QUANTIFYING ENERGY SAVINGS OF THERMAL SOLAR COOKERS IN U.S. HOUSEHOLDS

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ABSTRACT

Thermal solar cookers have been used in sunny U.S. locations to cook food to reduce energy consumption, to save money, and to "go off-the-grid." The 2009 Residential Energy Consumption Survey (2009 RECS) data indicates that cooking represents approximately 7% of the total electrical consumption in U.S. households. A significant portion of that energy can be saved by solar cooking, but to date there has been no published data to substantiate this.

In the last decade, we have witnessed acceptance of more efficient household products. Some of these save very little for each household, but have their greatest impact on the larger utility and community scale. For solar cookers to gain acceptance at these levels; however, there must be a better substantiated understanding of the potential savings achievable from them.

As a step in that direction, a survey was conducted interviewing U.S. solar cooks about their cooking habits during the summer of 2012. Several survey questions paralleled the 2009 and 2012 RECS.

The surveyed solar cooking households averaged over 70 solar cooking days in 2012, saving 33% of their total cooking energy during the solar cooking months. This was estimated to be equal to 15% of their total annual cooking energy. The survey results indicate that an average U.S. solar cooking household would save 190 kWh per year. Encouragingly, the survey results are not as climate-correlated as had been supposed.

1. INTRODUCTION TO SOLAR COOKERS

There are many dedicated energy-conserving and sustainability-promoting people who do not know what thermal solar cookers are. In contrast, one may not (yet) have a photovoltaic system installed on their roof, but most people would have at least a vague notion of what an inverter is. Likewise, to spot an article in a cooking blog on "how to brine your Thanksgiving turkey" would not seem out of place to many U.S. cooks; but solar cooking, a slow cook, juicy, perhaps more vitamin retaining cooking method that keeps your kitchen cool in the summer, has somehow slipped mainstream notice.

Food drying is reputed to be the earliest use of the sun to prepare food with records of this dating as far back as the 1200s (1) and likely much earlier. The idea of solar cooking food seems to have emerged and gained momentum over the last 100 years (2).

Using a glazing material as a solar heat trap is one principle frequently included in a solar cooker design; others are the use a dark cooking pot for absorbing solar energy, and the use of reflectors to concentrate the sunlight. The classic **box cooker** is in its most basic form is an insulated box with glazing. A dark pot with food inside is placed in the cooker (Fig. 1)

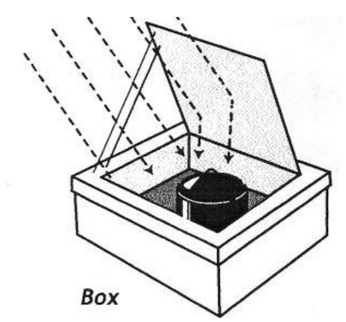

Fig. 1: Box-Style Cooker (3)

The **panel cooker** (Fig. 2) uses a reflector to direct sunlight to a dark pot placed inside a solar heat trap, such as a glass bowl or turkey oven bag.

The panel style cooker tends to be used for simmering food at lower temperatures, in the 220 °F range. The box cookers commonly achieve 100 °F higher temperatures, so that bread and cakes can be cooked in them.

The **concentrator cooker** (Fig. 3) produces the highest temperatures, relying on a large re-flector to focus the solar energy on a suspended cooking vessel. This style of solar cooker can be used to fry food. Solar cooking methods some-times blur and stretch beyond these simple stereotypes.

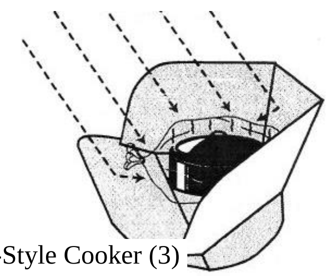

Fig. 2: Panel-Style Cooker (3)

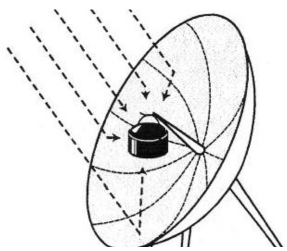

Fig. 3: Concentrator- Style Cooker (3)

More than 30 commercially available solar cookers sold in the U.S, many with special features and enhance-ments (4). There are many do-it-yourself designs available using materials including cardboard boxes and windshield sunscreens (5). Over a dozen solar cooker cookbooks are available. A subculture of solar cooks thrives in the U.S.as evidenced by the Solar Cooking Yahoo group discussing designs, recipes, and tweaks (6).

In lesser affluent parts of the world solar cookers raise a household's standard of living by offering a way to save on the cost of cooking fuel and to pasteurize water. When the usual fuel is wood or charcoal, there is the secondary benefit of improved kitchen indoor air quality (to the household), and reduced deforestation (to us all). Estimating household solar cooker energy savings has been the purview of non-profit organizations evaluating the effectiveness of their programs (9)(10)(11). Though there has been solar cooker research and development in the U.S., for instance the work done at UNM during the last 8 years (12) and the work done in Sacramento over a decade ago (13)(14), a survey of U.S. solar cooking household habits has not been published.

2. SURVEY OBJECTIVES

The objective of this survey is to establish the savings potential of solar cookers in the U.S. This has been shown to be as an important step in that process which has proven helpful with other "now emerged" technologies. This process has been characterized by three stages: evolution, entrepreneurism, and policy (7). Establishing savings potential for solar cookers is a "precursor to collaboration with utilities for the purpose of displacing the purchase of fossil fuel generated power. This kind of strategy has worked to mainstream compact florescent light bulbs and many energy efficient appliances."(8)

The following questions were asked about the collected data:

- Can the survey data be used to provide an estimate of energy saved by a household that regularly solar cooks?
- Can the survey's sample of U.S. households which regularly solar cook be compared to average national data (RECS 2009) in a useful way?

The quick answers are "yes" and "a definite yes" with elaboration in the following sections:

3. METHOD

3.1 Respondent Search

From October 2013 through February 2013, surveys were distributed. The first 20 respondents were from Sacramento area households which were at least indirectly known to the prime investigator through her involvement in demonstrating solar cooking at community events. Several other networks were successfully tapped to find survey respondents including contacting several U.S. non-profit solar organizations, and contacting solar cooker suppliers. Several organizations posted the request for respondents on Facebook (FB), and Solar Cookers International in particular supported the survey with FB postings, tweets, and space on their solar cooking wiki. The Yahoo Solar Cooking Group was notified and became a good way to inform the solar cooking community of the survey.

3.2 Respondent Criterion and Sample Population

There is a learning curve to using certain types of solar cookers. Cooking with a panel or box type solar cooker has been compared similar to cooking with an electric crock pot: the time to finish is slower than cooking on a traditional stove or oven and one has to typically tweak favorite recipes to get the moisture content the same as with a traditional stove or oven. Another well-known tale is that a person will buy a solar cooker, cook extensively with it for a while and then put the cooker in the closet to gather dust. To gather data from households that had achieved a certain amount of stability in how they used their solar cookers, it was decided that a qualifying survey respondent had to be in a household that had used their solar cooker(s) at least one year. Conversely, if a respondent reported that they did not solar cook during the 2012, but had solar cooked at least one year and identified themselves as being a part of a solar cooking household, their data was included in this survey.

After eliminating duplicate responses[1] and responses from households that had recently begun solar cooking, this study used data from 85 solar cooking households.

3.3 Questionnaire and RECS Data

The questionnaire consisted of less than 40 questions which asked about a household's demographics, solar cookers and their use, and traditional cooking appliances and their use. Survey questions necessarily drew upon people's qualitative memories of their 2012 solar cooking season while, minimizing their biases.

The questions about a household's traditional cooking appliances paralleled questions administered by the U.S. Energy Information Administration (EIA) in their triennial Residential Energy Consumption Survey (RECS). The RECS collects comprehensive national data on both consumption and expenditures for energy in the residential sector of the economy. Data are used for analyzing and forecasting residential energy consumption. Housing, appliance, and demographic characteristics data are collected via personal interviews with households, and consumption and expenditure billing data are collected from the energy suppliers. End-use intensities are produced for space heating, water heating, air conditioning, refrigerators, and appliances. Surveys were conducted every three years since 1978. The most recent survey completed in 2009 collected data from over 12,000 households statistically selected to represent the approximately 114 million households.

RECS data is publically available as standardized reports available on the EIA website and also as raw data downloadable as .csv files. Because of the availability of raw data from the 2009 RECS and the general public acceptance of the reports and conclusions drawn from this data by EIA, the questionnaire used 2009 RECS questions where possible. This allows comparisons between the collected solar cooking data and the RECS data.

4. RESULTS: ANNUAL COOKING ENERGY SAVINGS ($E_{sc\ yr}$)

The experience of the author indicates that several factors affect how much a solar cooker is used in a year and therefore how much energy it saved. These factors include the frequency of solar cooking, the length of the solar cooking season, and how solar cooker is used. Average energy savings can thus be expressed as follows:

$$E_{sc\ yr} = \sum_{i=1}^{n} (f_i \ x \ 4.33 \ x \ S_i \ x \ e_{sc\ day\ i}) \ / \ n \qquad (1)$$

where

$E_{sc\ yr}$ Average annual energy saved per solar cooking household, % of total cooking energy

n Number of households

f Frequency that a household solar cooks during the solar cooking season , days/week

4.33 Conversion, weeks/month

S Solar cooking season, months/year

$e_{sc\ day}$ Daily energy saved when household solar cooks, % of total cooking energy

Each term of the equation will be discussed in detail in the next subsections. Table 1 below is a summary of the term averages. The surveyed solar households averaged over 70 solar cooking days in 2012, saving 33% of their total cooking energy during the solar cooking months which is estimated to be equal to 15% of their total annual cooking energy:

TABLE 1: AVERAGE VALUES of TERMS in EQN 1

TERM	VALUE
n	85 solar cooking households surveyed
f_{ave}	2.9 solar cooking days/week (mean average)
S_{ave}	6 solar cooking months/year (mode average)
$e_{sc\ day\ ave}$	80% saved daily when solar cooking (mean average)
$E_{sc\ yr}$	15% annual cooking savings by solar cooking households

Note: $E_{sc\ yr}$ is calculated by multiplying f, S, and $e_{sc\ day}$ for each household. This product is then averaged for the 85 surveyed households.

4.1 Frequency that a Household Solar Cooks (f)

Respondents were asked to estimate the number of days per week that someone in their household solar cooked during the solar cooking season of 2012 (f) in the following question:

It has been suggested that in [Alabama and Georgia] there are [5] "pretty good" months for solar cooking, [April through Aug]. How many days per week during those months does someone in your household use a solar cooker?

The survey question was tailored to the climate where the respondent lived. To do that, each respondent was first asked their zip code and a quick check was made of where the respondent lived and the question was suitably modified before querying. The frequency distribution of responses to the question (f) is shown below:

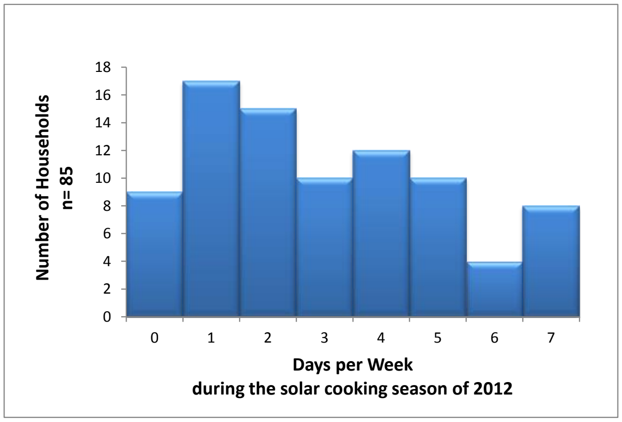

Fig. 4: How Often Households Solar Cooked (*f*)

Responses of 0-0.49 days per week were graphed as "0", 0.50 through 1.49 days per week were graphed as "1", etc. Some respondents answered with a range of days; in those cases the mean of the range was used. Some respondents kept detailed records and had very precise answers such as "2.4 days per week". There were a few solar cooks who did not solar cook at all during the summer of 2012, people who had solar cooked in years past and expected to solar cook in the future. A greater number of zeroes, however, were obtained from responses such as "once per month" or "2-3 times last summer in our RV".

4.2 Weather Suitable for Solar Cooking *(S)*

Solar data from the Solar Prospector website (http://maps.nrel.gov/prospector) was used to tailor the question for each respondent. The website, developed by National Renewable Energy Laboratory, is a public GIS mapping and analysis tool. Entering a respondent's zip code, a nearby weather station was selected and its average monthly solar data could be reviewed. The threshold of what was termed a "pretty good" month was one with an average GHI (global horizontal irradiance) of at least 5.0 kWh/m^2-day.[2] The distribution of respondent locations compiled by "pretty good" solar cooking months is shown below:

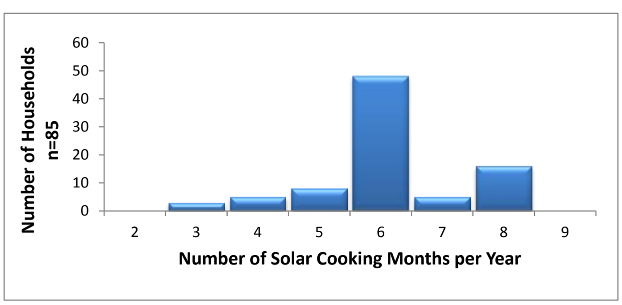

Fig. 5: Solar Cooking Season (*S*)

At the conclusion of the survey the comment section of each survey was combed for remarks about the "pretty good months" question. Fourteen percent of the respondents reported that the survey had understated the solar cooking season. On average, that group of commenters solar cooked over 10 months in 2012.

4.3 Daily Energy Saved when Household Solar Cooks ($e_{sc\ day}$)

The respondents were asked about the typical meals that they solar cooked:

On those days in the summer [when you solar cook], is hot food usually prepared for lunch? For dinner? For both?

Ninety percent of the respondents reported that they solar cooked dinner and a surprising 50% cooked lunch, that is, they succeeded in regularly solar cooking with just half of a day of sunshine. Nineteen percent of the respondents supplemented their answer by reporting that they solar cooked other times also: mostly breakfasts, and cooking in quantity for future meals. Baking breads and desserts were also specifically mentioned. A distribution of responses is shown below:

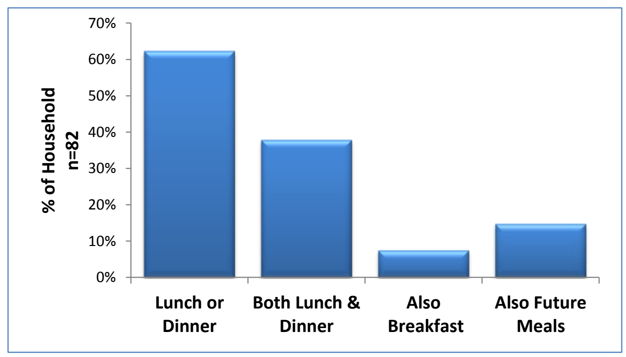

Fig. 6: Typical Meals Solar Cooked

It was assumed that a household's main meal, either a solar cooked lunch or dinner, saved 75% of the daily cooking energy. This compares favorably with solar cooking research being done: 75% of the average daily U.S. cooking energy is equivalent to the stove top cooking of about 1 cup of dried chickpeas/garbanzo beans (15). It was assumed that a second or third solar cooked meal saved an additional 10% of the household's daily cooking energy each. If it was reported that three meals were solar cooked, it was assumed that 95% of the daily cooking energy was saved with the last 5% still being used in traditional heating methods for making hot beverages, snacks, and reheating.

4.5 Qualitative Discussion of Bias in $E_{ave\ yr}$, f, S, and $e_{sc\ day}$

To use this data to make a claim of statistical confidence would not be appropriate. Obtaining a larger population sample would be desirable and using a study methodology which included a random sampling component would be essential. Bearing this mind, however, the data is still useful, because it offers a snapshot of solar cooking households. This initial survey points to future possibilities and is intended to encourage more encompassing and statistically robust work.

The respondents were solar cooker enthusiasts. Though it was explained to all respondents that they should answer the questions as best they recall, there was the possibility that they would unintentionally overstate the amount of solar cooking they did in 2012. To minimize this expected "overstating" bias, survey questions were designed to query a respondent regarding their household's equipment, "what type and how many…" which should have been accurately remembered. And if a question relied on an estimate from the respondent, a "how often did you..." question, it was framed in terms of "times per day", "times per week", etc. which seemed to be answered by the respondents with a lesser amount judging and "correcting". To also minimize the "overstating" bias, the households that did not solar cook in 2012 (but had done so in the past and planned to do so in the future) were included in the survey.

In addition, there were other survey biases which likely would have resulted in under-calculating the savings estimates. For instance, since many of the respondents volunteered information that they solar cooked more than just lunch and/or dinner, and because this information was not collected from of all respondents, an energy saving credit for this reported tendency could not be incorporated in $e_{sc\ day}$, except for the few respondents who volunteered information. This type of ambiguity would affect either f or $e_{sc\ day}$. For either variable, it is likely that the ambiguity would tend to create an "under-stating" bias in the energy saved estimate, $E_{ave\ yr}$.

This was supported by the responses to several questions about other ways solar cookers were used in households:

Are your solar cookers used for other cooking uses?
1. Food drying 2. Food canning 3. Other
Are they used for other than cooking?

Fifty-four percent of the households used their solar cookers for other food related cooking, and a third of the households listed at least one non-food cooking use of their solar cooker:

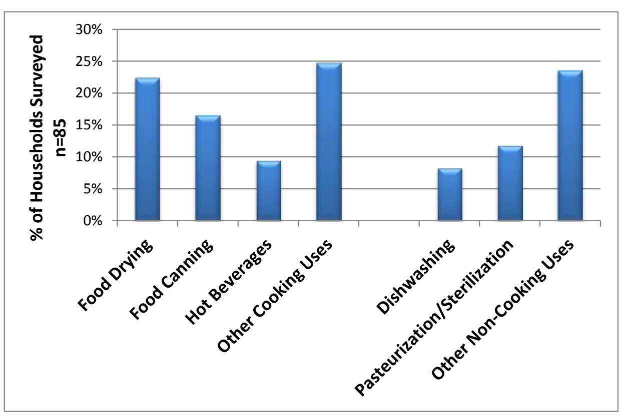

Fig. 7: Other Solar Cooker Uses

5. RESULTS: COMPARISON TO 2009 RECS

Solar cooking survey respondents were asked several questions regarding their "traditional" cooking appliances which were identical to 2009 RECS survey questions, including what type of cooking appliances the households had, including stoves, stovetops, wall ovens, microwave ovens, outdoor grills, indoor grills, toaster ovens and coffee makers. A side-by-side comparison of responses is as follows:

TABLE 2: TRADITIONAL COOKING APPLIANCES

Households having at least one:	SURVEY	2009 RECS
Stove, Oven, or Combination	99%	100%
Microwave Oven	85%	96%
Toaster Oven	47%	37%
Coffee Maker	48%	63%

A comparison between the survey and 2009 RECS shows that the solar cooking households reported that they used their oven and /or stove more often than the RECS survey households <u>when they were not solar cooking</u>. Solar cooking households also report that they ate at home more often:

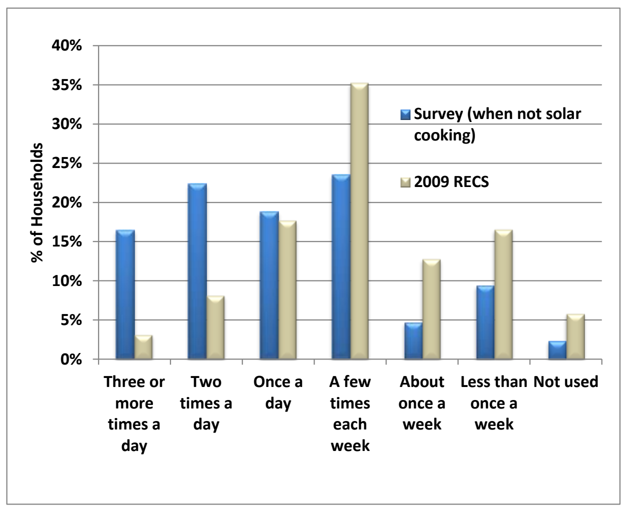

Fig. 8: Oven and Stove Use

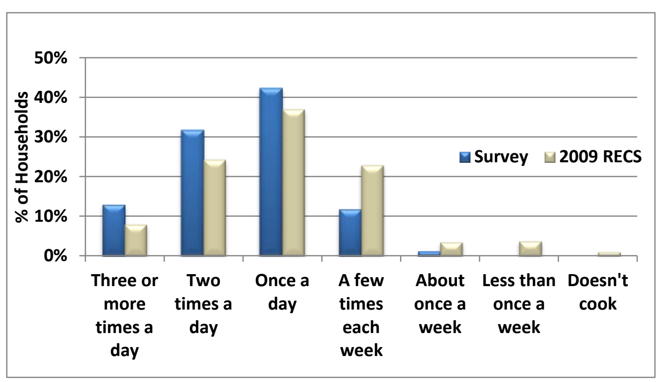

Fig. 9: Hot Meals Cooked at Home

From the comparisons it appears that the surveyed solar cooking households appear to be close to the norm, except in one respect. It appears that the ages of the members of the household are older in the surveyed solar cooking households than in the 2012 RECS. If this is truly a trend, this could be significant for solar marketing and incentive program design:

TABLE 3: AGES OF HOUSEHOLD MEMBERS

	Survey	2012 RECS
Members under 6 years	0%	9%
Members 6-11 years	2%	10%
Members 12-17 years	5%	10%
Members 18-64 years	40%	54%
Members over 65 years	53%	17%

If this is truly a trend, this could be significant for solar marketing and incentive program design:

6. OTHER RESULTS

6.1 Solar Cooking Appliances in Households

A surprise for some may be that most of the surveyed households owned many more than one solar cooker:

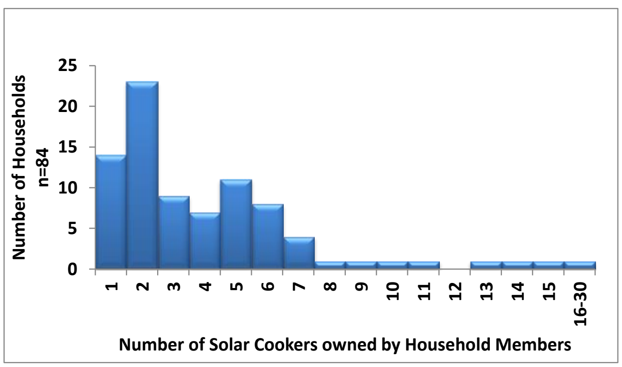

Fig. 10: Solar Cookers Owned by Household

Of those solar cooking appliances, 34% were panel style cookers (Fig.1), 43% were box style cookers (Fig. 2), and 13% were concentrating style cookers (Fig. 3). And 11% of the cookers did not fall neatly into any of those three categories.

6.2 Solar Cooking Frequency versus. Climate

Another surprise may be that solar cooking frequency was not found to be a strong function of a sunny climate. The box and whisker plot shows the maximum, "75%" quartile, median, "25%" quartile and the minimum solar cooking frequency group by number of solar cooking months[3]:

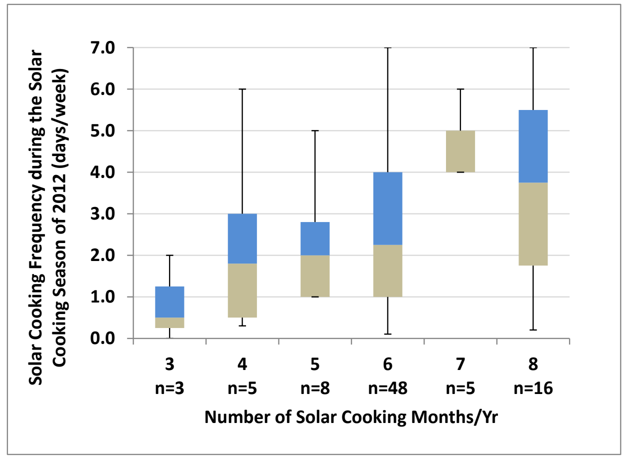

Fig. 11: Solar Cooking Frequency as a Function of Climate

Note that for climates with 4-6 solar cooking months per year, the box lengths are very similar and the means are essentially the same. U.S. areas with 4-6 solar cooking months include all of southern U.S. except parts of California, Arizona, Utah, New Mexico, and Texas which have more months. It also includes areas as far north as Idaho, Minnesota, and Maine. In other words, most households used their solar cookers about 2 days per weeks when the sunshine shone no matter where they lived in the U.S.

7. CONCLUSIONS AND NEXT STEPS

A result from the 2009 RECS is that 6.5% of the average U.S. household energy is consumed by the range top, oven, micro-wave, and toaster oven. That amounts to 1240 kWh per year or 3.4 kWh per day. The annual average household savings because of solar cooking then would be as follows:

1240 kWh/yr x 15% saved by solar cooking = 190 kWh/yr

Using Pacific Gas & Electric's (PG&E) current residential elec-tricity rates, gives the following annual cost savings. These do not include the additional smaller order air-conditioning savings for not having to remove the cooking heat from the home:

TABLE 4: ANNUAL SOLAR COOKER COST SAVINGS

	PG&E Tier 1	PG&E Tier 4
Solar cooking savings (kWh/yr)	190	190
Cost of electicity ($/kWh)	$ 0.13	$ 0.36
Solar cooking savings ($/yr)	$ 25.00	$ 68.00

Though there is a wealth of speculation and study of why ostensibly cost-effective energy efficiency technologies are not widely adopted (7)(16)(17), clearly with respect to solar cooking, a $25 to $68 annual savings will not substantially enter into a household's buying decision. Solar cookers cannot be sold on the basis of cost savings alone. Nevertheless in the last decade, other technologies with similar market obstacles have gained wide acceptance.

What kind of nurturing does the solar cooker technology need to become more widespread in the U.S.? For instance, if 50,000 households saved 15% of their cooking energy by solar cooking then the 190 kWh/yr savings per household translates into 9,500 MWh/yr or over $1 million dollars for a community. From a utility standpoint there is additional peak demand reduction associated with solar cooking. These are obtainable benefits.

What about utility support? To make solar cooking a candidate for a utility conservation acquisition program, more and statistically more robust surveys may be required to create confidence in the potential energy savings. This survey is an initial step. Other further steps could include pilot programs and household monitoring. Nevertheless, there is a tendency to assume we need hard direct measured data to make utility decisions. That is not necessarily the case. Multiple highly distributed points of conservation, such as solar cooking, may just require robust ball-park numbers to determine how, not if, they can be accepted in a conservation acquisition program. That is, the net energy saving potential of solar cooking may not merit a separate utility program, but may be sufficient to be included in a broader program.

Equation 1 can form the basis of a methodology to verify energy savings, an essential component of any utility conservation acquisition program. The equation is based upon the experience of solar cooking households and includes relevant factors that impact the amount of solar cooking done. It opens the way for verification from an inexpensive survey oriented approach:

$$E_{sc\ yr} = \sum_{i=1}^{n} (f_i \ x\ 4.33\ x\ S_i\ x\ e_{sc\ day\ i}) \,/\, n \qquad (1)$$

Still to be done is gaining a better understanding of the "persistence of savings" of a solar cooker program, i.e. how long do solar cookers last and how long will owners continue to use them.

On the state and national level, policy makers should be made aware that solar cooking has the potential to be a low-cost viable energy saving technology.

Here are some things that the solar cooker community can be doing now to assist the process: fostering lifestyles that include solar cooking (thereby increasing the scale of the market and the persistence of savings) and continuing to collect long term data (increasing data robustness and showing trends). The way forward needs to be inexpensive. The key resource is the already proactive solar community.

We, the solar community, also should insist that solar cookers are added to the everyday energy saving and sustainability vernacular. They should be included in the numerous publicized lists of "Tips to Save Energy" promulgated by utilities and government agencies. For example, PG&E's residential customers recently received the first of semiannual "Climate Credits" ($30 for this author's household). The money could be used in anyway, but we were encouraged to invest it on energy efficient measures: "…you'll see even more savings. And our climate will be the better for it." (18) Solar cookers were not to be seen on the list of good ideas.

Yet the cost of a manufactured solar cooker starts at $40. You can make your own for less than $10. Isn't it about time to have solar cooking acknowledged as an effective energy technology?

8. ACKNOWLEDGEMENTS

I thank Jon Biemer, P.E. of Creating Sustainability, Portland OR who was instrumental in encouraging me to look at how this survey fits into the big picture. I thank Bill Blackburn who was my chief editor and is my partner in solar cooking (among other things).

I also thank the following people and organizations for their time and other resources in getting the word out about the survey: Solar Cookers International in Sacramento CA, Citizen for Solar centered in Tucson AZ, Solar Household Energy headquartered in Chevy Chase MD, Cantina West in St. George UT, those involves with the solar cooking work done at the University of New Mexico, Gallup NM, and, definitely not least of this list, Yahoo Solar Cooking Group. I also thank all of the solar cooks who participated in this survey. Any errors herein were mine in the making.

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[1] There appeared to be a couple both of whom completed the survey. They had different last names, but the same zip code and the same number of solar cookers and kids. They disagreed on the age of one of the kids.

[2] This threshold was chosen based upon several prior interviews with active solar cooks in Sacramento and Seattle areas who were asked in which months they did their solar cooking. In Sacramento, it was generally reported that April through September were “pretty good” solar cooking months. In Seattle from July through September was deemed “pretty good”. These anecdotal responses where compared to the Solar Prospector irradiance for those locations to arrive with the threshold.

[3] For each climate ranging from n=3 being Seattle and n=8 being Tucson, the beige/blue belly band of each box indicates the average solar cooking frequency for households in that climate. Each box brackets the 25% - 75% quartiles, or the middle half of the survey responses. That would be like the center peak of a normal distribution curve. This survey data, by the way, is non- normal; however, one can still speak of quartiles even in a non-normal frequency distribution. The “whiskers” are the ¼ of the respondents above and below the box (the tails in a normal distribution curve).