3/2022/07/Heat-Flow-Meter-Manual.pdf

From left, Katarina with direct connect ISECs, testing outside the laboratory, mounted solar panels at the farm, and lithium titanate battery supplemented ISECs.

<u>Power optimization and electronic control</u>

As described in our "Hot Diodes" publication,[2] a solar panel cannot optimally transfer electrical power to a directly connected resistive heater under varying solar intensities. However, a microprocessor-controlled buck convertor can modulate the voltage to the ISEC, optimizing the power delivered under all solar intensities. The solar panel voltage output is modulated by a buck convertor that is controlled by a microprocessor monitoring the voltage on the ISEC electrical load. *work in progress*

4. Analysis of the results

Two important challenges are: (1) the transfer of thermal energy from the energy storage to the food, and (2) disengaging the thermal storage when none is wanted, for instance when the thermal storage is cold and the user wants to cook food directly. Our phase change model (Figure 1) accomplishes both needs elegantly. Both the erythritol and nitrate salt PCMs are thermal insulators in the solid state, but readily convect heat in the liquid state. Also, the heater is at the bottom of the cookpot, immersed in the PCM. When the ISEC is cold and the sun comes up, energy from the heater will not be transferred to the PCM until it melts, allowing food to be cooked at temperatures approaching 120ºC. After the food is cooked, the PCM will first melt around the heater, and convect the heat to uniformly warm the PCM. Later, when food is introduced into the hot ISEC, the cookpot will be the coldest part of the ISEC and be quickly heated by the convecting PCM. Once the PCM is solid, the heat will transfer slowly to the food, allowing food to stay hot for many hours at a low boil.[3] When we added shredded aluminum to the PCM, the power at hot temperatures decreased (the shredded aluminum impeded convection) and the power at low temperatures increased (the shredded aluminum increased the thermal conductivity). We regard both of these changes as undesirable and do not recommend adding conductive metals to the PCM in this geometry.[3]

It is not so easy for solid thermal storage to be as convenient as the above PCM because disengaging the thermal storage requires that the user move something to prevent conduction. Additionally, heat does not readily conduct from one metal surface to another unless the surfaces are exceedingly flat and smooth. With less than perfect surfaces (i.e. in all the cases we tested) heat transfer between an aluminum thermal storage puck and an aluminum cookpot was increased with the insertion of a silicone thermal pad such as that produced by Aiunni, with a thermal conductivity of 6 W/mK. However, Solid thermal storage is appealing because it will not degrade, is easier to build, and it still allows the user to independently engage the thermal storage by physically disengaging it from the heater.

The most reliable and inexpensive ISEC is "direct connect" without any storage capacity, requiring people to change the way they cook: filling the ISEC in the morning with lunch, and at noon with dinner to be cooked over a longer period of time. Robert Van Buskirk has been prototyping a hybrid model: during the day the ISEC heats water and charges a small LTO battery. In the evening, a small electric pressure cooker is filled with beans and hot water. The battery provides a small amount of extra energy to bring the beans to a boil. We have been testing this prototype. We anticipate that in a short time, batteries, and likely lithium titanate batteries will be the dominant energy storage medium.

We have had difficulty with some heaters and power wires connected to the heaters. When we directly connect nichrome wire to copper power leads, the junction creates a hotspot, presumably due to increased resistance at the junction point. The resistance of the junction increases and eventually fails. Additionally, flexible finely braided copper wires that stay hot corrode over a period of months. Hence, the inner wires that do not need to routinely bend should be made of solid copper wire of reasonably large diameter (14 gauge or less). Alexis does not report these difficulties, so we will learn from him, but reports that the industry standard is to spotweld the NiCr wire to steel power leads that connect to copper wires in a cooler environment. Pete plans to join Alexis's workshop at Living Energy Farm in July, 2022.

We have learned from collaborators, students, and everyone who has engaged in this project, and the project has taken turns we would have never predicted. We continue our locally-produced construction and distributed dissemination model. Our collaborators prefer constructing the ISECs themselves and having ownership over their work. With the technical knowledge behind ISEC, collaborators are able to fix and repair the cooker when it is broken and allows them to teach others. Many collaborators have also taken steps further in search of partnerships or other collaborations.

Bidjanga has been conducting ISEC training sessions on a weekly basis for his community. He has taken ISEC education to a new level by teaching students from his community as well as university students. Salma has also held ISEC demonstrations and workshops and plans to follow this path of community education.

Insulation is crucially important for cooking food with low power, and is surprisingly difficult to find in tropical, low-income communities. We discourage the use of biological materials (such as coconut husks) and old clothing because cotton and many other fabrics can catch fire at ISEC temperatures. Fiberglass and Rockwool are hard to find. Some collaborators are using wool (high combustion temperature), perlite, and vermiculite. Good insulation can be imported, but it seems there must be appropriate, locally available insulation material that we have yet to find.

Summary of Technological Lessons

- With proper heater placement and ISEC geometry, minimal heat is transferred to PCM storage as long as there is food being heated in the cookpot.
- erythritol (melting point = 118 ºC) is an ideal PCM, but degrades from thermal cycling over a few months. However even degraded, erythritol still functions as liquid thermal storage
- xylitol does not degrade, but is inferior to erythritol in cost, specific heat, heat of fusion and melting temperature (92 ºC, below the boiling point of water).
- The high temperatures of nitrate salts (melting above 200 ºC), used in SunBuckets and our ISECs, result in higher performance but require expensive materials and safety precautions.
- There is a considerable drop in temperature across a solid-solid interface such as transferring heat from a thermal storage vessel to a pot of food. The surface smoothness and flatness are crucially important.
- Resistive heaters benefit from voltage modulation to optimize power from the solar panel but are more thermally robust than diode heaters that don't need voltage modulation.
- Hot wires and wire junctions often corrode over the course of a few months.
- We are still looking for insulation material available in collaborator communities.

Summary of Global Learning Community lessons learned

- ISEC deployment is inherently linked to rural electrification - a large selling point. People want electricity for many uses, especially revenue-generating solar electric irrigation.
- The superior performance of battery storage along with the continued decrease in battery prices will make batteries the future of energy storage.
- ~200 Cal Poly students have developed technology and/or interfaced with international collaborators.
- Diversity in both technology and dissemination strategies among collaborators stimulate learning - both locally and in the Global Learning Community.

5. Changing the narrative on modern energy cooking services

Appliance performance and acceptance

We perceive that local design, construction, support, and dissemination are the most effective way for a community to recognize ISEC as a desirable way to cook. Our collaborators are not only design-builders, they are also practitioners. Additionally, collaborators have the knowledge to welcome additional collaborators – which is happening now. We have found that technological ability is not a prerequisite for success; enthusiasm and commitment is. For instance, Bidjanga does not have a technological background, but is a successful collaborator because of his commitment and ability to leverage people and community resources to meet the needs of the project challenges.

Our collaborators claim that aesthetics is important and complained that our ISEC is ugly. We invited each collaborator to creatively improve the appearance of their ISEC consistent with local tastes. The ISEC allows great versatility in the outer appearance. Cal Poly is committed to supporting the technical functionality and provides a platform to share technical as well as aesthetic innovations.

The ability of ISEC to displace traditional cooking fuel is inherently limited by the availability of sunlight. Storing energy, both thermally and with batteries has limitations. While several thermal storage strategies can easily cook meals in the evening after sundown, it is more difficult to store thermal energy for the next morning's meal – especially if much of the energy has already been used cooking dinner. Batteries can hold the energy without loss for long periods of time but will still be drained cooking through enough days of rainy weather. And while these challenges can be overcome with more solar panels, thicker insulation, and larger thermal storage (or batteries), these improvements cost more. Thus, the off-grid ISEC cooker will always need to have a contingent fuel source, knowing ISEC will reduce fuel costs and exposure to smoke whenever implemented. Our present thermal storage designs aim to provide high power cooking at the end of a sunny day, with enough energy left over to warm food or tea in the morning.

Market Surveys

Market surveys indicate that traditionally women will be using our product. In general, people who answered our surveys want more power and ability to cook when they please, which is why having an option for thermal storage is beneficial. Alternatively, this information also presents the opportunity of introducing simple alternative cooking methods utilizing direct cook ISEC that people may try as part of their cooking repertoire, reducing the evening meal's fuel demand such as cooking root crops during the course of the day.

Supply chains

Our goal is to source as many materials as we can locally. For example, aluminium is mined, refined, and processed in several collaborator countries. However, not all materials are made in the intended country. We have initiated low-cost large-scale importation with Robert Van Buskirk in sourcing low-cost solar panels and electrical appliances to collaborators. So far, we have delivered one shipment of solar panels to Salma in Togo. Importing goods into different countries sometimes presents challenges with taxes and paying duties, so Robert is careful to first import a smaller test quantity before committing to an entire shipping container.

Monitoring electricity supply and use

There is no structure yet in place to monitor electricity supply and use in the homes of first adopters. We have left this activity to each collaborator. However, Pete will likely explore mechanisms to monitor ISEC use and reductions in other fuels during his coming year-long trip visiting collaborators.

Finance and affordability

A direct ISEC system would cost $50-$100 including the solar panel. We strive for a sustainable dissemination model with local assembly, using as much local material as possible and importing only what is not locally available. Thus, most of the money spent on an ISEC stays within the community.

Stakeholder interactions

Important stakeholders are collaborators, funders, and students (at Cal Poly and in Africa) and other electric cooking efforts. Our collaborators continue to work hard in their construction and dissemination. Our weekly meetings have proven effective in maintaining good relations and supporting our network of stakeholders.

Scaling up electric cooking

The transition to clean energy cooking will continue to grow, buoyed by the continued decrease in solar panel and battery cost. More families are willing to make that initial investment if they see it paying off – observation of Robert Van Buskirk in Malawi. While our Global Learning Community has built a small amount of ISECs (on the order of 100 - 200), production and implementation continue to grow; both in terms of growth of number of collaborators in the community as well as increase in production of each collaborator. Again, we anticipate that this growth may be accelerated by Pete’s trip over the coming year.

6. Social inclusion and Impacts

Bidjanga offers free ISEC trainings to his community, open to all ages but geared towards the youth. He provides equipment and technical training to educate many individuals from his community on ISEC technology. The impact of his trainings are felt amongst the community. Many of the younger members of the community attend the training sessions on a weekly basis. Bidjanga provides these informational sessions on the weekends when the majority of people have the most free time. A recent, multi-week course costing money allows for students to construct an ISEC and take it home.

Gender

The majority of the students attending Bidjanga's workshops are girls and women. In his region it is most common for women to be using the technology, therefore they are the target audience in learning how to build and use ISECs. Not only are they receiving education on this specific technology, but it also saves them time that would otherwise be spent away from home in search of wood as well as keeps them safe from both assault and indoor air pollution. We will continue to promote these activities with other collaborators as they launch outreach efforts.

ISEC workshop in Cameroon

7. Next steps

We will continue to guide ISEC technology via weekly meetings and correspondence. We will also continue to facilitate sourcing materials and solar panels. We presently have three students at Cal Poly doing full-time summer research. We are seeking further funding to support new collaborators.

Pete Schwartz will spend the next academic year on sabbatical (actually "difference in pay leave") visiting collaborators teaching about ISEC, promoting rural electrification, food production, and permaculture while learning about local culture and challenges.

8. Conclusions

We have improved ISEC technology to include a variety of thermal storage strategies to cook with more power and to cook after sundown.

The most affordable and reliable ISEC is still the “direct-connect” with no energy storage. While this technology works beautifully, it will only slow cook, requiring at least some change in cooking routine.

We have reliably stored heat in a solid such as aluminum or by melting a phase change material such as a nitrate salt and a sugar alcohol. Each method has associated advantages and technical challenges. Aluminium solid thermal storage is the simplest, most straight forward thermal storage method.

ISEC implementation inherently involves rural electrification, and the scaling challenges are mostly the sourcing of parts not manufactured in Africa.

Likely the greatest achievement is the formation of the global learning community - the “SuperGroup” that meets every Thursday. We have a network of creative, curious change agents with considerable technical knowledge and insights to share.

What began as a technological challenge may shift to one of business and sociology as we consider how to empower and support small local enterprises to bring value to their communities.

9. Appendix

Progress Reports from Collaborators

Alexis Zeigler https://docs.google.com/document/d/1AC9s2nXVmbBNfLNvADw-TtUVJq-T4mb59M2leL89MsY/edit?usp=sharing

Andrew Mayanja and Alicwamu Moses
http://sharedcurriculum.peteschwartz.net/wp-content/uploads/sites/3/2022/07/ASEI-ISEC-report.pdf

Chris Musasizi
https://docs.google.com/document/d/1wIxjSDY5snzk84y90IeYrRsA1KpF2oCiSQU1IPyLE8o/edit?usp=sharing

Hawazin Khaleel
https://docs.google.com/document/d/1_pTcVdDU0oW6qIvQVktYzxdRVnCj2tKzbb5S1lImf5E/edit?usp=sharing

Bidjanga Zach
https://docs.google.com/document/d/1EIV6bzw3w2abHI5v6GkgF8wivSctepfO4PZzgpr7oNA/edit?usp=sharing

Mark Manary
https://docs.google.com/document/d/17a6eG8PEEkTc_FidmKmNc7hJdbxwlc6Q/edit?usp=sharing&ouid=106906045117624018280&rtpof=true&sd=true

Salma Bougoune
https://docs.google.com/document/d/1tAHu20MEyIg68D66JJSWEdO-rpZuGy3yB42bIoCKt0Q/edit?usp=sharing

Presentations

ISEC Research team from FROST summer research (June 2021-August 2021) presented their results which begins at time 45 minutes, 41 seconds
https://calpoly.zoom.us/rec/play/yban5SNJFO_XQy0WW5y1X6MBPbxWeSEJwyyVGn1VR9xgLEZt9dvkl9MwkcIyl41LBjJAH1G9-fCa0o6L.1aAPdf9sdc0hG2w0?startTime=1628886765000&_x_zm_rtaid=JNPBkWmLQRy33hCW7eI6Bg.1633110860571.a42538096cfe371294b80d352c625965&_x_zm_rhtaid=813

Dr. Pete Schwartz presented at a conference for Engineers Without Borders (EWB)
https://www.youtube.com/watch?v=hkosRwstw9M

Katarina Brekalo presented at the ETHOS conference in January 2022
https://www.youtube.com/watch?v=gxMzO8bvM5E

Questionnaires

Cooking Method
https://docs.google.com/document/d/1nLRoVA1UlGon6mtPG-ufMenho_zbZ1PYLC7eSAUhjGA/edit?usp=sharing
ISEC
https://docs.google.com/document/d/1VSg8QtOGeiF2vieWBG1fiZh8y02EMBzw/edit?usp=sharing&ouid=106906045117624018280&rtpof=true&sd=true

Auxiliary DSC data and temperature cycling on erythritol from Elsa Micklin, Sid Gamoji, and Daniel Nagy, Spring 2022: http://sharedcurriculum.peteschwartz.net/wp-content/uploads/sites/3/2022/07/Sid-Elsa-Daniel-cycling-erythritol.pdf

Acknowledgements

We are grateful to MECS for the funding as well as consistent guidance (especially Jane Spencer and Simon Batchelor) and partnership that reminds us we are working together as a community. This gratitude extends to the collaborators that have joined this community as well as the ~200 students and supportive faculty who have engaged in research and service-learning projects in the past 3 years. Robert Van Buskirk (Kuyere!, Kachione LLC, also a MECS grant recipient - look for his final report) supports inexpensive sourcing from China. We acknowledge the generous support from the William and Linda Frost Fund.