



Performance Evaluation Process (PEP)  
Preliminary Results Report  
1 May 2017

**Solar Cooker: LIBERTAD 400**  
**Manufacturer: SUNplicity**  
Cookware: Customer Supplied  
Standard Cooking Power: 81 Watts  
SCI Test Code: PEP.P13

Solar Cookers International (SCI) Testing Center: Pollock Pines, California, USA  
A Regional Testing and Knowledge Center, listed by the Global Alliance for Clean Cookstoves  
Tester – Justin Tabatchnick

## Introduction:

Solar Cookers International (SCI) developed dedicated instrumentation and software for a performance evaluation process (PEP) to conduct the ASAE S580.1 protocol for testing and reporting solar cooker performance. Testing is conducted at SCI testing centers in California and New York as well as at partnered, regional network testing centers. In addition, SCI is the testing center convener, providing standard operating principles (SOPs) and quality assurance recommendations. SCI also maintains a global data bank of solar cooker testing results accessible by testing participants, NGOs and those in a decision-making position. This enables informed choices as far as what is best suited for a specific application based on the comparative data.

## Background:

SCI evaluated the Libertad 400 reflective-panel solar cooker in accordance to the ASAE S580.1 protocol. Cooker and cooking pot/lid were supplied by the requester. The SCI standard PEP test station was used for automated, real-time data acquisition for wind speed, solar irradiance, geographic position, and ambient and cooking temperatures. Data were stored in a space delineated file on an SD card for subsequent post processing. Test equipment was calibrated prior to testing. Data acquisition occurred over the course of one day, under atmospheric conditions suitable for the testing protocol. Test results are summarized in this report with raw data available upon request. Raw data and results can be posted on the SCI PEP website ([www.solarcookers.org/PEP](http://www.solarcookers.org/PEP)) once customer agrees and releases it in writing. Test is preliminary and consists only of a single days testing. It does not include the ASAE required 3 separate tests.

## Test Equipment:

<b>Electronics platform</b>	Weather-proof enclosure contains: Arduino Mega open-source electronics, liquid crystal display and removable SD card
<b>Temperature</b>	Type K thermocouples for measuring water and ambient temperatures
<b>Wind speed</b>	Anemometer (Adafruit, New York, New York, USA)
<b>Solar irradiance</b>	SP-215 amplified pyranometer (Apogee Instruments, Inc., Logan, Utah, USA) mounted to a horizontal, bubble-leveled plane, as suggested by the manufacturer
<b>Additional</b>	global positioning system

## Test Setup:

- Position test station with pyranometer wire connector parallel to North / South compass direction.
- Level the pyranometer using the bubble level on mount fixture.
- Insert thermocouple plugs into sockets and ensure ambient probe is out of direct sunlight.
- Insert test probes into pot lids.
- Setup solar cookers and place test pot in cooker.
- Connect 12 VDC battery pack to test station.
- Add pre-measured quantities of test water to cookers and cover with pot lids.
- Compare ambient temperature to cooker temperatures on display and if they are within 2 °C then press the reset button to restart test and begin testing. If cooker temperatures are below ambient then wait until temperatures approximately equalize to start testing by pressing reset. If starting temperatures are more than 2 °C above ambient then change water and wait for it to reach ambient temperature in cooker and then push reset to start testing.
- Adjust cooker every 20 minutes to track the sun.



*Libertad 400 Under Test*

**Test Station Variables (sample from 1 May 2017):**

<b>Variables</b>	<b>Value</b>	<b>Variables</b>	<b>Value</b>
<b>test_time_hrs</b>	4	<b>Interval (min)</b>	2
<b>Delays (mS)</b>	400	<b>Ambient ( C)</b>	2
<b>wind_min_volt</b>	0.4	<b>smth_wndw</b>	10
<b>temp_cal</b>	1	<b>Elevation(Angle)</b>	66.32
<b>GPS_Wait (min)</b>	10	<b>norm_aptr(Angle)</b>	66.32

**Solar cooker parameters:**

- Solar cooker type: Parabolic
- Cookware: Customer supplied
- Cooker elevation angle: 66.32 degrees
- Aperture area, maximum: 0 m<sup>2</sup>
- Reflector area, maximum: 0.456 m<sup>2</sup>
- Intercept (Aperture + Reflector) area, maximum: 0.456 m<sup>2</sup>

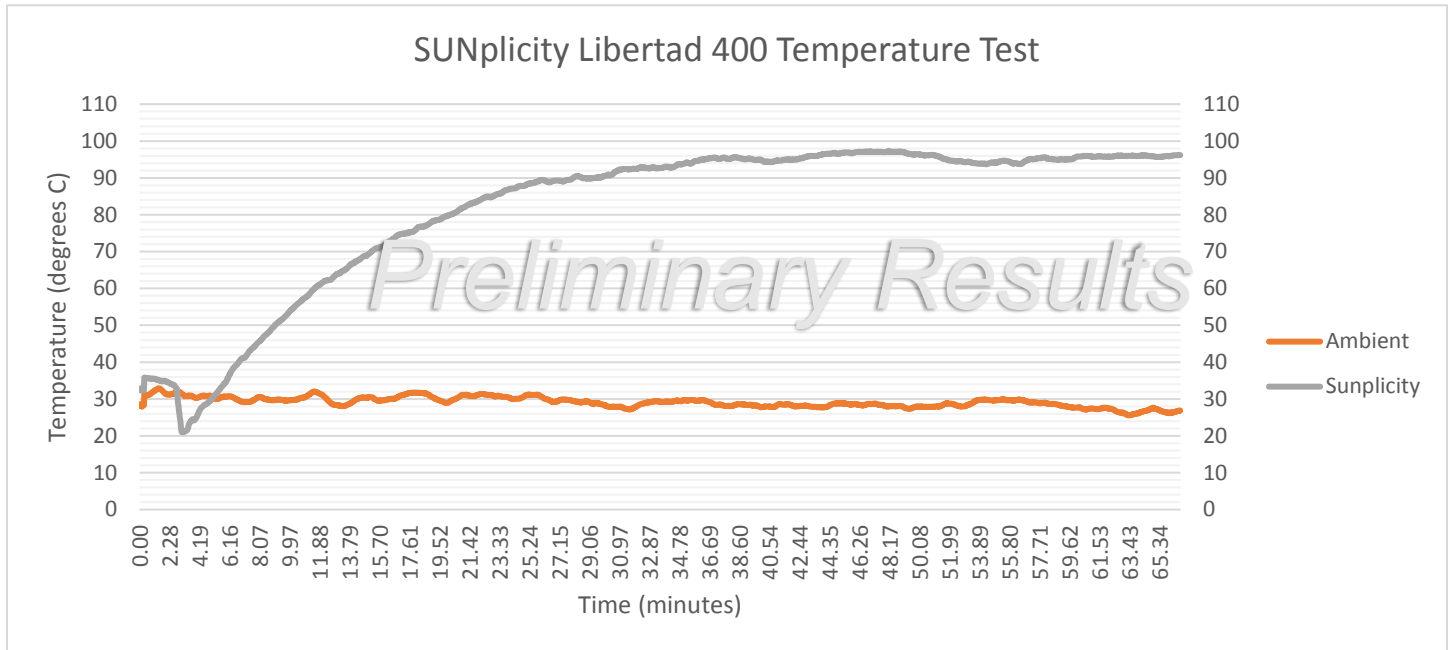
**Test Results:**

	<b>Test 1</b>	<b>Test 2</b>	<b>Test 3</b>
<b>Test Date</b>	1 May 2017		
<b>Latitude</b>	38°43'31.69"N		
<b>Longitude</b>	120°34'96.9"W		
<b>Altitude</b>	1128.1 m		
<b>Average Sun Elevation Angle</b>	66 degrees		
<b>Effective intercept area</b>	0.456 m <sup>2</sup>		
<b>Test Load</b>	1000 g		
<b>Solar Noon</b>	12:58 PM		
<b>Test Duration</b>	1.1 hours		
<b>Time Start</b>	11:30 AM		
<b>Time Finish</b>	12:36 PM		
<b>Tracking interval</b>	20 minutes		
<b>Average ambient temperature</b>	29.17°C		
<b>Average Wind Speed</b>	0.314 m/s		
<b>Number of observations</b>	18		

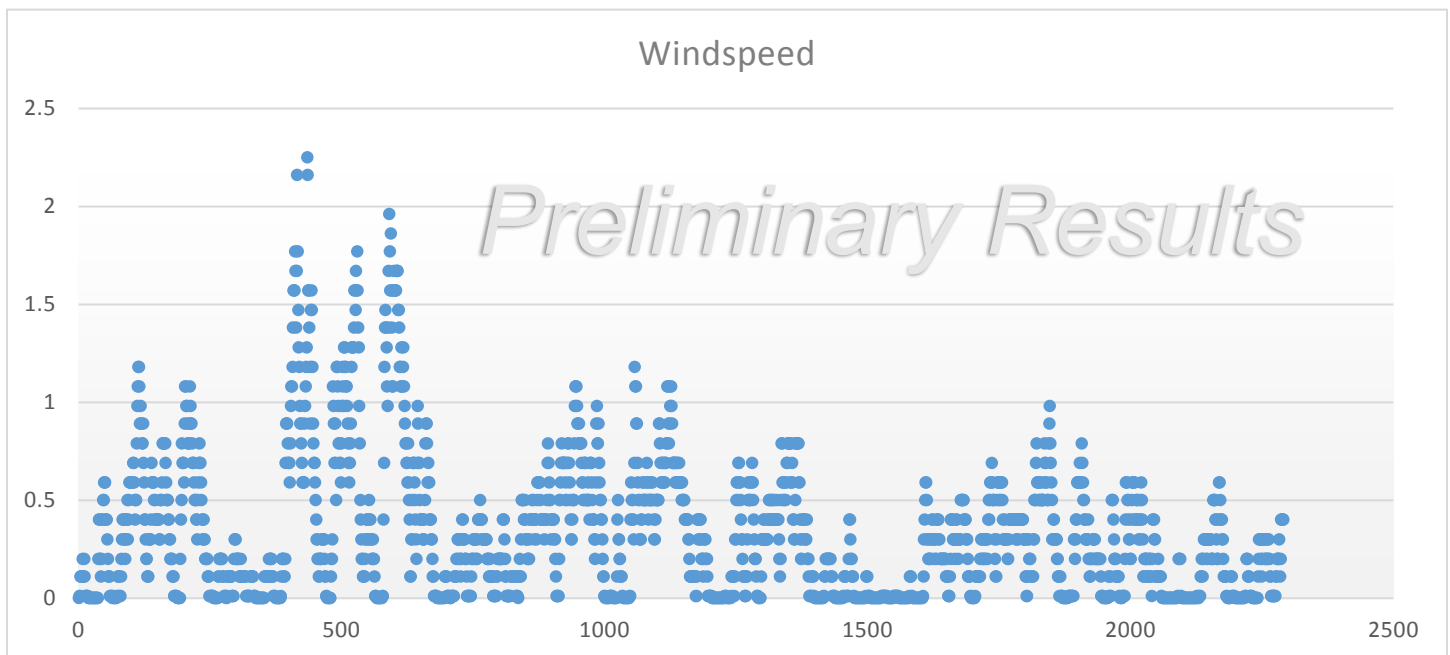
**Results**

This thermal performance evaluation for the Libertad 400 solar cooker took place during 1 May 2017. Graphical visualizations of acquired data are shown below for temperature, wind speed and solar irradiance. The data calculation interval was reduced from 10 minutes (standard protocol) to 2 minutes to provide additional cooking power values during the shortened test time. Following customer’s approval, files of raw data for this one-day test will be available at the SCI PEP website, for SCI Test Code: PEP.P13: [www.solarcookers.org/PEP](http://www.solarcookers.org/PEP)

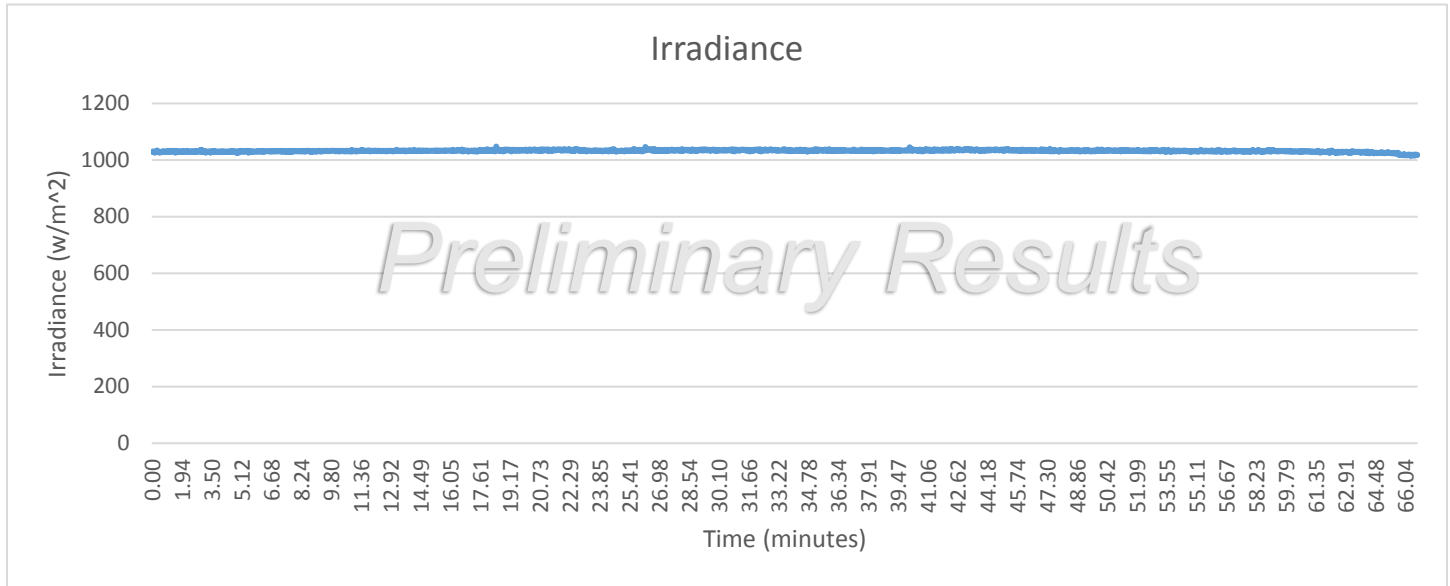
**Test day 1: 1 May 2017**



Temperature profile of 1 liter of water (in gray) and ambient air (in red) recorded on 1 May 2017 while monitoring a Libertad 400 Parabolic solar cooker with customer supplied cooking vessel.

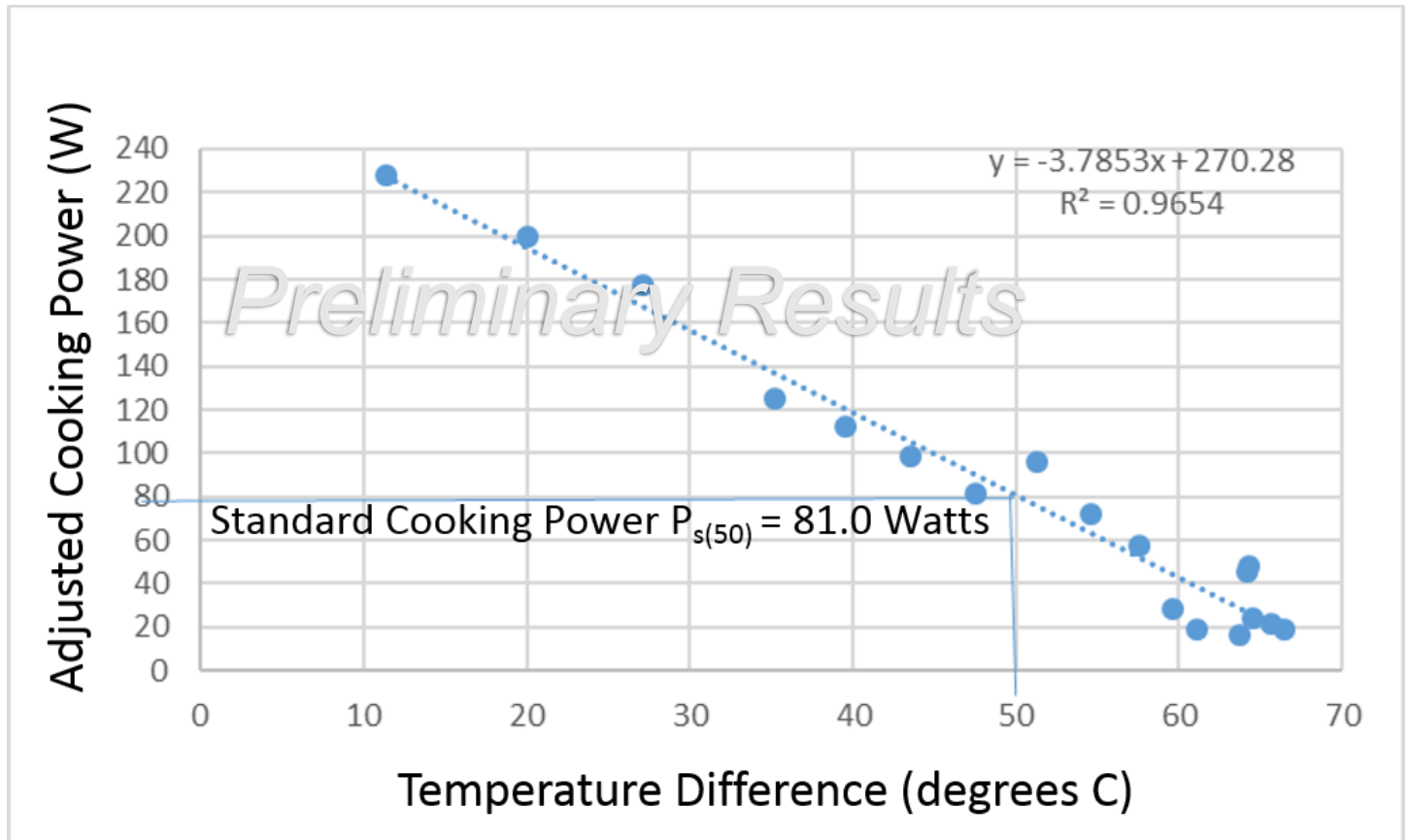


Wind speed recorded on 1 May 2017. This graph shows windspeed values (in m/s) within the constraints of the ASAE S580.1 protocol; hence, there were no rejected data points due to excessive wind conditions.



Solar irradiance recorded on 1 May 2017.

**Final Results: Adjusted cooking power values and the standard cooking power**



Adjusted cooking power for the Libertad 400 reflective-panel solar cooker recorded by an SCI PEP test station on 1 May 2017. While these preliminary results are from a single day of testing producing fewer than the 30 observations required by the ASAE S580.1 protocol, they demonstrate reproducibility.

## APPENDIX A: Standard Cooking Power Calculation

The ASAE S580.1 protocol<sup>1</sup> provides a single measure of performance for solar cookers: the standard cooking power,  $P_{s(50)}$ , in Watts, for a cooking temperature 50 °C above ambient temperature. Cooking power is calculated from measurements of temperature change in an amount of water proportional to a cooker's intercept area (7000 g/m<sup>2</sup>). Results are normalized using incident solar radiation, allowing comparable results independent of testing date and location.

To summarize the ASAE S580.1 protocol, it first calculates the cooking power for a solar cooker using the following equation, where  $P_i$  is the cooking power (W) for a 10 minute interval  $i$ ;  $T_2$  is the final water temperature (°C);  $T_1$  is the initial temperature (°C);  $M$  is water mass (kg); and  $C_v$  is heat capacity of water (4186 J/[kg °C]).

$$P_i = \frac{(T_2 - T_1)MC_v}{600} \quad (\text{eq. 1})$$

Adjusted cooking power,  $P_s$ , for each 10-minute interval is corrected to a standard insolation of 700 W/m<sup>2</sup> by multiplying cooking power  $P_i$  by 700 and dividing by the interval average insolation  $I_i$ ; a term used interchangeably with irradiance in this article.

$$P_s = P_i \left( \frac{700}{I_i} \right) \quad (\text{eq. 2})$$

Standard cooking power,  $P_{s(50)}$  (W), the single measure of performance for a solar cooker, is determined where a linear regression fit to adjusted cooking power values (from no fewer than 30 ten-minute observations, and plotted with respect to temperature above ambient) crosses the temperature-difference value of 50 °C.

### *ASAE S580.1 data collection*

The test results are presented as adjusted cooking power values (in Watts) with no fewer than 30 total (10-minute) observations over three different days. The standard cooking power is determined from a linear fit to the adjusted cooking power values and is presented as a single measure of thermal performance (in Watts) so consumers may compare different designs when selecting a solar cooker

NOTE: for product labeling and sales literature an independent laboratory using a statistically adequate number of trials shall determine this number. While this value, like the fuel economy rating of an automobile, is not a guarantee of performance, it provides consumers with a useful tool for comparison and product selection.

ASAE S580.1 protocol requirements for data collection satisfy the following constraints:

1. **Average wind.** Tests shall be conducted when average wind during the duration of the test is less than 1.0 m/s, measured at the elevation of the cooker being tested and within ten meters of it.
2. **Maximum wind.** Should the wind exceed 2.5 m/s for more than ten minutes the test data shall be discarded.
3. **Wind shielding.** If a wind shelter is required, 1) it shall be designed so as to not interfere with incoming total radiation and 2) the wind instrumentation shall be co-located with the cooker in the same wind shadow.
4. **Ambient temperature.** Tests should be conducted when ambient temperatures range between 20 and 35 °C.
5. **Water temperature.** Test data shall be recorded while cooking vessel contents (water) are at temperatures between 5 °C above ambient and 5 °C below the local boiling point.
6. **Insolation.** Available solar energy shall be measured in the plane perpendicular to direct beam radiation (the maximum reading) using a radiation pyranometer. Variation in measured insolation greater than 100 W/m<sup>2</sup> during a ten-minute interval, or readings below 450 W/m<sup>2</sup> or above 1100 W/m<sup>2</sup> during the test shall render the test invalid. For convenience, the pyranometer may be fixed on the cooker at the average

beam radiation zenith angle as calculated for the entire test period. NOTE: The pyranometer on an SCI PEP test station mounts to a horizontal, bubble-leveled plane, as suggested by the manufacturer. While this positioning differs from the ASAE S580.1 protocol, trigonometric corrections to SCI solar irradiance measurements give accurate results within instrument tolerance, for solar irradiance incident on solar cookers being tested.

7. **Solar zenith and azimuth angle.** Tests should occur between 10:00 and 14:00 solar time. Exceptions necessitated by solar variability or ambient temperature shall be noted.

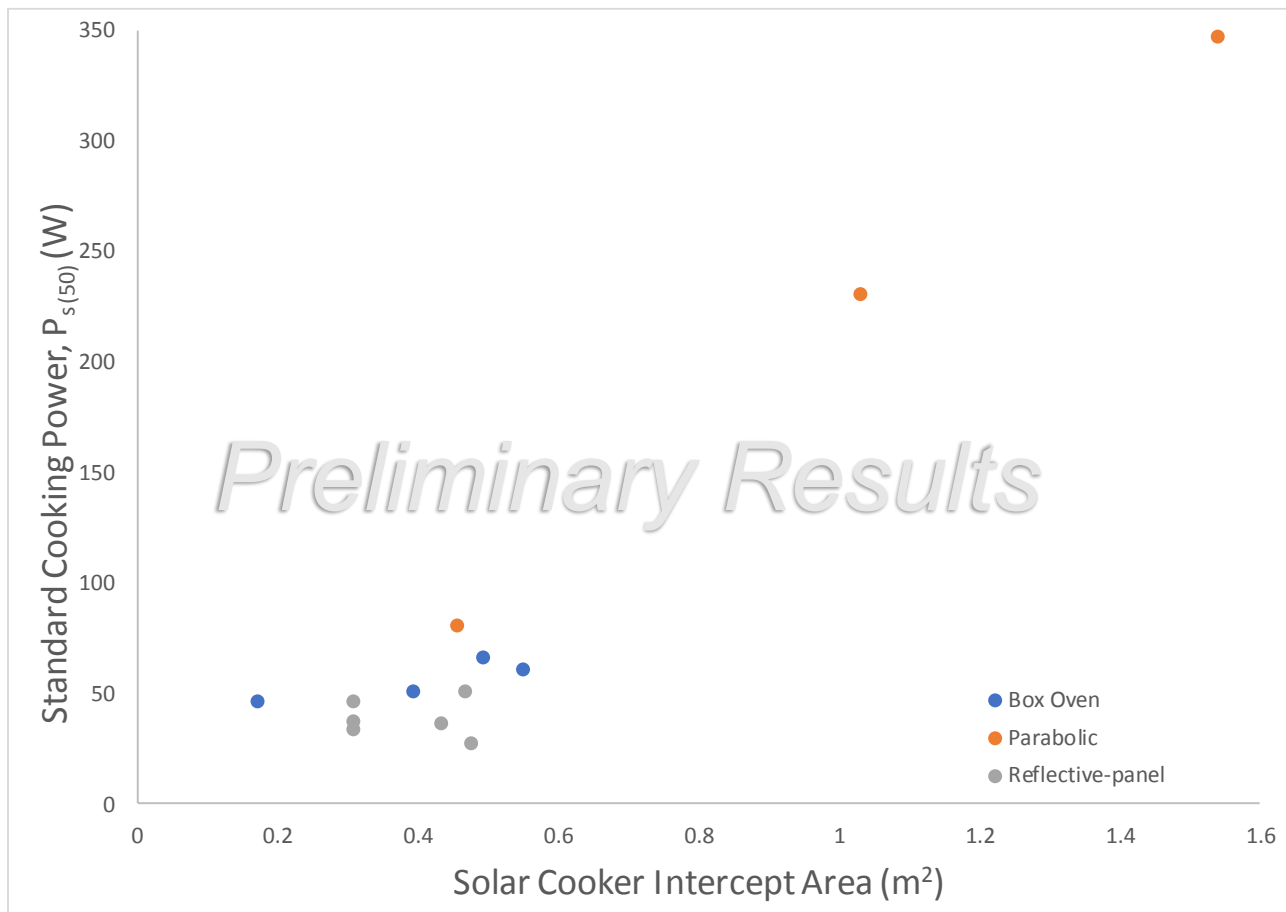
#### References:

1. American Society of Agricultural and Biological Engineers. (2013). ASAE S580.1 Testing and Reporting Solar Cooker Performance. St. Joseph: American Society of Agricultural and Biological Engineers; <https://www.asabe.org/media/200979/s580.1.pdf>

## APPENDIX B: Comparative results

During spring and summer of 2017, SCI applied the PEP testing stations at SCI testing centers in New York, USA and in California, USA for preliminary trials for the three basic types of solar cookers: reflective-panel, box oven, and parabolic reflector. Several solar cooker manufacturers donated products for these trials, and given the preliminary nature of these trials, these manufacturers remain anonymous here.

Preliminary SCI PEP results indicate the standard cooking power (in Watts) for each solar cooker tested. These standard cooking powers, which are each a single measure of performance for a particular solar cooker, are plotted below as a function of intercept area. This graph depicts the general trend that standard cooking power tends to scale with intercept area. These preliminary results are shown for informational purposes only.



Graph of standard cooking powers for the basic types of solar cookers (box oven in blue, parabolic reflector in orange, and reflective-panel in grey, plotted as a function of intercept area.