

Phase change thermal storage: Cooking with more power and versatility

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ABSTRACT

A 100 W solar panel directly powering an Insulated Solar Electric Cooker (ISEC) can slowly cook 5 kg of food over the course of a day. However, 0.4 kWh of the day's energy can be stored in 2.5 kg of erythritol phase change material, allowing ISEC to cook more rapidly, as well as cook after sunset. We control supercooling by forcing crystallization, making erythritol an ideal thermal storage material for cooking and other thermal-storage processes, but the erythritol degrades in quality when cycled for several months over 180 °C. The efficiency of thermal storage is comparable to that of more expensive systems using battery storage and induction cooktops. ISECs can be built in low-income communities, and the best design varies depending on availability of materials, access to building technologies, and local preferences. A Global Learning Community of researchers, funding agencies, nonprofits, student groups, and local enterprises is collaboratively developing the open source technology with partners in low income communities to optimize designs, construction, and dissemination.

1. Introduction

1.1. The challenge of cooking

The World Health Organization estimates that three billion people cook with biomass and coal, which causes 4 million deaths per year from breathing the associated emissions (WHO, 2016). Besides the dangers of indoor air pollution (Lim et al., 2012; Subramanian, 2014), cooking over open fires also results in deforestation, and greenhouse gas emissions of CO₂ and soot (Bailis et al., 2005; MacCarty et al., 2008).

While solar cookers eliminate health and environmental impacts, they are often not readily adopted for reasons including inconvenience and incompatibility with traditional cooking methods. Although natural gas and electrical cooking reduce the health concerns of biomass cooking, they remain a costly option with environmental impacts.

With strongly declining cost trends for solar panels and batteries (Kavak et al., 2018; Barbose et al., 2016; Swanson, 2006), there has been a renewed interest in the contribution that solar-electric cooking can make in advancing the clean and modern energy cooking transition in developing countries (Batchelor, 2015; Simon et al., 2012; Lombardi et al., 2019).

1.2. Insulated Solar Electric Cooking (ISEC)

We introduced Insulated Solar Electric Cooking in 2015, utilizing solar electricity to directly cook food in a well-insulated chamber (Watkins et al., 2017). The insulation reduces heat loss, making maximum use of the heat produced from either a resistive wire or a chain of diodes (Gius et al., 2019). A 100 W solar panel (with a present manufacturing cost of less than \$20) generates ½ kWh of electricity over the course of a sunny day, capable of bringing 5 kg of food to a boil. The

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Nomenclature

ISEC	Insulated Solar Electric Cooker (Cooking)
PCM	Phase Change Material
PCA	Phase Change Assembly
ET	Erythritol
MPPT	Maximum Power Point
PCC	Phase Change Composite
NiCr	Nickel Chromium
MECS	Modern Energy Cooking Services
USB	Universal Serial Bus

electricity can also power an inexpensive USB charging accessory, found to be of great demand in off-grid communities (Wilson et al., 2018).

While low-power is ideal for day-long “boil and simmer” cooking, users consistently request both increased power and the ability to cook after sundown. While battery systems cost more than \$100, phase change material (PCM) can store thermal energy less expensively as both latent heat and sensible heat.

1.3. Thermal storage

Thermal energy stored in a PCM allows the user both access to greater power (by rapidly drawing the stored heat) as well as the ability to cook when the sun is not out. Additionally, inexpensively storing variable renewable energy is universally important beyond cooking, and a wide variety of PCMs have been explored (Mofijur et al., 2019). The classes of PCMs appropriate for cooking (temperature range 50–200 °C) include Paraffins, salt hydrates, sugar alcohols, nitrates and hydroxides; and oil has been explored as a sensible heat storage medium (Mawire, 2016). Many solar cooking designs have incorporated a variety of PCM storage strategies, but share some challenges related to the need to access sunlight while insulating the stored thermal energy. Simple box cookers can incorporate PCM on the base of the cooker (Sharma et al., 2000; Saxena et al., 2013), but are not able to get very hot. Solar concentrators can achieve high temperatures, but require either a complicated, expensive pumping system (Sharma et al., 2005; Mawire, 2016) or a mobile phase change assembly (PCA) (Alonso, 2018; Lecuona et al., 2013) to move the PCM to where it can be insulated and/or used. Because the ISEC cooking unit receives electrical energy via a wire, the PCA is a stationary part of the cooking system itself, reducing cost and complexity. We estimate parts and materials to cost between \$20 and \$40. 100 W solar panels are less than \$20 at the factory door in China, retail for about \$50, and continue to decrease in price.

Erythritol (ET), a sugar alcohol has been explored as a PCM (Shukla et al., 2008; Adachi et al., 2014; Mofijur et al., 2019; Vivekananthan and Amirtham, 2019; Höhlelein et al., 2017) with a melting point of 118 °C, although two different melting points (105 °C and 118 °C) have also been reported (Höhlein et al., 2017). Volumetrically, ET has a heat of fusion slightly more than that of water, and a liquid heat capacity slightly less than water. 2.5 kg of ET releases about 0.4 kWh of thermal energy in cooling from 180 °C to 70 °C; enough thermal energy to bring more than 4 kg of water to a boil (see Table 1). 1000 melting cycles to 120 °C has been observed to result in a 10% loss of ET’s heat of fusion (Shukla et al., 2008) implying thermal degradation of ET over time.

1.4. Supercooling

Liquid ET doesn’t immediately crystallize and release the heat of fusion as it cools through the melting point, but cools to a lower temperature before crystallization is initiated, raising the temperature back to the melting point. This “supercooling” is a problem because it allows the temperature to drop below the melting point, reducing the

Table 1

Physical Properties of Erythritol.

Physical Property	Value
Solid Density	1.48 g/cm ³ at 20 °C
Liquid Density	1.30 g/cm ³ at 140 °C
Melting Point	117–120 °C
Boiling Point	330.5 °C
Heat of Fusion	315–379.6 J/g
Solid Specific Heat	1.38 J/g°C
Liquid Specific Heat	2.76 J/g°C
Solid Thermal Conductivity	0.733 W/m°C, at 20 °C
Liquid Thermal Conductivity	0.326 W/m°C, at 140 °C

Characteristics of Erythritol (ET), from National Center for Biotechnology Information & Höhlelein et al. (2017).

temperature and power of delivered thermal energy. While some dismiss ET as a PCM because of supercooling (Höhlein et al., 2017), others recognize supercooling as a means to store latent heat at lower temperatures (and thus reduced thermal loss) until needed (Mofijur et al., 2019). The relaxation of supercooling has been reported by using nucleation agents (Zeng et al., 2017; Adachi et al., 2014; Yuan et al., 2019) and encapsulation (Wang et al., 2017).

This Paper’s Contribution: In this study, we:

- demonstrate the benefit of erythritol (ET) as a thermal storage medium for cooking, with potential for other thermal storage applications;
- report on how to control ET supercooling by forcing crystallization;
- report the caustic effects of hot ET and how to mitigate them; and
- describe the global learning community that is subsidizing and mentoring international collaborators to develop manufacturing capacity of this open source technology.

2. Experimental setup

2.1. Designing the phase change assembly (PCA)

A 12 V, 100 W solar panel has a maximum power point (MPPT) voltage of about 18 V, driving about 5.5 A of current through either a resistive heater (Watkins et al., 2017) or a chain of diodes (Gius et al., 2019). Rather than slowly cook food at 100 W, the heat can instead slowly melt a PCM (Unger et al., 2019) housed in a Phase Change Assembly (PCA), to heat food later.

One example of a PCA (Fig. 1) houses 2.5 kg of ET, between two concentric pots. An electric heater is physically and thermally attached to the bottom of the smaller, inner PCA pot, immersed in the PCM (Fig. 2). Hot ET dissolves plastics, insulating foam, and high-temperature silicone wire insulation (leading to the electrolytic oxidation of the newly-exposed positively-biased copper wire). Hot ET does not seem to react with JB-Weld epoxy and PFA insulation. Thus, wires can be insulated with PFA, or protected by covering with JB-Weld and/or unbiased metal (Walker, 2020), such as shown in Fig. 2.

The PCA is completely surrounded by insulation in a bucket (Fig. 3), reducing both heat loss and risk of burning people. An airtight gasket of silicone RTV on the lid and a tube of high-temperature silicone allows water vapor to vent without soaking the insulation (Fig. 3, middle).

We develop ISEC technology mindful of construction and deployment in a low-income community, using only inexpensive materials and simple assembly. While the experiments we describe involve only fiberglass-insulated ISECs as in Fig. 3, we have also constructed the PCA in a 3 L double-walled vacuum thermos (Fig. 4).

ET and aluminum have thermal conductivities of 0.73 W/m/K, and 205 W/m/K, respectively. Lack of thermal conductivity will limit thermal flow to the food, but a thermally conductive phase change composite (PCC) can be made by percolating aluminum filler into the ET (Sheng et al., 2019). Adding aluminum to ET is discussed further in the

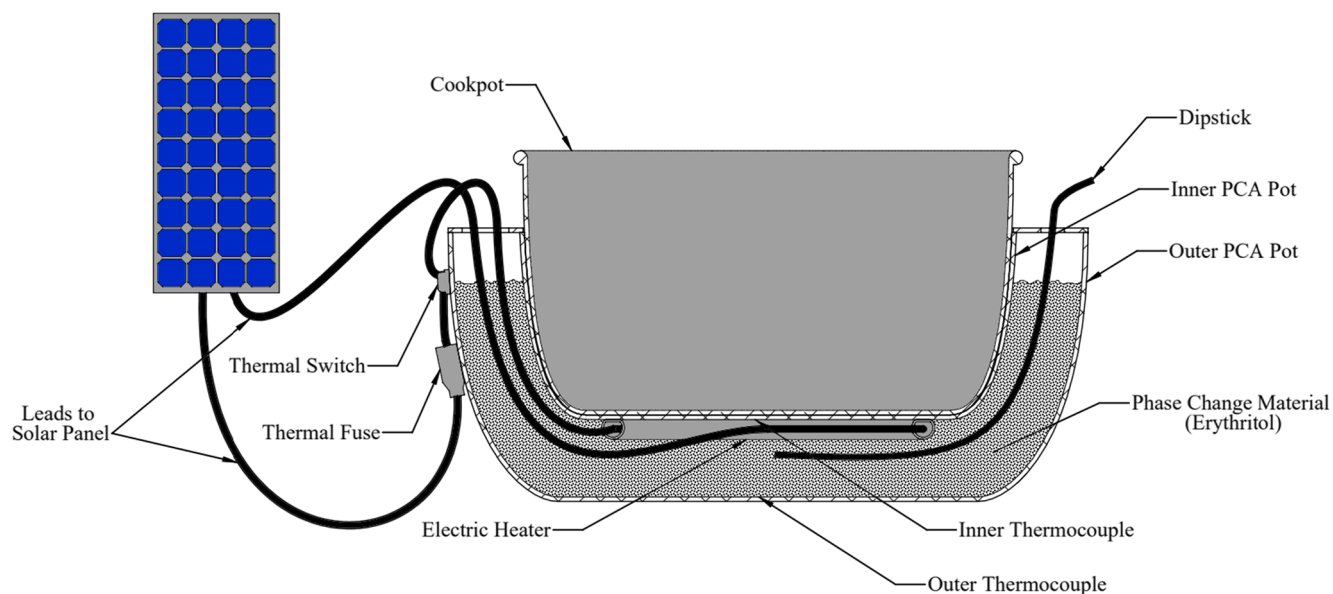


Fig. 1. Schematic of the ISEC with thermal storage made from a 24 cm outer pot and a 19 cm inner pot.

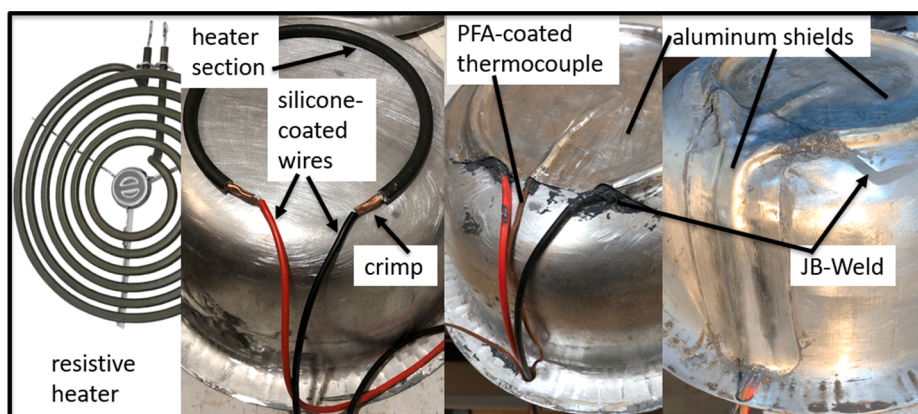


Fig. 2. from left to right: A 20 Ohm electric heating element is cut into 3.5-Ohm sections for a heater, crimped to high temperature silicone-coated power leads, and glued to the bottom of the inner PCA pot with high temperature epoxy (JB-Weld). Epoxy also coats the electrical connections and bonds aluminum foil shielding over the wires of the completed inner PCA.

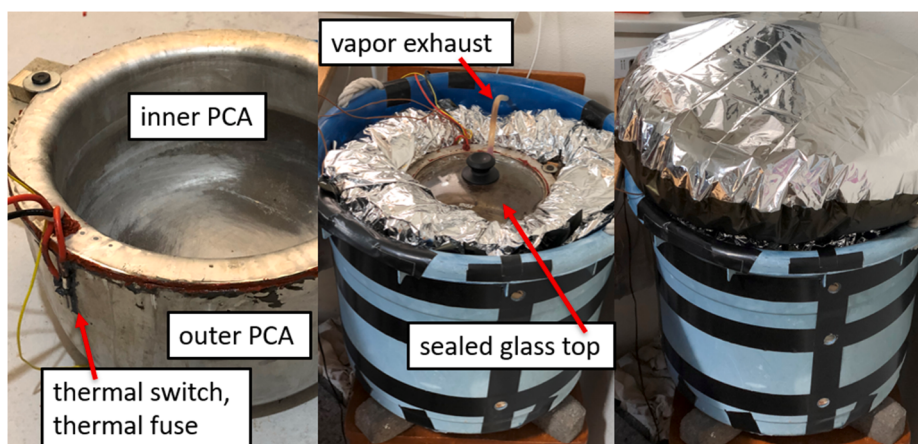


Fig. 3. (left) Full Phase Change Assembly (PCA) with inner PCA (Fig. 2 at right) inserted into outer PCA containing erythritol. (middle) PCA immersed in fiberglass insulation, aluminized Mylar provides improved, hygienic surface, and (right) seals the top insulation.

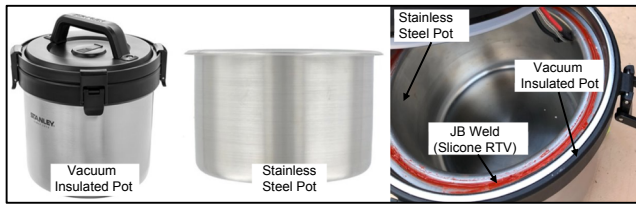


Fig. 4. A portable ISEC is constructed by gluing the inner PCA directly into a vacuum thermos. The wires for the heater and a thermocouple are routed through a hole in the side of the pot, then through the lid.

Thermal Conductivity section. We conducted experiments with pure ET, with 0.09 kg of corrugated aluminum foil (thickness = 0.25 mm) pressed between the inner and outer PCA pots, and by adding 0.5 kg of shredded aluminum to the PCM.

2.2. Experiment: simulating cooking after dark

In order to simulate cooking after dark with stored thermal energy, we heated an insulated PCA (as in Fig. 3) from room temperature with 100 W for 6 h, disconnected the power for three hours, and then inserted the cookpot containing 1.5 kg of cold tap water. Temperature data were taken with a 4-channel type-K thermocouple data logger by Gain Express with 0.1 °C precision and 1 °C accuracy. Fig. 5 documents the temperature evolution of the water and in two places on the PCA (as indicated in Fig. 1). While energy is flowing into the PCM (the first 6 h), the inner PCA (to which the heater is attached) is hotter than the outer PCA because the PCM must melt before the outer PCA's temperature can exceed 118 °C. When energy flows from the PCM to the food (between 9 and 13 h), the inner PCA (closer to the water/food) is colder than the outer PCA. The surfaces are near the same temperature when the only energy flow is the low-power thermal loss through the insulation (between 6 and 8 h; and after 14 h).

The total energy delivered to the water is the sum of the two following energies: (eq. 1) the energy to raise the water to the boiling point,

$$E_{\Delta T} = mC\Delta T \quad (1)$$

(where m is the mass of water, C is the specific heat capacity of water and ΔT is the change in temperature of water), and (eq. 2) the energy to boil away the amount of water lost,

$$E_v = m_v H_v \quad (2)$$

where m_v is the mass of water vaporized and H_v is water's heat of vaporization. These energies, respectively, for the experiment illustrated in Fig. 5 are: 0.50 MJ and 0.58 MJ.

The ISEC's thermal resistance can be calculated from the rate of temperature loss at the two times when the ISEC is thermally equilibrated, cooling without external power. Both of these regions yield a thermal resistance of about 10 °C/W, meaning that our ISEC will lose 1 Watt of power for every 10 °C its temperature is elevated above the ambient. For example, it will lose about 10 W when the temperature of the ISEC is 120 °C for the insulation depicted in Fig. 3. The vacuum thermos ISEC (Fig. 4) has slightly poorer insulation with most of the heat being lost through the top.

Thermal conductivity between the PCM and food is crucially important in providing adequate power, because of the small temperature difference between the food and PCM. In order to heat food, the stored thermal energy must first transfer from the PCM to the inner PCA pot and then to the cookpot. Fig. 6 compares four experiments where 1.0 kg of water was added to a ~142 °C PCA. The shortest boiling time of 25 min was recorded when the water was added without a cookpot directly to the PCA with no aluminum added to the PCM (6a). The time to boil is increased by adding aluminum shavings and foil into the PCM

(6b) and also by including the cookpot between the PCA and water (6c). The added thermal barrier of the added cookpot is reduced if a drop of cooking oil is placed between the cookpot and PCA (6d). Comparing 6a and 6b, we see that adding aluminum shavings and foil to the PCM increases the time to boil, but decreases the total boiling time, while boiling away the same amount of water; indicating that the added aluminum decreases the thermal flow in liquid PCM (by decreasing convection) but increases thermal flow in solid PCM because of aluminum's high thermal conductivity. The thermal flow depends greatly on the temperature difference between the PCM and food. In a different experiment, 1.0 kg of water was added directly into a 180 °C PCM with no added aluminum, bringing the water to a boil in 5 min, 20 s, corresponding to an average power of 1000 W; and an average of 1500 W for the first two minutes.

2.3. Crystallization and supercooling

Consistent with H  hlein et al. (2017), we observe ET crystallizing at either 118 °C or 105 °C; and sometimes (though rarely) at both temperatures in a single, undisturbed cooling (Fig. 7). The 118 °C crystallization process happens faster than crystallization at 105 °C.

Supercooling is evident in Fig. 6a for ~1½ hours until ~10:30, when the crystallization is initiated by some unidentified process. However, despite the lower PCM temperature due to supercooling, experiment 6a boiled the water in the shortest amount of time. Heat may better *convect* from the supercooled liquid to the PCA surface than it would *conduct* through the solid ET layer had the ET solidified at the melting temperature.

As stated, supercooling can be an asset if the crystallization can be induced when desired. We can force crystallization in supercooled ET, rapidly releasing the heat of fusion by either adding cold food to the PCA (Fig. 8 middle), or by inserting a wire ($D = 2$ mm, see "dipstick" in Fig. 1) coated with a film of crystallized ET into the PCA, seeding a line of crystallization (Fig. 8 middle). Additionally, while unforced crystallization (Fig. 8 bottom) often equilibrates to the lower crystallization temperature over about an hour, forced crystallization always equilibrates to the higher crystallization temperature in a shorter period of time. When cold water is added to the PCA already below the water's boiling point (Fig. 8, top), the ET initially rapidly supercools as the outer PCA drops to about 92 °C and the inner PCA to 43 °C (the temperatures of the water and inner PCA are not shown until they recover to 90 °C) before crystallization liberates the heat of fusion, raising the temperature of the PCM to 118 °C. In subsequent heating, the ET melts at the same temperature as that of the previous crystallization.

2.4. In the kitchen

Over four months, we cooked directly in the PCA (without a cookpot) with the arrangement shown in Fig. 3. The cooking method has evolved in accommodating ISEC strengths and limitations. While it is naive to assume others will use the ISEC similarly, illustrating these changes may be illuminating. The ISEC has 2.5 kg of ET with shredded aluminum and foil, and a 3.9 Ohm heater (slightly higher than optimal) providing only 81 W under full sunlight and 36 W when powered by a 12 V, grid-connected power supply. The ISEC can be used to cook whether or not power is flowing to the heater, although added power slightly increases cookpot temperature.

During most use, the ISEC rarely cooled to room temperature, or even below the crystallization temperature, allowing the temperature to usually vary between 118 °C and 180 °C. The 428 kJ of sensible heat was repeatedly used rather than the 870 kJ of latent heat of fusion because the higher temperature PCA provided greater cooking power. However, after dinner, we often cooked soups, stews, and beans overnight using the slow release of latent heat of fusion.

Fig. 9 provides an example of daily cooking. When the sun is up, the heater provides ~ 81 W. Otherwise, the 12 V power supply provides ~

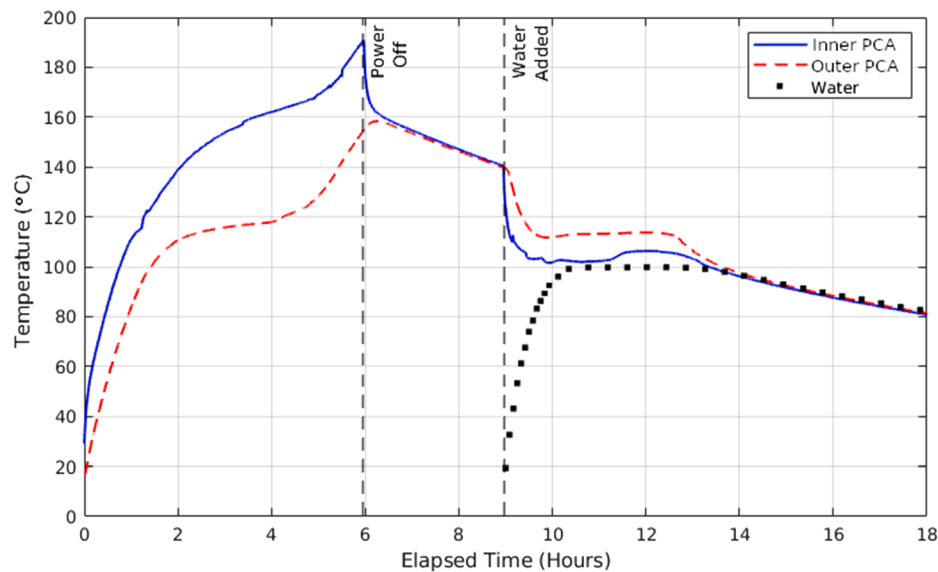


Fig. 5. The phase change assembly was heated for 6 h at 100 W and left without power for three hours before inserting the cookpot (as in Fig. 1) containing 1.5 kg of water. The water comes to a boil in about 1.5 h and boils for about 2.5 h, boiling away 256 g of water before depleting the stored energy in the PCM.

36 W. Each time 1 kg of water was boiled, the temperature of the PCM rapidly dropped, but recovered in about 2 h. At about 20:00, the PCM super cooled to about 100 °C (red dotted line), but increased in temperature as crystallization began, providing lower power, but sufficient energy to bring 2 kg of cold fruit to a boil. After removing the jam, a small amount of water was boiled for canning. This final act of canning (just before 24:00) completely crystallized the PCM, removing the last amount of thermal energy.

3. Discussion

For cooking, ISEC with PCM can provide both a “hot spot” that is often ready to cook akin to a microwave oven with ~1 kW power for ~5 min; as well as capacity to cook large meals over the course of an hour or more. More broadly, in a future of negligible solar panel cost, phase change thermal storage provides a partial solution to solar energy’s intermittency problem. Erythritol is an inexpensive PCM with high specific heat, high latent heat of fusion, and a melting point appropriate for domestic and industrial thermal storage utility.

We have found that supercooling presents no practical difficulty, as crystallization is easily initiated. However, thermal degradation warrants additional investigation. After three months of continuous ISEC use, usually cycling two to three times daily to 180 °C (although ET near the heater rises to 195 °C), we observed decreases in the higher crystallization temperature (from 118 °C to 103 °C), the lower crystallization temperature (from 106 °C to 70 °C), and the supercooling temperature (from 94 °C to 58 °C). Further reduction of the crystallization temperature will not allow heat of fusion to be available for boiling temperatures, although the sensible heat will still be accessible. Future experiments will quantify thermal degradation of ET, seek to reduce thermal degradation (likely through reduction of maximum temperature), and also explore other PCMs.

3.1. Efficiency

We define efficiency as the ratio of the heat delivered to the food to the electrical energy received by the cooker. In the experiment illustrated in Fig. 5, the energy delivered to the ISEC was $100\text{ W} \times 6\text{ h} = 0.6\text{ kWh} = 2.16\text{ MJ}$. Accordingly, the 1.08 MJ of energy to heat and boil

the water corresponds to an efficiency of 50%. In our experiments, energy not transferred to the food is either that initially “used” heating the PCM to 100 °C or heat “lost” to the environment through the insulation. Thus, the ISEC’s thermal energy efficiency will increase with shorter energy storage times, increased insulation, and if the PCM starts warm from the previous day. If the ISEC is used hot (with liquid ET, as in Fig. 9), the efficiency is the ratio of the energy absorbed by the food to the total energy harvested. If the average temperature = 130 °C, then the difference in temperature to the outside world is about 110 °C, corresponding to losing heat through the insulation at about 11 W or, 264 Wh over the course of the day. The total heat harvested is about $81\text{ W} \times 6\text{ hrs}$ (full sunlight) + $37\text{ W} \times 18\text{ hrs}$, at night, corresponding to an efficiency of about 77%, or about 45% if there were no 12 V power supply.

It may be instructional to compare the efficiency of this thermal storage to that of a solar electric/battery/induction cooker. Electric battery storage has ~90% efficiency and induction cookers have 72% efficiency (Department of Energy, 2014), yielding a total “solar electricity to hot food” conversion efficiency of about 65%. However, electrical cooktops are typically not insulated, so after the food is at the boiling point, close to 100 W is necessary to maintain this temperature for a 4 quart pot. Consequently, electric cooktops may have better efficiency (than ISEC) for very short cook times, but for hours-long “boil and simmer” cooking, the efficiency of an uninsulated battery – electric system will be very low.

3.2. To heat with resistors or diodes?

We made our first ISEC heaters from Nickel Chromium (NiCr) wire (Watkins et al., 2017), and then made heaters from a string of diodes because diodes more effectively couple power from a solar panel over a wide range of solar intensities (as we explain in Gius et al., 2019). Further experiments yield advantages and disadvantages of each heating technology, which we summarize below. After considering all factors, we have returned to using resistive heaters.

- **Power extraction:** We showed that, over a variety of solar intensities, diode heaters (Gius et al., 2019) more effectively extract electricity from a solar panel than do resistive heaters. However, the difference is small on sunny days, and on very cloudy days, there is little solar

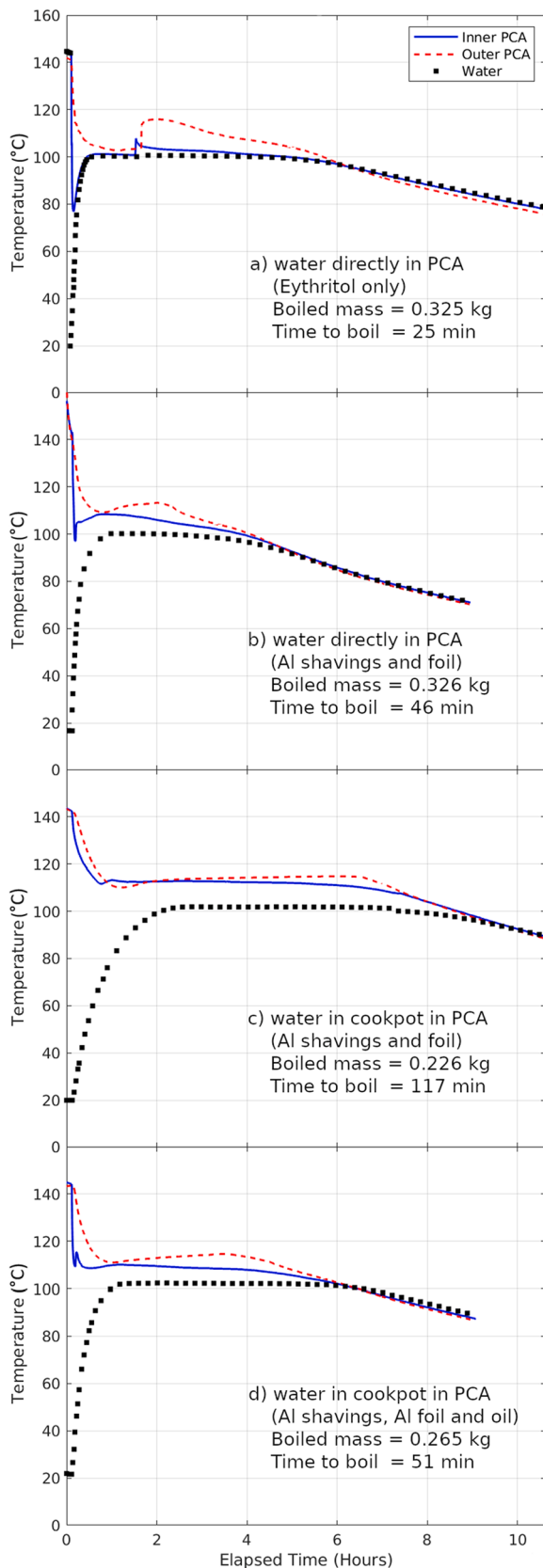


Fig. 6. In four experiments comparing heat transfer from the PCM, 1.0 kg of room temperature water was added to the ISEC when the ET had cooled to about 142 °C. Data are taken every 10 s.

electricity available for either technology. Thus, diodes significantly outperform resistive heaters only on days that are somewhat cloudy.

- **Construction:** A variety of resistive heaters can be purchased or made from NiCr wire (as described in Watkins et al., 2017). Diode-based heaters (as described in Gius et al., 2019) consist of a chain of diodes to be connected individually. The high operating temperatures (above that of the diode specifications) make solder joints challenging.
- **Durability:** The many electrical joints in a diode heater provide many points of potential failure from disconnection, shorting, and corrosion. Additionally, diodes are subject to failure by overheating. Thus, care must be taken to thermally anchor each diode.
- **Grid connection:** A resistive heater can be directly connected to different electrical sources in parallel, such as a solar panel and a grid-connected 12 V DC supply (as demonstrated with Fig. 9). Diode heaters can not be connected directly to a voltage source.

It is also possible to power a resistor-heated ISEC solely with electricity from a source other than a solar panel, including a grid-connected power source. The insulation would still provide a great efficiency improvement over conventional electric cookers. The user must take care to not inappropriately connect the wrong voltage. In particular, directly connecting line voltage to the presently-described ISEC would immediately destroy the ISEC and likely cause a fire or damage the building's electrical system.

3.3. Cost

Battery electric systems cost well over \$100, requiring a battery, charge controller, induction cooker and pot. We anticipate the cost of the ISEC with thermal storage to be about \$30. Presently, a 100 W solar panel (necessary for both types of energy storage) retails for about \$50. We recently did a Levelized Cost of Energy (LCOE) for ISEC cooking (Watkins et al., 2017) finding between \$0.074/kWh and \$0.46/kWh depending on conditions. Herein, we allow the above comparison between ISEC and battery system capital costs to suffice. ISEC is inexpensive and effective. However, finance is one of many factors affecting adoption. To learn more, we are getting ISECs into use as fast as possible.

3.4. Dissemination via global learning community

ISEC with thermal storage is an inexpensive cooking technology that allows the user to both cook while inside and to cook after dark, overcoming documented adoption barriers faced by traditional solar thermal cooking technologies (Otte, 2014). The ease of also providing limited electricity access for rural off-grid communities should further aid adoption (Wilson et al., 2018). There remain many unknown barriers separating this working technology from widespread adoption including cultural preference, durability, manufacturing, supply chain, and government support; all of which vary by location. Thus, rather than securing intellectual property to pursue industrial manufacturing for global distribution, we are exploring solutions by starting a Global Learning Community of students, practitioners and other ISEC stakeholders. Our global learning community is improving the open source technology while a UKAid grant (MECS, 2020) subsidizes collaborating enterprises in target communities leveraging the following benefits:

- The decreased costs of labor and resources in low-income communities allow funding to go much further.
- The diverse learning community more quickly explores different ideas.
- Product development is more responsive to local preferences, resources, and challenges.
- Local development and production of a product for local consumption stimulates the local economy.

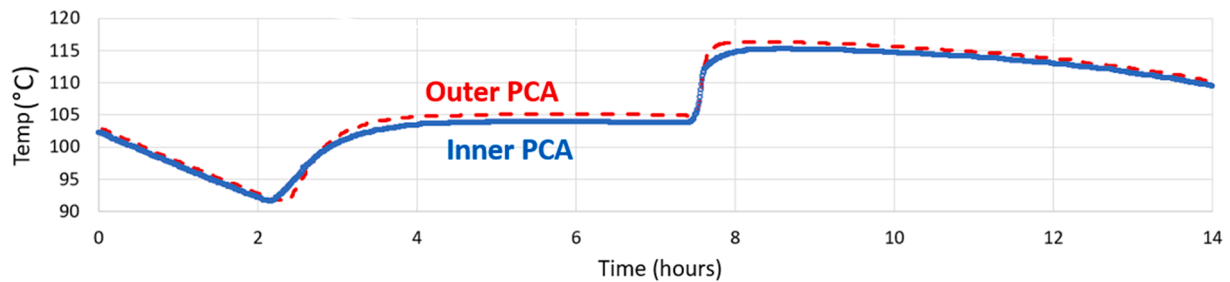


Fig. 7. With power off, the ISEC temperature drops and supercools to about 92 °C at which point it takes about an hour to equilibrate to crystallizing at 105 °C. At about 7:30, the temperature abruptly jumps over 5 minutes to crystallizing at 118 °C.

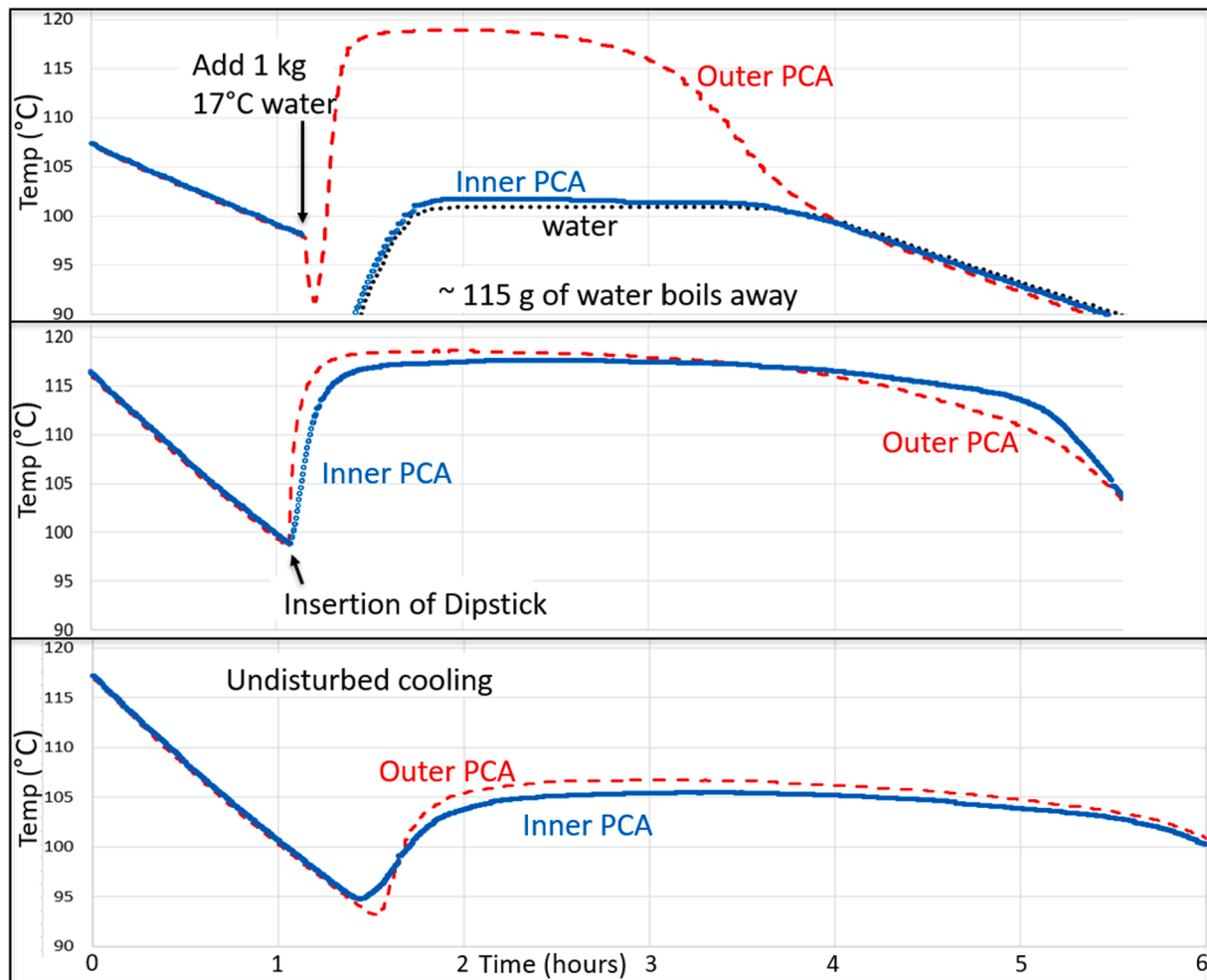


Fig. 8. Three cooling experiments are done in a PCA with 2.5 kg of pure erythritol (no aluminum filling) with no power connected. (bottom) The PCA is allowed to cool undisturbed, supercooling to about 94 °C, before crystallizing at 106 °C. Crystallization to 118 °C is forced by inserting a crystal-coated wire at about 98 °C (middle), or by adding 1.0 kg of 17 °C water (top, where the full temperature drop of the inner PCA to 43 °C is not shown).

Our research website¹, provides technical support with continually-evolving construction manuals and videos as well as an open forum for community members to share knowledge on ISEC construction, use, and improvements. This forum, and weekly meetings have helped us create a truly collaborative atmosphere within our global learning community.

As we previously reported (Gius et al., 2019), ISEC design was facilitated by engaging more than 100 Cal Poly students: dedicated research students, engineering students engaged in year-long senior

projects, and students enrolled in service-learning courses directed by Schwartz.² One consequence of switching to distance learning during the pandemic, is that international collaborators can be seamlessly added to the class as a student, project group member, or presenter.

In 2019, a research team travelled to Ghana to explore local ISEC production and deployment. We formed a company to build and disseminate ISECs, that has been plagued by difficulties (including the pandemic), providing a constant flow of lessons for the learning

¹ <http://sharedcurriculum.peteschwartz.net/solar-electric-cooking/>

² <http://appropriatetechnology.peteschwartz.net/about-us/>

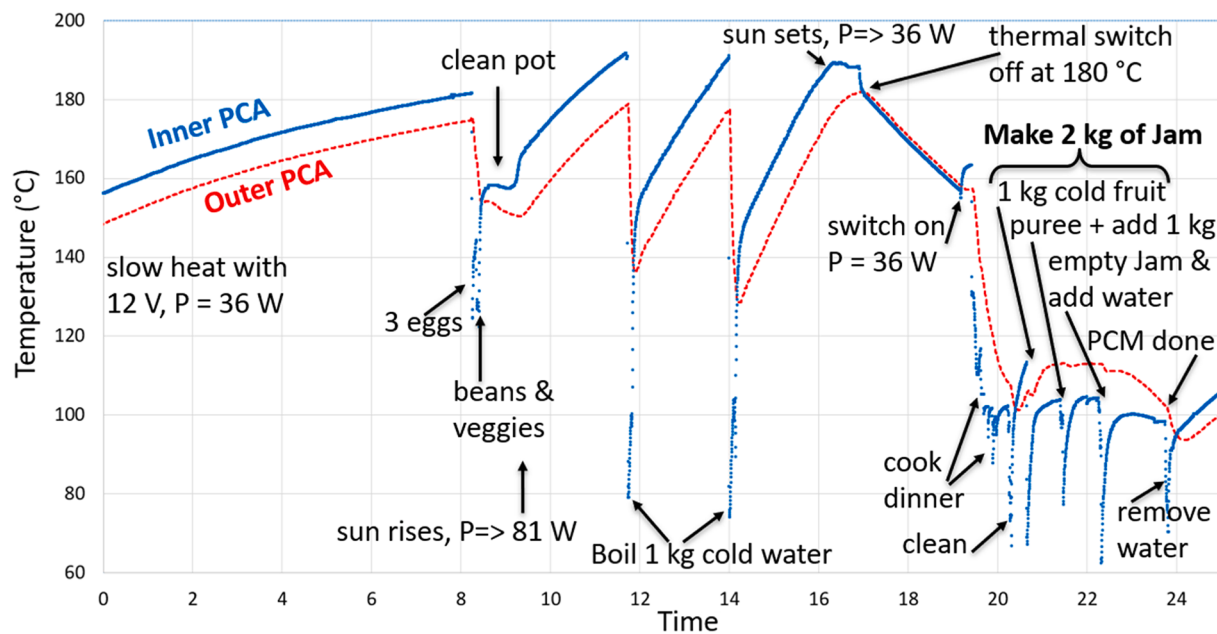


Fig. 9. One day of ISEC use. The temperature of the PCM is close to that of the outer PCA pot. In this scenario, a 12 V power supply provides 36 W in the absence of sunlight. Delivered power with sunlight is about 81 W.

community. We've deployed 10 ISECs (without thermal storage) in Ghana and observe the need to be able to cook after dark, consistent with previous studies (Upadhyay, Kothari, & Shanker, 2013; Otte, 2014). Additional collaborators in Sierra Leone, India, South Africa, Uganda, Togo, and Jamaica have initiated plans to build and disseminate ISECs. As our attention shifts from design to dissemination and adoption, new learning community members studying anthropology and GIS (Graphical Information Systems) provide ISEC-related health and environmental information as we study the adoption process.

Eastern Illinois University's Hospitality and Tourism Department has a commercial cooking lab, where we will test ISEC in traditional meals from regions of interest. Researching the quality of solar-cooked food, particularly focusing on the temperature, texture and overall consistency of the food, has been identified as a gap in previous studies (Touma, 2016).

4. Conclusion

We made Insulated Solar Electric Cooking (ISEC) more effective and convenient by storing the day's energy in molten erythritol, allowing one to cook after dark and with increased power. We are able to control erythritol's supercooling, better qualifying it as a general thermal storage medium between 100 °C and 200 °C, particularly appropriate near the crystallization temperature of 118 °C, although erythritol will degrade after months above 180 °C. Thermal storage efficiency is comparable to that of battery/solar electric systems for a small portion of the cost, although each system has unique strengths and limitations.

Rather than mass producing ISECs at a central factory, we are supporting a global learning community, both technologically (with open online resources at our website and forum), as well as financially. Local production both develops the local economy as well as better accommodates local resources, challenges, and preferences.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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