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Results of Testing the EcoPlancha III Cookstove in Antigua, Guatemala for EcoComal and StoveTeam International

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June-July, 2016

Abstract

The EcoPlancha III biomass cookstove developed by Marco Tulio and produced at the EcoComal factory in Guatemala was evaluated for fuel use, emissions, safety, design, and user experience by Oregon State University students and faculty in June of 2016. The stove design includes a ceramic rocket elbow combustion chamber, a steel plancha with multiple sizes of removable pot rings, and a chimney. The stove performance was tested using the Water Boiling Test and Controlled Cooking Test with six local cooks. Emissions were quantified using the Aprovecho Portable Emissions Monitoring System and Indoor Air Pollution Monitor for personal exposure measurements. Results of the WBT showed Tier 1 performance for thermal efficiency and Tier 4 performance for indoor emissions escaping from the stove body according to the ISO IWA tiers of performance. Total emissions out the chimney were not measured. While relatively low heat transfer efficiency for water boiling is typical of stoves equipped with chimneys and planchas designed for frying tasks, there are several recommendations for improving this performance including improving air flow through the fuel shelf and increasing the area of the flow channels under the plancha and through the chimney. Results of the CCT performed 5 times by each cook indicated that the in-field use of the EcoPlancha to prepare a typical meal of beans, rice, and tortillas by experienced local cooks indicated an average reduction in fuel use of approximately 29% and a 32% reduction in cooking time as compared to the three-stone fire. Emissions released into the room showed a 98% decrease in CO and a 96% decrease in particulate matter as measured by the PEMS above the stove body, corresponding to an estimated reduction in exposure to the cook of 78% for CO and 73% for particulate matter as measured by the personal exposure monitor in a statistically insignificant sample of one cook each. Surveys with all cooks following the CCT revealed that four out of six cooks were extremely satisfied with the stove and they appreciated the time savings, reduction in smoke, and the ability to cook multiple items at once. If possible some indicated they would like to be able to cook larger quantities of food and be provided with a grill or barbeque accessory. According to the biomass stove safety evaluation, the cookstove achieved a rating of Tier 1, however this could be increased to Tier 3 relatively easily by fully shielding the chimney and following the design recommendations to increase draft through the stove.

Introduction

The Ecoplancha III biomass cookstove (Firgure 1A) was tested at the EcoComal Factory outside of Antigua Guatemala during a field course for the humanitarian engineering program at Oregon State University with the support of StoveTeam International. Two test series were conducted to determine the performance of the new stove design, including the Water Boiling Test (WBT) 4.2 to measure efficiency and emissions under standardized conditions (Bailis et al., 2007), and the Controlled Cooking Test (CCT) to quantify fuel and time savings offered by the stove relative to the three-stone fire (Bailis, 2004). Emissions were measured using two systems on loan from Aprovecho Research Center including the Portable Emissions Monitoring System (PEMS) which captured emissions escaping the stove body (as opposed to out of the chimney), and the Indoor Air Pollution Monitor operating as a personal exposure monitor by being worn in a backpack with a sampling point near the breathing zone of the user (Figure 1B). Upon completion of the CCT, a survey was conducted with the cooks to determine their satisfaction with the stove design and any recommendations for improvements they may have had. Safety tests and design evaluations were also performed on this stove.

(A) **(B)**

Figure 1. The Ecoplancha Stove (A) in use by local cooks while preparing tortillas, and (B) with cook wearing IAP monitor

The Ecoplancha III Stove consists of a rocket elbow combustion chamber, a steel plancha with three pot holes equipped with multiple sizes of removable rings, and a chimney. Stoves of this design are useful for tasks that involve boiling, such as soups, beans, and stews; in addition

to frying tasks such as cooking tortillas which are a staple food in Guatemala. The combustion chamber is made of baldosa with a novel fuel shelf made from baldosa with five 1-inch holes to allow for airflow. The stove body is made of reinforced concrete with lightweight bricks added along the bottom of the flow channel underneath the plancha. There are tile shelves added along the sides of the plancha which serve as a counter space to set implements and increase usability. The plancha is made of durable steel with space for three pots of various sizes decreasing in size toward the chimney and equipped with 1-3 sizes of removable pot rings in each pot space. A narrow channel leads to the 9-cm diameter chimney equipped with metal mesh shielding and a chimney cap.

The hardwood *Grevillea Robusta,* or silky oak, was purchased locally for use as fuel. This was reportedly the most common wood for both purchase and collection in the communities in this region due to the abundance of the species resulting from its use to provide shade in coffee plantations. The wood was purchased in bundles cut and split into average sizes of 3 cm X 3 cm by 30 cm long pieces (Figure 2). The fuel had been air dried prior to purchase. Due to unforeseen circumstances researchers were unable to bring a sample to the US for testing of moisture content or heating value, so a moisture content of 10% on a wet basis and higher heating value of 25,760 kJ/kg from the literature were assumed (Chand and Singh, 2003).

Figure 2. Fuelwood available for purchase

This report will highlight the results of these evaluations in the following sections:

1. Water Boiling Test
2. Controlled Cooking Test
3. User Feedback Survey
4. Safety Evaluation
5. Flow Path Evaluation
6. Conclusions and Recommendations

Annex 1. ISO/IWA Performance Certificate

1. Water Boiling Test

Project Lead: Jessica Chadwick, Ecological Engineering

The EcoPlancha III was tested using the Water Boiling Test (WBT) and processing spreadsheet version 4.2.3 in order to evaluate the efficiency and emissions performance of the cookstove on a standardized basis. The WBT is intended to be a laboratory test with conditions such as heating procedure, pot size, tending method, and fuel supply maintained as consistently as possible across tests and testing facilities. The WBT consists of three phases to fully capture the performance of the stove, including cold start, hot start, and simmer. In the first phase of the test, 5 Liters of water in the primary pot are brought to a boil with the stove operating at high power and starting with a cold body. In the second phase, a second batch of room-temperature water is brought to a boil in the primary pot with the stove body already hot. Finally, the water in the primary pot is simmered at low power at a target of 3°C below boiling temperature for 45 minutes. The second and third pot holes of the EcoPlancha were also equipped with pots containing 2.5 liters and 0.5 liters of water, respectively. The water temperature of these was monitored to credit the heat transfer into these pots as well.

For measurement of emissions, the Portable Emissions Monitoring System (PEMS) designed and on loan from Aprovecho Research Center was used. The PEMS consists of a hood structure, blower and flow measurement system, and sensor-based data acquisition system. The PEMS was hung 1 meter above the stove body to capture the emissions escaping from the body, known as fugitive emissions, in order to quantify the *indoor emissions* released into the kitchen which were of more interest than the *total emissions* which were exiting the

chimney and not measured (Figure 3). The equipment collects and records the levels of CO_2, CO, and PM in real-time during the tests.

Figure 3. PEMS setup above EcoPlancha

The goal of the testing was to quantify the stove's performance in relation to the ISO/IWA tiers of performance (Table 1). These tiers are the result of nearly a decade of international collaboration toward a standard methodology and set of metrics on which to compare performance of cookstoves. The tiers are designed to indicate the relative performance in nine areas, ranging from Tier 0 which is representative of the three-stone fire, all the way to Tier 4 which represents the aspirational, health-protective performance similar to that of LPG. Tiers are evaluated in terms of heat transfer efficiency, total emissions, indoor emissions, and safety.

Table 1. ISO/IWA Tiers of Performance Definitions

	units	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4
High Power Thermal Efficiency	%	< 0.15	≥ 0.15	≥ 0.25	≥ 0.35	≥ 0.45
Low Power Specific Consumption	MJ/min/L	> 0.05	≤ 0.05	≤ 0.04	≤ 0.03	≤ 0.02
High Power CO	g/MJ_d	> 16	≤ 16	≤ 11	≤ 9	≤ 8
Low Power CO	g/min/L	> 0.2	≤ 0.2	≤ 0.13	≤ 0.1	≤ 0.09
High Power PM	mg/MJ_d	> 979	≤ 979	≤ 386	≤ 168	≤ 41
Low Power PM	mg/min/L	> 8	≤ 8	≤ 4	≤ 2	≤ 1
Indoor Emissions CO	g/min	> 0.97	≤ 0.97	≤ 0.62	≤ 0.49	≤ 0.42
Indoor Emissions PM	mg/min	> 40	≤ 40	≤ 17	≤ 8	≤ 2
Safety		< 45	≥ 45	≥ 75	≥ 88	≥ 95

WBT Results

The results of the WBT for the Ecoplancha III showed excellent indoor emissions performance but less than optimal heat transfer, as would be generally expected for a plancha stove with a chimney. The chimney successfully removed most of the emissions from the room through the chimney, with the exception of 0.03 g/min of CO and 6.93 mg/min of PM escaping into the room. This could be attributed to ambient pollution in the room from the test procedure itself, and/or the smoke escaping from the body through leaks along the plancha (observed for one stove later during the CCT) or out of the fuel entrance when the draft is slowed or there is a buildup of charcoal (discussed later). However this performance still achieves the optimal tier 4 rating.

Table 2. ISO/IWA Performance of EcoPlancha III

		Average	Deviation	Tier
High Power Thermal Efficiency	%	10%	3%	0.7
Low Power Specific Consumption	MJ/min/L	0.08	0.02	0.6
High Power CO	g/MJd	N/A	N/A	N/A
Low Power CO	g/min/L	N/A	N/A	N/A
High Power PM	mg/MJd	N/A	N/A	N/A
Low Power PM	mg/min/L	N/A	N/A	N/A
Indoor Emissions CO	g/min	0.03	0.03	4.9
Indoor Emissions PM	mg/min	6.93	4.97	3.8

N=3 for simmer and hot start, N=2 for cold start

Heat transfer efficiency from plancha stoves with chimneys is typically lower than that of single-pot stoves due to 1) the transfer of heat to the large plancha which is not captured by the water but is useful for cooking regardless, 2) the reduced surface area of the pot(s) in contact

with the hot gases due to the necessary sealed nature of a stove equipped with a chimney, and 3) the large (and safer) stove body requiring time and energy to heat up. Therefore the tier level rating of 1 close to that of the three-stone fire is expected. There are however a number of recommendations to improve this heat transfer efficiency which are discussed in the Conclusions and Recommendations (Section 6).

2. Controlled Cooking Test

Project Lead: Brett Sonflieth, Construction Engineering Management

The CCT is the second test recommended in both the VITA International Testing Standards (1987) and the revised University of California at Berkeley standard testing protocol series (2003). After stove prototypes are developed in the lab using the Water Boiling Test, the CCT is designed to measure performance of the stoves when used by local cooks preparing traditional meals. The CCT is designed to provide a direct comparison between the improved and traditional stoves as used by each cook. In these tests, a common standard meal was chosen, and a series of six female cooks were asked to prepare that meal as they normally would by using the traditional and improved stoves three times each. The CCT is designed to investigate stove performance as used under local conditions, with local fuel, local pots, and local practice. The CCT is an essential step in validating field performance, measuring whether a stove that performs well in the lab can also perform well when used by cooks in the region where stoves are to be disseminated.

A total of six local cooks were chosen for the testing and recruited from the after-school program shared by the children of the factory owners. All of them had spent some time cooking with the EcoPlancha prior to the test. All of the cooks were excited about participating in the study and were paid a reasonable amount for their time. The cooks were not instructed in any way on how to cook their meals. Prior to the test series, black beans (frijoles), rice (arroz), and tortillas in the quantity needed for a typical family of 4-5 were chosen as the representative meal through discussions with Ana Luisa Herrera from the EcoComal factory. At the beginning of the testing, researchers asked the cooks to agree on the specific mass of each ingredient to use so that each meal was prepared with the same quantity of ingredients, shown in Table 3. All ingredients were weighed out before each cook started their test in order to ensure accuracy. Some cooks seemed to not like this system as it meant they couldn't add ingredients at freely as they normally would. But after a few tests they all seemed to understand. The dish was

prepared a total of 30 times. The cooks were asked to bring their pots from home to use for the testing. Most were the traditional aluminum 6 liter pots of various sizes found in the local markets.

Table 3. Recipe for standard meal

Food	Ingredients	Amount (g)	Instructions
Black beans	Wet black beans	680	Soak black beans overnight, add wet beans to dry pot followed by some of the bean broth and fresh water. Once the beans come to a boil add in diced onions and garlic. "Doneness was determined by the skin peeling of the bean.
	Black bean water	450	
	fresh water	2000	
	Onions	78	
	Garlic	4	
Rice	Rice	200	First fry the rice, onions, and tomato in a pan without the water. Once the cook is satisfied then add the fresh water.
	Onions	30	
	Tomato	50	
	Fresh Water	800	
	Cooking oil	N/A	
Tortillas	Wet Masa	840	A communal container was filled with dry masa then water was mixed in to achieve desired consistency. Masa balls were then weighed out and distributed.

Two separate methods were used to quantify the expected improvement in air quality through use of the stove: 1) measurements of the total emissions escaping the cookstove body and not exiting the chimney using the PEMS as in the WBT (Section 1), and 2) personal exposure monitoring using an Indoor Air Pollution meter. The PEMS was set up 1 meter above the body of the EcoPlancha as with the WBT, and later hung 1.5 meters above the three-stone fire set up on the floor inside the testing shed. To compare the potential exposure of CO and PM to the cook, the Aprovecho IAP meter was used to monitor concentrations of CO and PM every 10 seconds near the breathing zone of Cook #2 (Figure 1B). The monitor was placed in a backpack with a sampling tube over the shoulder of the cook. The average concentration of both CO and PM were compared between stoves as meals were being prepared, inside the shed for the the EcoPlancha and outside in the courtyard for the three-stone fire.

It should be noted that these emissions measurements are approximations only. The sample size is too small for statistical significance, and the testing conditions were not ideal. For example, the wind had a larger impact when measuring air pollution for the three-stone fire since it was closer to the barn entrance. At times, smoke would get blown to the side before the PEMS had a chance to suck it up for measurement. And for the IAP measurements, the cook

was asked to leave the area of the open fire for approximately 30 minutes to participate in the survey, reducing her exposure during that test.

The experiment consisted of a total of 30 tests (Table 4). The goal was 36 tests, three per cook per day, but due to a learning curve and agreeing on the exact recipe on the first day, time did not allow for a 3rd test on day 1. The EcoPlanchas were installed in a row at the back of a large shed, while the open fires were operated outside near the factory entrance with a tarp later added to protect the cooks and fires from rain each afternoon.

Table 4. CCT Experimental Design

	Day 1			Day 2		
Cook	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**
1	EcoPlancha	EcoPlancha	N/A	Traditional	Traditional	Traditional
2	EcoPlancha	EcoPlancha	N/A	Traditional	Traditional	Traditional
3	EcoPlancha	EcoPlancha	N/A	Traditional	Traditional	Traditional
4	Traditional	Traditional	N/A	EcoPlancha	EcoPlancha	EcoPlancha
5	Traditional	Traditional	N/A	EcoPlancha	EcoPlancha	EcoPlancha
6	Traditional	Traditional	N/A	EcoPlancha	EcoPlancha	EcoPlancha

CCT Results

The results and average of time and fuel savings for the six different cooks comparing the efficiency of the EcoPlancha to a traditional three-stone fire are shown in Figures 4-5 and summarized in Table 5. Each bar represents the average specific fuel consumption savings and time savings for each cook for a total of 5 tests each. The error bars indicate the range of values measured. As mentioned previously, a sixth test for each cook was planned for but time did not allow and therefore statistical analysis was not performed due to the reduced sample size.

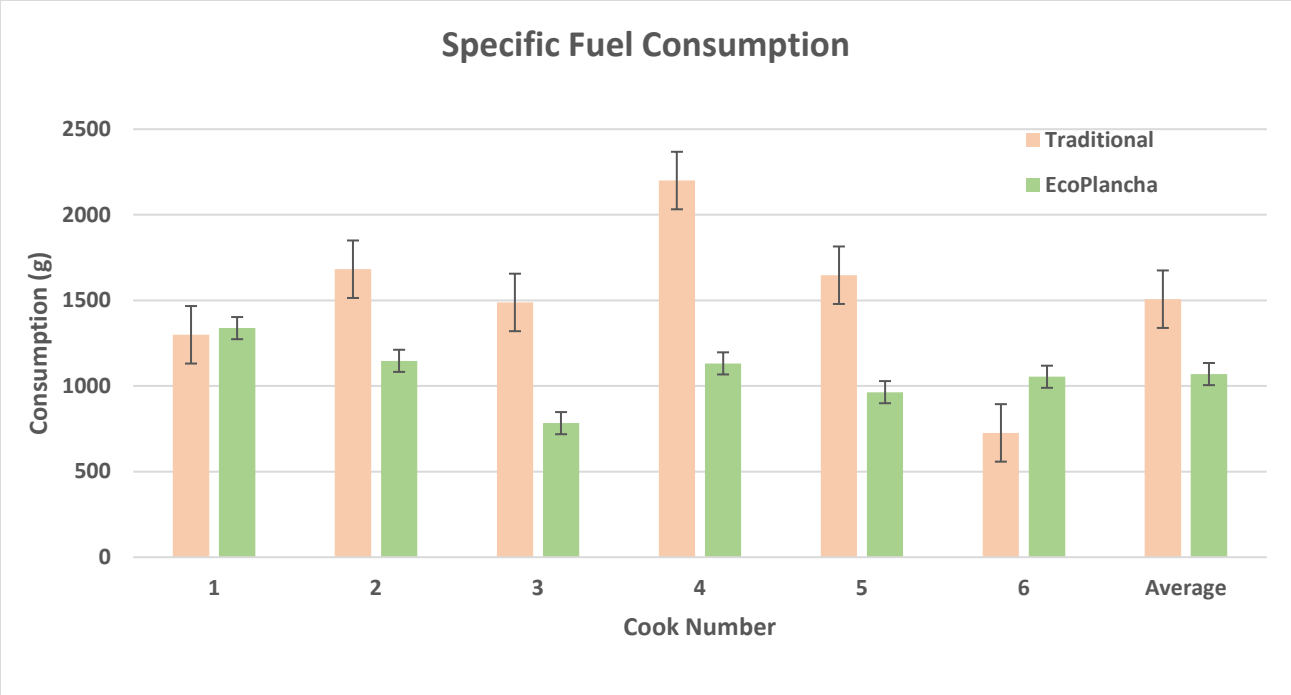


Figure 4. Fuel consumption for the CCT, by cook

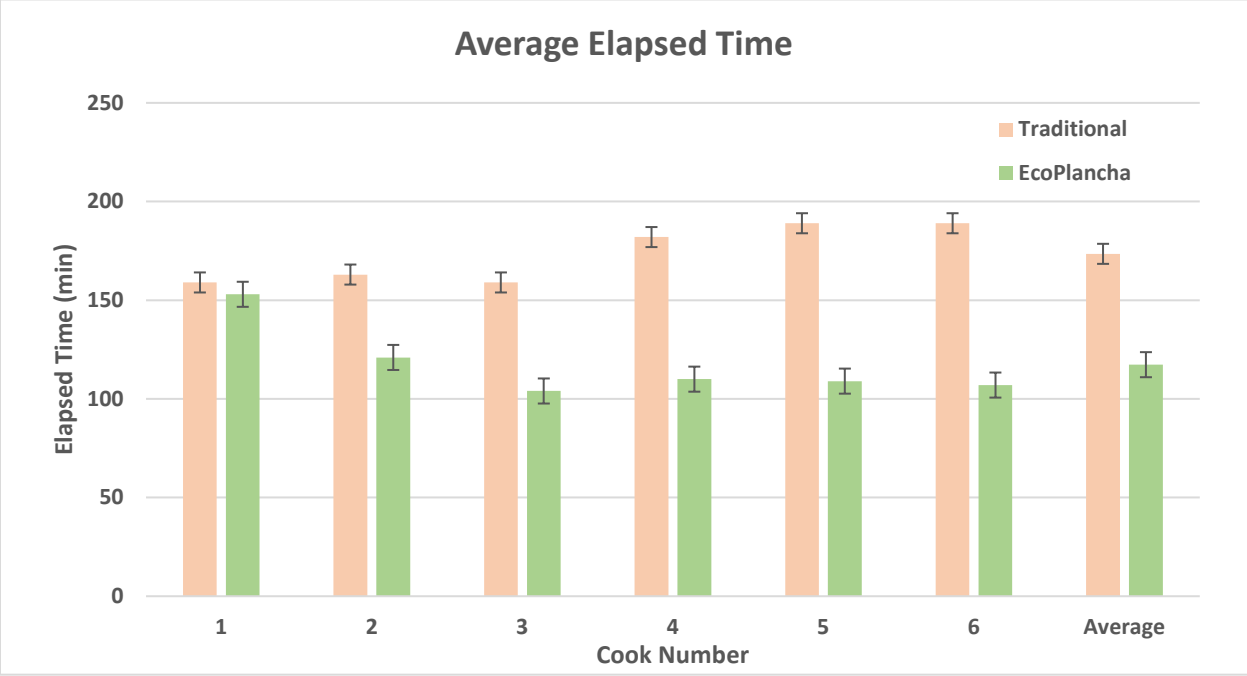


Figure 5. Time to prepare the meal for the CCT, by cook

Table 5. CCT Results of Fuel and Time Savings of EcoPlancha

	Traditional		EcoPlancha		Percent Difference	
Cook #	Average Consumption (g)	Average Time (min)	Average Consumption (g)	Average Time (min)	Consumption	Time
1 (PEMS)	1299	159	1338	153	-3%	4%
2 (IAP)	1682	163	1147	121	32%	26%
3	1488	159	783	104	47%	35%
4	2200	182	1132	110	49%	40%
5	1647	189	964	109	41%	42%
6	726	189	1054	107	-45%	43%
Average	**1507**	**174**	**1070**	**117**	**29%**	**32%**

As shown in Table 5, Cook #1 showed very low changes in elapsed time and an increase in fuel use. Cooks #2, #3, and #4 all show a decent decrease in both fuel use and elapsed time with fuel use being greater then elapsed time. Cook #5 shows similar results and she consumed the most amount of wood and took the longest amount of time during the three-stone test but used nearly half that same amount during the cook stove tests. Cook #6 has the largest percent difference in elapsed time of all the cooks but this is most likely contributed to the fact that she used nearly twice the amount of wood to cook her meal on the EcoPlancha. This would cause a hotter fire which would cook her meal faster. Overall, four out of six cooks saved fuel using the EcoPlancha, and five out of six cooks saved time.

Tables 6 and 7 present the savings in exposure to air pollution as measured by the PEMS and IAP meters.

Table 6. Emissions exposure during the CCT

	PEMS		IAP			PEMS		IAP	
Test	**CO (g)**	**Appx PM (mg)**	**CO (ppm)**	**Appx PM (µg/m³)**	**Test**	**CO (g)**	**Appx PM (mg)**	**CO (ppm)**	**Appx PM (µg/m³)**
1	1.03	2100	0.1	4382	**3**	150	45854	0.8	21747
2	3.98	770	0.2	6577	**4**	138	30411	0.8	23740
					5	120	28164	0.4	16506
Average	2.50	1435	0.1	5480	**Average**	136	34810	0.7	20664

Table 7. Overall exposure reductions for the EcoPlancha

	PEMS		**IAP**	
	CO	PM	CO	PM
	98%	96%	78%	73%
Overall	**97%**		**75%**	

Results from use of the PEMS to monitor cook #1 and the IAP monitoring for cook #2 show large differences between the two stoves. When compared to the three-stone fire the EcoPlancha reduced particulate matter by 96% and carbon monoxide by 98%. IAP monitoring for cook #2 revealed that PM was reduced by 73% and CO was reduced by 78%. These differences between methods may be in part to the differences in cook operation, but more likely differences in the measurements methods and the effects of ambient and non-ideal testing conditions. Thus it is re-emphasized that these are estimates only, as the sample size is small and since there were six cooks operating stoves in close proximity in sometimes windy situations the emissions measurement conditions were not ideal. Future studies should monitor emissions for multiple cooks and be conducted in more representative in-home situations.

Overall, EcoPlancha was shown on average to save approximately 30% in cooking time and fuel consumption, and reduce CO and particulate matter emissions by 75-90% as compared to the three-stone fire when preparing a typical meal consisting of beans, rice, and tortillas. There are a few points that should be considered when making generalizations from these data:

1. Discussions with the cooks revealed that their cooking processes were not perfectly representative of the way they would cook at home. Many said they would typically start the three-stone fire in the morning and slowly cook beans, and only every other day. Then at mealtime the rice would be prepared, followed by the tortillas. Therefore cooking all of the dishes simultaneously (on the EcoPlancha) or in quick succession (on the three-stone fire) was not an ideal representation.
2. Cooks using the same type of stove in close proximity would start and end at approximately the same time, suggesting that the cooks may have determined their end cooking time based on when others around them were finishing. This has been previously observed with the CCT and should try to be avoided in design of future studies.
3. The cook's knowledge of the research goals may have had an impact on their cooking style. If they understood that the EcoPlancha was designed to use less wood, then they may have tried to use less wood for the EcoPlancha compared to the three-stone fire.
4. On the first day of testing, two of the cooks were operating the stove with the pot submerged into the pot hole directly above the combustion chamber, rather than flush with the plancha surface as-designed. The stove seemed to function acceptably, but it is unclear the effect that this will have on performance or how common it is used this way by cooks.

3. User Feedback Surveys

Project Lead: Robi Nilson, Public Policy; Jordan Cox, Nuclear Engineering

At the conclusion of the CCT, the cooks were asked to participate in a survey to better understand their experience with the stove. The questions and number of cooks responding to each option are shown in Table 8. Most of the questions were open-ended rather than multiple choice, so the cooks were not prompted with options for answers.

Table 8. Results of post-CCT survey

Question	Response	# of cooks out of 6 responding
What do you like about your traditional stove?		
	Uses less wood	1
	Cooks quickly	2
	Tortillas are better	2

Cooks more food	1
What do you not like about your traditional stove?	
Uses more firewood	1
Takes more time	2
Makes more smoke	4
Too short	1
Difficult to light	1
Smoke irritates eyes	1
Wind blows it out	1
Nothing	1
What do you like about the EcoPlancha?	
Saves fuel	2
Saves time	4
Reduced smoke	2
Reduced health problems due to smoke	1
Less soot, cleaner kitchen	1
Cooks multiple items	5
What do you not like about the EcoPlancha?	
Cannot barbeque	1
What else do you like about the EcoPlancha?	
Can stand to cook	1
Coals stay warm	1
How satisfied are you with the EcoPlancha	
Extremely satisfied	4
Satisfied	2
Is the amount of smoke more, less or the same?	
Less	6
Does the stove use more or less fuel?	
Less	6
Is the new stove better for cooking?	
Yes	3
No	3
Which foods cook better on the EcoPlancha?	
Beans	3
Tortillas	2
Rice	1
Grilled meat	1
Every type	2
Which foods cook better on the old stove?	
Large quantities of food	3
Tortillas	1
Rice	1
What is not functioning about the stove?	
Gets clogged; chimney not removing smoke	1

Too much wood breaks combustion chamber	1
What would you change about the stove	
Bigger fuel entrance	2
Bigger stove	3
Bigger pot areas	1
Better material for chimney	1
Removable grill accessory	2
Eliminate rust on plancha	1
Have you changed the way you cook?	
Multiple foods at once	2
No	2
Which stove do you prefer?	
EcoPlancha	1

Overall the cooks clearly value the reductions in smoke provided by the stove, and the reduced occurrences of stinging eyes that result. Cooks seemed to value or notice savings in time more than fuel. They particularly value the ability to cook multiple foods at once on the EcoPlancha, and were observed to be heating water on the secondary pots at all times during the cooking process, likely to make best use of the available heat. All six of the cooks prefer the EcoPlancha over the three-stone fire, and were either satisfied (two) or extremely satisfied (four) with its overall operation, yet only half said that it cooks food better. Some indicated they would also appreciate the ability to cook larger quantities of food on a larger stove, and/or the ability to grill food with some sort of accessory of possible.

4. Safety Evaluation

Project Lead: Jennifer Ventrella, Mechanical Engineering

The safety of the EcoPlancha design was evaluated using the biomass cookstove safety protocol (Johnson and Bryden, 2016). This protocol evaluates and weights ten characteristics of the stove from 1-4, with 4 being highly safe. The Ecoplancha III model evaluated received a total score of 72 out of 100, corresponding Tier 1 for safety (Table 9). Overall the Ecoplancha should receive a relatively high safety score. It had very few sharp edges and it had such a large heavy structure that it was very unlikely to be tipped over. However, in the model evaluated, the chimney shielding did not cover all of the exposed chimney surface, reducing the score by 10 points. The back-drafting of flames from the combustion chamber also reduced the

score by 12 points. These two sub-scores can be improved by addressing the recommendations in Section 6, which would increase the total safety score to 89, or Tier 3. The safety rating tiers are shown in Table 1.

Table 9. Safety Ratings

#	Procedure	Rating	Value	X	Weight	=	Total
1	Sharp edges and points	Best	4	X	1.5	=	6
2	Cookstove tipping	Best	4	X	3	=	12
3	Containment of fuel	Fair	2	X	2.5	=	5
4	Obstructions near cooking surface	Best	4	X	2	=	8
5	Surface temperature	Poor	1	X	2	=	2
6	Heat transfer to environment	Best	4	X	2.5	=	10
7	Handle temperature	Best	4	X	2	=	8
8	Chimney shielding	Fair	2	X	2.5	=	5
9	Flames surrounding cookpot	Best	4	X	3	=	12
10	Flames exiting fuel chamber	Poor	1	X	4	=	4
					Score		**72**
					Tier		**1**

5. Flow Path Evaluation

Project Lead: Jennifer Ventrella, Mechanical Engineering

One of the most critical design elements of a biomass cookstove is the cross-sectional area of the flow path throughout the stove body. This is highlighted in the *Design Principles of Wood burning Cookstoves* developed by Dr. Larry Winiarski (Bryden et al, 2015), available in Spanish at http://www.pciaonline.org/design-principles. The flow path dictates the ease with which the hot combustion gases can pass through the stove and ultimately effects both the heat transfer and combustion efficiency. Therefore the flow path through the stove was analyzed, shown in Figure 6 and Table 10.

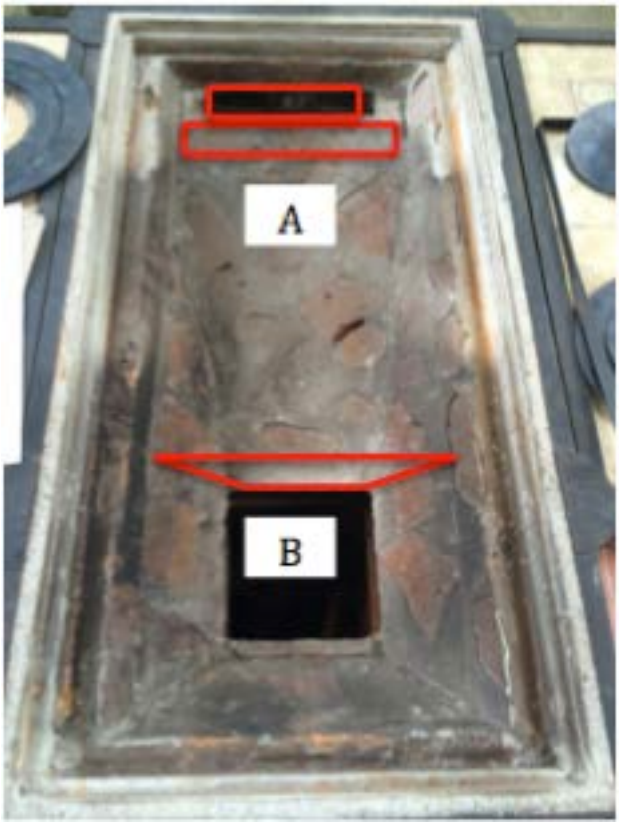
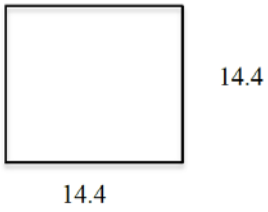
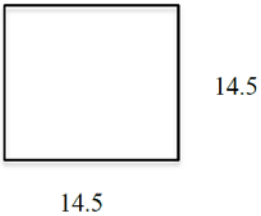
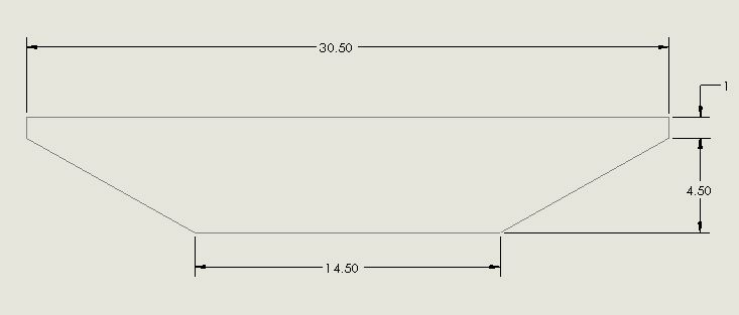
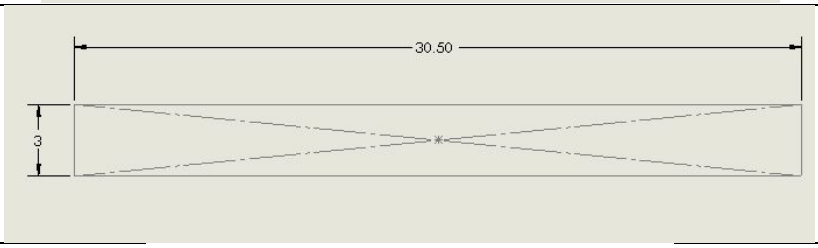
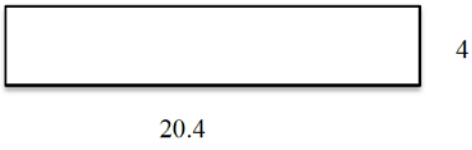
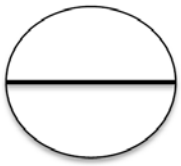


Figure 6. Flow areas underneath the plancha

Table 10. Flow path analysis

Area	Cross-section	Area (cm^2)	Flow area reduct-ion
Fuel entrance		207	
Combustion chamber exit		210	Basis

Trough front (B in figure)		132	37%
Trough exit (A in figure)		92	56%
Channel into chimney		82	61%
Chimney		63.6	70%

Relative to the size of the combustion chamber which dictates the rate of firepower and combustion, there are severe constrictions in the flow at the approach and entrance into the chimney with cross-sectional area reductions from 60 to 70%. This severe constriction is most likely impacting the heat transfer and combustion efficiency of the stove significantly, as the velocity of the volume of hot gases produced by combustion are reduced. This reduced velocity results in slowed draft through the stove and ultimately leads to 1) reduced heat transfer coefficients, 2) increased buildup of charcoal and resulting increase of emissions, 3) increased backdrafting of the flames out the fuel entrance, and 4) increased likelihood of smoke escaping through gaps in the stove body. Therefore in order to improve measures of efficiency, total emissions, and indoor emissions, it is recommended that the areas up to and including the chimney are increased to a maximum of 25% reduction. This would require expanding the gap under the plancha toward the chimney, and using the next larger size of available chimney.

6. Conclusions and Recommendations

Drawing on many years of cookstove design and testing experience, the lessons learned from this testing lead to some recommendations for potential design changes for the EcoPlancha. Some of these recommendations may be challenging or costly to implement, and should be tested to verify performance improvements. The testing protocol and processing spreadsheets used here are all available (some in Spanish) at http://cleancookstoves.org/technology-and-fuels/testing/protocols.html. It is left up to the EcoComal staff to choose which of these recommendations, if any, to apply and they are invited to contact the authors with any questions or requests for assistance in the future.

1. **Increase the air flow up through the coals** – The present design of the fuel shelf includes a solid ceramic piece with five small holes for air flow to the fuel bed. These holes are quickly blocked by charcoal, virtually eliminating primary air flow and therefore reducing the quality of combustion in the stove. In all tests a large buildup of charcoal was observed, indicating that there is not enough oxygen reaching the coals for combustion. It is recommended to update the design to either increase the area of the holes significantly, or eliminate the holes in favor of a fully open space. In either case it would be helpful to design the fuel chamber so that the coals remain in close proximity to the fuel while still allowing air to pass underneath the ends of the burning sticks.
2. **Increase the diameter of the chimney and chimney passage** – The current stove design creates a 70% reduction in cross-sectional area from the combustion chamber to the chimney. This is a frequent problem seen in biomass stoves with chimneys where smaller diameter chimneys are selected in order to reduce costs. However it creates a significantly reduced draft in the stove, thereby reducing heat transfer coefficients and increasing the backdrafting and escape of gases out of the body. Backdrafting can be identified by black soot on the outside of the stove body above the combustion chamber (Figure 7). Increasing the area of the channel to and along the chimney will increase the velocity and heat transfer in the stove, improving the speed and efficiency of cooking and also making required chimney cleaning and maintenance less frequent and easier.
3. **Test the stove with pots submerged and adapt as needed** -- During the CCT it was observed that several cooks were using the stove with the pot submerged underneath the plancha to sit directly on top of the combustion chamber. It is uncertain what impacts this will have on overall efficiency and emissions, so these should be evaluated and users trained or stove design adapted accordingly, perhaps to provide pot supports on top of the

combustion chamber that are at least 3 cm tall to ensure sufficient area for the gases to exit the combustion chamber.

4. **Provide complete chimney shielding** – For stoves that are distributed, chimneys should be completely surrounded by shielding in order to improve the safety score.

Figure 7. Evidence of back-drafting due to insufficient draught

Overall the EcoPlancha III is a well-designed, precision-manufactured stove that protects health and safety and is appreciated by the users. It seems to be durable, well-functioning, and adaptable to meet the variety of boiling and frying tasks necessary to prepare the traditional cuisine in many areas of Guatemala.

Acknowledgements

Special thanks to all of the Oregon State University students, faculty and StoveTeam members who participated in the testing, translating, and other assistance in addition to the authors: Kim Forrest, Liz Schroeder, Roberta Nilson, Yusra Al Sawaii, Davis Jacob, Judy Jiang, Nolan Kelly, Alexandra Giza, Jordan Conger; as well as the EcoComal factory owners Marco

and Ana Luisa Herrera for testing support and hosting our visit. And our sincere thanks to Aprovecho Research Center for the advance training and the loan of the PEMS and IAP Meter for the trip.

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Annex 1 – IWA Certificate

IWA Tiers of Performance Report

Stove Manufacturer	EcoComal
Stove Model	EcoPlancha III
Testing Center	Oregon State University field visit to EcoComal Factory
Test Protocol	Water Boiling Test - Version 4.2.4
Fuel Used	Grevillea Robusta
Pot Used	Local
Test Dates	June 15-16, 2016

These results were obtained in accordance with the IWA and the Global Alliance for Clean Cookstoves' reporting requirements[1]. This data and additional supporting data are shared publically through the Clean Cooking Catalog.

Name of Tester(s)	Dr. Nordica MacCarty, Jessica Chadwick, Jordan Cox

		Metric	Value	Unit	Sub-Tier
Efficiency / Fuel Use					
Tier	**1**	High power Thermal Efficiency	10	%	1
		Low power Specific Consumption	0.078	MJ/min/l	1
Emissions					
Tier	**N/A**	High power CO	N/A	g/MJ_d	N/A
		Low power CO	N/A	g/min/l	N/A
		High power PM 2.5	N/A	g/MJ_d	N/A
		Low power PM 2.5	N/A	mg/min/l	N/A
Indoor Emissions					
Tier	**4**	Indoor emissions CO	0.03	g/min	5
		Indoor emissions PM 2.5	6.9	mg/min	4
Safety					
Tier	**1**	10 weighted safety parameters	72.0	Points	

Tier 0 → Improving Importance → Tier 4