Collaborative Development of Ultra Efficient Photovoltaic Solar Cooking
Supplementary Information

Obvious?:
While it is common knowledge that one can directly heat a coil with Photovoltaic Electricity and increase efficiency with insulation, we are unaware of this being done to the degree we propose - one rendering a cost-effective electric cooking technology. Additionally, extreme insulation allows for a block of concrete to provide heat through the night into morning.

Background:
Electrical cooking, particularly with induction stoves (Subramanian 2014) has been suggested as an alternative to biomass cook stoves. However, these induction cookers require over 1000 W of grid electricity, which is too expensive or nonexistent in many areas. However, as the cost of photovoltaic cells continues to decrease, Photovoltaic Electric (PVE) systems will become increasingly cost competitive. We are exploring PVE cooking in order to reduce cost while adapting and accommodating the technology to different community cooking practices so that when the appropriate PV solar panel price point is reached, the cooking technology will be ready.

Increasing affordability of photovoltaic cells:
Figure 1 shows the steady decrease in price of silicon-based photovoltaic power over the last 40 years (Swanson 2015, Samual 2015). There are concerns that the recent price decrease, from Chinese companies selling below cost, is artificially deflated. However, this likely more than compensated by the emergence of new technologies (Green and Emery et al. 2014) including cadmium telluride (presently the least expensive PV technology) and experimental perovskite materials (Green and Ho-Baillie et al. 2014).

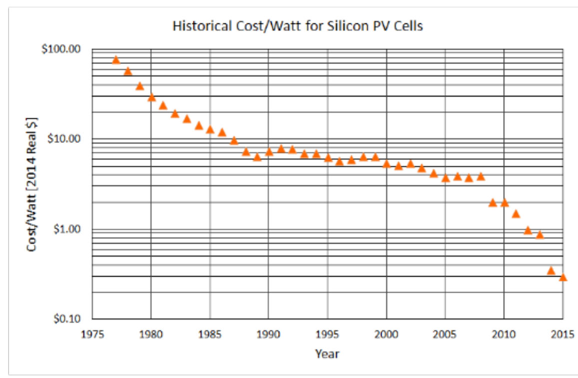

Figure 1: Decrease in cost of photovoltaic panels ($/Watt)

Value of Electricity:
In converting sunlight to electricity and then to heat, we lose about 80% of the sun's available energy. However, this loss may be well worth the added value gained by electrical conversion:

1. Electrical transmission allows us to bring the sun's energy into the house, or wherever else it is needed.
2. Electrical transmission facilitates the use of insulation to lower the power necessary to cook, reducing costs compared to conventional solar concentrated cooking.
3. The power of a PVE cooking system could be increased over time with additional solar panels.
4. Electrical conversion enables energy storage in batteries for nighttime use, and the extreme insulation allows for a thermal mass to store heat through the night.
5. Electrical power enables automated control of time and temperature.
6. PVE systems provide electricity for other domestic and commercial services.
7. Because combustion-free cooking is supported by carbon credits, PVE cooking systems lower the financial barrier to disseminate a resilient infrastructure of distributed PV. (Hogarth 2012) (Smith, 2010)

Methods:

Accepting that the retail price of solar panels is twice the manufacturing cost, a 1000 W electric stovetop capable of boiling a liter of water in 5 minutes requires an investment in solar panels of $700 now, projected to be $300 in 2020. However, the PV panel costs for a 100 W system, capable of boiling a liter of water in 50 minutes would only be $70 now or $30 in 2020. A 100 W stovetop would likely never reach boiling because of heat losses, but heat loss can be reduced with insulation. Thus, our design focuses on optimizing an insulated cooker with a 100 W photovoltaic solar panel directly connected to the heater, eliminating the need for costly power electronics. Figure 2 is a photograph of our prototype: a 5-gallon steel drum insulated from the surrounding 55-gallon plastic drum. Some insulation is removed to better visualize the design. 100 W is provided by a heating element, thermally connected to the lid of the inner metal drum (Figure 3).

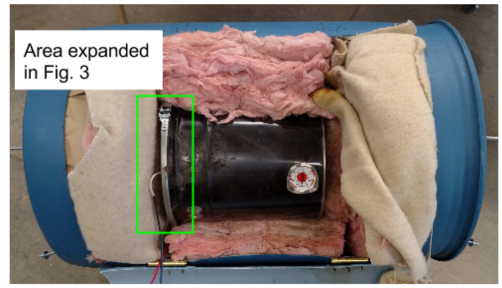

Figure 2: Placement in insulation

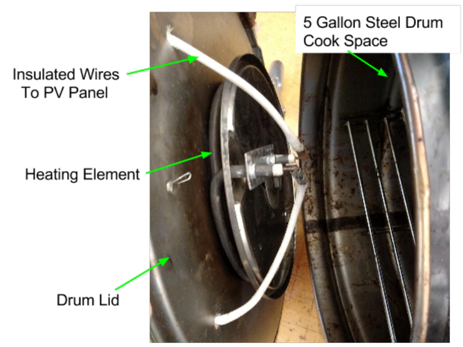

Figure 3: Cooking area with heating element

The calculated equilibrium temperature for a 5-gallon drum heated with 100 W and insulated with 13.5 cm of fiberglass is 358°C (676°F), although we have yet to attempt to reach that temperature experimentally. Also, 100 W should be sufficient power to boil a liter of water in under an hour. In the financial calculations, we do not consider the cost of the outer, plastic container with the assumption that locally-sourced materials could provide this outer shell with little expense. Additionally, while the electric heater retails for $10, other nichrome wire options are less expensive. These engineering challenges will likely find different solutions depending on local interests and resources.

Experimental Trial:

As a proof of concept, we cooked ~ 2 kg chicken with ~ 1.6 kg of vegetables in a 5-gallon prototype using a 100 W heating element. As seen in figure 4, Poultry's minimum safe internal temperature of 74°C (165°F) was reached in about 2 hours. After 5 hours, the chicken's internal temperature was over 100 °C and the air temperature inside the steel drum was 111°C (232°F). The chicken was thoroughly cooked, as were the vegetables inside the chicken. The theoretical time necessary to heat 3.6 kg of water from 20.5°C to 100°C is almost 3 hours 20 min, roughly consistent with our experimental results allowing for some heat loss through conduction and boiling.

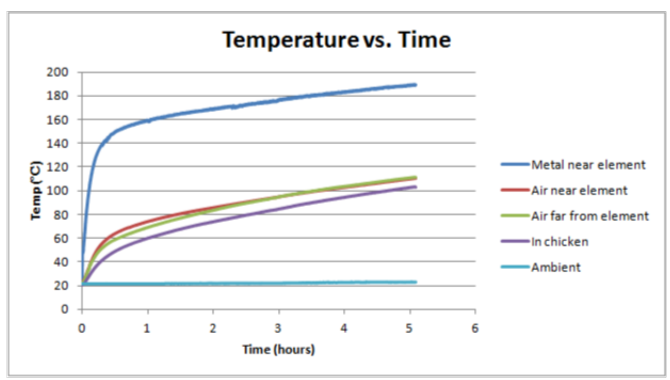

Figure 4: The Temperature vs. Time profile for the chicken bake

This will never work:

There are many challenges to implementing PVE cooking including:

- Insulation will encumber cooking styles, and may require people to cook in a manner that is different than what they are used to.

- PVE will be ineffective during seasons that have constant cloud cover.
- Places with significant rain may also have significant wood for cooking eliminating need for PVE cooking.
- Working with the carbon market is notoriously difficult and presently the carbon market is trading low - slightly over $10/ton and $5/ton on the California and European Union Exchanges, respectively.

Yet, every region is different, people are adaptable, and the cost of PV will continue to decrease. In the distant future, possibly in the year 2035, PVE cooking may be the most inexpensive option for every sunny place on or off the grid. Between now and that time it will be the most advantageous for some people depending on their geographic region, financial resources and cooking needs/preferences. During this time, we might explore how to adapt the cooking technology, the practices of people, and the business model. Herein, we propose only a cooking technology. The devil in the implementation details will be negotiated differently depending on the place, the people, and the year.

References:

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