Indonesian Clean Stove Initiative Pilot Programme

Test Methods and Product Evaluation Criteria

Based on SeTAR S.O.P. 30.03.01

This document has four sections:

- Objectives and testing principles
- Testing method
- Determination of results
- Examples of Test Results

Section 1 Objectives and Testing Principles

1. Objectives of the stove evaluation process are:
   1.1. To evaluate biomass fuel burning cooking appliances in such a realistic manner such that their future performance in the hands of a given community is reasonably predictable. That performance prediction is based on key metrics that can be obtained during testing conducted under controlled conditions;

   1.2. To evaluate all such products and fuel combinations in a balanced manner using methods that do not unduly reward or disadvantage any technology because of the manner in which its cooking performance is achieved;

   1.3. To rate performance using metrics that are appropriate for communicating to all interested parties the product's key performance criteria which are:
   - the 'system efficiency', also called the 'overall thermal efficiency', which is the useful heat energy gained by a cooking vessel (inclusive of heat gained by the vessel material) divided by the potential heat energy available from the net amount of raw fuel consumed during any in a series of identical replications, save the first, of one or more standardised cooking tasks or during a proxy test that combines multiple cooking tasks, expressed in per cent;
   - the mass of carbon monoxide (CO) emitted per MegaJoule of net heat energy accumulated by a cooking vessel when completing such standardised proxy cooking tasks, expressed in mass of CO per MJ_{NET}[1];
   - the mass of fine particulate matter ($PM_{2.5}$) emitted per MegaJoule of net heat energy accumulated by a cooking vessel when completing such standardised proxy cooking tasks, expressed in mass of $PM_{2.5}$ per MJ_{NET};
   - a product safety rating to be provided by a suitably qualified expert reviewer using culturally appropriate methods.

[1] This is not the same as the quantity of heat delivered from a hot gas stream into the pot, which would include the net heat retained (useful cooking heat in MJ_{NET}) plus the heat transferred to the pot but lost through conduction, convection and radiation into the surrounding environment. That lost portion of the heat delivered to the pot is not measureable and is not useful for cooking. At low power such losses are well over 50% of the total heat delivered to the pot MJ_D.

1.4. Guiding Principles for the evaluation of domestic biomass fuelled cooking appliances

1.4.1. To qualify for inclusion in the CSI Pilot, the performance targets must be achieved. The CSI Pilot will support any biomass burning technology that can safely meet the performance requirements. There are three performance tiers. It is up to the market aggregators to convince the public their cooking technology is worth buying and using.

1.4.2. Energy efficiency will be based on the heat energy potentially available in the raw fuel consumed per cooking cycle and the heat gained by the cooking vessel or vessels.

1.4.3. The energy consumption rating, whether expressed in MJ or in an equivalent mass of raw fuel, is based on the need to draw new raw fuel for the replication of the standard task from the available resource, when possible reusing leftover fuel from a previous replication. It is expressed as the number of MegaJoules theoretically available from the fuel consumed, as received (AR). This approach is taken to avoid using a mass of fuel consumed as a metric.[2] Each time a test is repeated, usable fuel leftover from a previous test will be included, if the stove can burn it. If not, 'fuel consumed' will be the net energy equivalent all new raw fuel entering the stove per burn cycle.

1.4.4. Emissions of pollutants are reported from ignition of the fire until the completion of the task including any following burnout phase if that is the local practice.

1.4.5. If the local practice is to leave the fuel remaining in the fire after cooking to burn out (often applied to tasks such as drying fuel for the next day or drying clothes), all resulting emissions of that phase are included in the total emissions. This is the case even if no cooking is done at the very beginning or at the very end because those emissions may create exposure for the family. The Technical Test burn cycle will include this because it is tuned for cultural relevance.

1.4.6. The stove will be tested using the selected Technical Test which is based on local requirements for cooking energy. The stove will be operated according to the manufacturer's operating instructions.

1.4.7. Stoves with equal performance must receive an equal rating even if they are of different sizes or their methods of operation are different. This impacts the metrics chosen to represent performance. Stoves with unequal performance must receive an unequal rating.[3]

1.4.8. The metrics must be chosen so that performance is assessed fairly. If several different stoves have the same actual performance and the test method does not reflect this in their ratings, the test method and the metrics shall be investigated and corrected.

1.4.9. "The scientific method requires that a physical model fulfills two conditions: it has to reconstruct and predict (or forecast) physical observations."[4] The test methods used for

---

[2] Identical masses if different fuels often contain very different amounts of potential combustion energy. Expressing the energy content on a dry fuel basis allow intercomparison between stove+fuel combinations. In order to compare stoves burning different fuels, the net energy available in those fuels is considered and the appropriate metric is MJ.

[3] The meaning of this is that one might find a way 'cheat' in a test by exploiting a loophole in the methodology to get a better rating. When such a problem is identified, the test method should be adjusted using more appropriate metrics or calculations.

[4] Scarfetta, N, 2011 .p12, http://www.fel.duke.edu/~scafetta/pdf/Scafetta_models_comparison_ATP.pdf

rating the performance of domestic stoves must therefore be culturally relevant and implemented so as to reasonably predict field performance in typical use.[5]

2. Definitions
   - 2.1. **Biomass Fuels** are those found in Indonesia including but not limited to: wood, chopped wood products, processed wood products, crop residues, crop processing residues, wood pellets, biomass pellets, charcoal, torrefied biomass products, sawdust, leaves and grasses.
   - 2.2. **Fuel Consumption** of a biomass burning stove is defined as the need to provide new fuel drawn from a supply that is sourced outside the cooking system in order to conduct any one of a series of identical replications of a burn cycle, save the first.
   - 2.3. **Burn Cycle:** The combustion of fuel from ignition to extinction at any and all power levels require to perform a specified cooking cycle. The fuel load is normally adjusted to be at least adequate for the completion of the cycle. The product manufacturer may recommend a standard ignition or extinction method or methods.
   - 2.4. **Cooking Cycle:** The cycle that uses the heat available from a burn cycle for the preparation of food or the heating of water. The whole cooking cycle is normally contained within the burn cycle though in special cases retained heat stoves might continue cooking after the fire has been extinguished. The product manufacturer may recommend a cooking power adjustment method or methods for example exposing or shielding the bottom of a pot.
   - 2.5. **Cooking Power:**
   - 2.6. **System Efficiency** is the ratio of the useful heat energy gained by a cooking vessel[6] divided by the energy originally available in the fuel consumed (as defined above) expressed as %. Synonyms include ‘overall thermal efficiency’ and ‘overall energy efficiency’.
   - 2.7. **3-Star Rating system**: Product performance will be compared with a set of performance targets and a tier rating assigned. To qualify on a performance tier, the performance ratings for CO, PM emissions and overall thermal efficiency must each meet or exceed the requirements for that tier.
   - 2.8. **Cooking Stove**: any biomass fuelled cooking appliance that delivers heat at an acceptable rate into one or more cooking vessels, having the facility such that an operator can adjust the cooking power to high and low enough rates so as to properly cook the foods typically prepared in the market area of interest, in this case Central Java, Indonesia.
   - 2.9. **Water Heater**: any biomass fuelled water heating appliance which can deliver heat at an acceptable rate into one or more water containers.
   - 2.10. **Emissions per Net MegaJoule**: The net heat gained by a cooking vessel during a cooking cycle is determined and expressed in MegaJoules. This figure includes the heating of the pot and its contents plus the evaporation of water, while disregarding other heat flows through the pot such as radiative and convective losses. The mass of CO and $PM_{2.5}$ emitted during the burn cycle necessary to complete a culturally relevant cooking cycle are determined and divided by the figure for net heat gained yielding emission factors, for example CO of *m* grams per MJ_{NET} and $PM_{2.5}$ of *n* milligrams per MJ_{NET}.

---

[5] Typical use is defined as the average performance during two dissimilar cooking tasks that are typical in the community of interest. See the Cooking Test section for details.

[6] See para 1.3 above for the definition of heat gained.

2.11. **Compliant products** will be capable of controllably delivering adequate heat into one or more cooking vessels without exceeding the emissions or the fuel consumption thresholds necessary to achieve at least a 1-Star rating.

2.12. **Heat Flow Rate**:[7] the rate at which heat enters a cooking vessel per unit area of heated surface, normally taken to be the area of the bottom of the vessel.[8] It is a measure of cooking power per unit area expressed in units of J/sec/cm^2 or Watts/cm^2. The measurement is made for the largest diameter pot used during the test cycle.

2.13. **Turn Down Ratio**: During the cooking of foods typical in the community of interest, the high power and low power net heat flows into the vessel are determined. These are the upper and lower limits of cooking power required by the users. The ratio between these power levels is the Turn Down Ratio. Specialised water heaters are not required to demonstrate any capacity to control the cooking power.

Section 2 Testing Methods

3. Performance evaluation applies the concept of the "Stove Testing Toolbox". The "Toolbox" is a set of approved[9] measurement methods which can be combined in various ways to give a performance evaluation based on the diverse cooking requirements in communities of interest. Not all tools are used on all occasions as the cooking cycles differ from project to project. Provided the test is conducted using a combination of accepted tools, the result is acceptable.

4. There are four stages in the development of the laboratory test:
   - evaluation of typical cooking cycles and selection of Cooking Tests, determining baseline emissions and fuel use;
   - HFR Cooking Test to establish the cooking power, system efficiency and emissions per MJ_{NET};
   - the creation of a Technical Test by combining two or more Cooking Tests;
   - use approved methods to measure and report the performance of the product during the Technical Test.
   - comparison of the Technical Test result with the technical evaluation of the Cooking Tests to show that the laboratory test can predict actual cooking performance.

   Each element used in this process is a 'tool' and has its rules and metrics.

5. Evaluation of typical cooking cycles and the selection of Cooking Tests
   From a survey of local cooking practices two common meals or cooking patterns are selected.[10] These are chosen on the basis that the cooking power patterns are distinctly different. Typically one cycle requires a high cooking power and the other a low cooking power. Also considered is the need

---

[7] This is also called the Heat Flux or the Density of Heat Flow, depending on which language is used. For example 热流密度 or Плотность теплового потока both mean the latter. The meaning is the same: either J/second per sq metre J/S·m^2 or J/sq metre per second J/m^2·S. Using CGS it can be written Watts/cm^2.

[8] Sunken pots and skirted pots will be treated differently, with the heated surface area calculated appropriately.

[9] Approved by the funding organisation or the relevant Standards Authority.

[10] More than two different tasks may be used to create the Technical Test. This would be appropriate when the third task (or other task) requires stove functionality not explored by the only two.

to control the cooking power level during the session. The chosen cooking tasks should be common in the community of interest. In order to ensure agreement about the cooking and fire management processes, a focus group should be observed replicating them. The focus group should be familiar with the cooking cycles and the stoves used. The baseline performance is determined during these demonstrations.

5.1. Selected Cooking Test 1, Central Java

The task is steaming 0.5 kg of dry rice using a water boiling pot, a soblok (rice steamer) followed by bringing 3 litres of water to a boil.

Time Zero
Ignition
Place a pot with lid containing 1 litre of water and 0.5 kg of washed rice on the stove
When boiling, open the lid and stir the rice
Elapsed time 9 minutes
Replace the pot with the soblok containing 2 litres of water in the bottom section
Bring the water to boiling
Elapsed time 10 minutes
Put the par-boiled rice into the soblok
When the rice is done remove the soblok
Elapsed time 30 minutes
Place a pot (with lid) containing 3 litres of water on the stove
When the water is boiling, the cooking cycle is complete
Elapsed time 10 minutes
Total time: 59 minutes.

Cooking power	High	Medium	Low	High	Total
Minutes	19	30	0	10	59

5.2. Selected Cooking Test 2, Central Java

The task is making *Opor* (chicken with coconut milk soup) with fried *sambal*

Time Zero
Ignition
Place a pot with lid containing 365g of coconut milk, 600 g of chicken, 60g of seasoning and 1.4 litres of water on the stove
Bring everything to a boil
Elapsed time 9 minutes
Simmer and stir as needed
Elapsed time 58 minutes
Remove the pot and replace it with a wok containing 60 g of oil
Cook the chillies at low power
Elapsed time 9 minutes
Total Time 67 minutes

Cooking power	High	Medium	Low	High	Total
Minutes	9	0	58	0	67

A triplicate replication is required to establish the typical performance the Cooking Test times. Each Cooking Test is replicated 3 times. If the stove can use fuel remaining from a previous test, then four replications are require: one to create the 'fuel remaining' and three to get the average times for each portion of the whole cycle. The numbers used above are the result of three Cooking Test times.

6. HFR Cooking Tests

Having established which of the cooking cycles will be used and having measured the overall CO, PM and fuel demand per cycle, it is necessary to conduct the same burn cycles using the pot-swapping method to measure the useful heat gained by the pots during each cycle and the rate at which heat flows into them.

6.1. Calculation of the Heat Flow Rate (HFR)

6.1.1. The maximum and minimum HRF measured during the Technical Test are calculated and reported to the manufacturers and market aggregators. This does not constitute a performance requirement. It is information that is relevant to understanding consumer expectations.

6.1.2. The HFR represents the minimum cooking performance requirement in the opinion of potential users of the products in the target communities. This information is relevant to the selection of technologies the market aggregators will promote.

HFR Formula

$$\frac{\text{Net heat gained by the pot}}{\text{Time x Heated area of the pot (usually the bottom)}} = \frac{\text{Joules}}{\text{Seconds x cm}^2} = \text{HFR}$$

6.2. An HFR Cooking Test 1 is performed three times using the pot-swap method. The burn cycle is identical to Cooking Test 1. Instead of cooking food, identical pots of water are placed in sequence on the stove throughout the whole burn cycle, replaced once they reach 70°C. The total heat gained is continuously assessed and the heat flow rate (HFR) per square centimeter is calculated (for each pot, if there is more than one) at each fire power level.

6.3. The total emissions, fuel consumption, energy efficiencies, heat flow rates and cooking powers are tabulated. As before, fuel remaining from a previous identical burn cycle is included[11] in each test when applicable.[12]

6.4. The total potential energy in the fuel consumed and the useful cooking energy are quantified. If there is a difference between the mass of 'used fuel' added during the first replication and the

[11] This implies that 4 replications are required to get the performance from three tests.

[12] The portion of 'fuel remaining' that can be used in the next cycle is retained and used during the next burn. Usually this reusable fuel is the sticks with burned ends. Some stoves can burn the char remaining from a previous test. Some require 100% new fuel each time they are lit.

mass remaining after the third replication, an adjustment is made to the $\sum MJ_f^1$ figure giving the total energy available in all the consumed fuel.[13]. For stoves that cannot reuse any of the fuel remaining, this correction is not required as all fuel is considered consumed. The amount of useful heat gained in all three tests is summed ($\sum MJ_{NET}^1$) as is the available heat energy of all the raw fuel consumed ($\sum MJ_f^1$).

6.5. The total masses of CO and PM emissions are summed giving $\sum CO^1$ and $\sum PM_{2.5}^1$. The total masses of CO and PM are compared with the sum of values obtained during the three replications of Cooking Test 1. If there is a match, the HFR Cooking Test is validated.

6.6. The $\sum CO^1$ and $\sum PM_{2.5}^1$ values for cooking cycle 1 are divided by the total useful heat gained to yield the baseline emissions:

$\sum CO^1/\sum MJ_{NET} = CO^1/MJ_{NET}$ and $\sum PM_{2.5}^1/\sum MJ_{NET}. = PM_{2.5}^1/MJ_{NET}$

The heat gained during all three tests $\sum MJ_{NET}^1$ is divided by the total energy available in the fuel consumed $\sum MJ_f^1$ to yield the system efficiency expressed in %.[14]

$\sum MJ_{NET}^1/\sum MJ_f^1 \times 100 = \eta^1$ for Cooking Test 1

6.7. The whole process is repeated for HFR Cooking Test 2 yielding:
CO^2/MJ_{NET}
$PM_{2.5}^2/MJ_{NET}$
η^2

6.8. The Values for the two tests are averaged as follows:
$(\sum CO^1 + \sum CO^2)/2$ = Average $\sum CO$
$(\sum PM_{2.5}^1 + \sum PM_{2.5}^2)/2$ = Average $\sum PM_{2.5}$
$(\sum MJ_{NET}^1 + \sum MJ_{NET}^2)/2$ = Average $\sum MJ_{NET}$

7. Technical Test Construction
The burn cycles of the two Cooking Tests are combined to create a single Technical Test that averages the time of each power level, rounding up:

Cooking power	High	Medium	Low	High	Total
Avg Minutes	(19+9)/2 =14	(30+0)/2=15	(0+58)/2 =29	(10+0)/2=5	63
Rounded Values	14	15	29	5	63

This Technical Test has 4 separate cooking power sections with a total length of 63 minutes.

---

[13] The fuel remaining does not have the same heating value as raw fuel. The energy available is adjusted accordingly.

[14] This procedure does not give the same answer obtained by averaging the efficiency values for individual tests. Efficiency numbers are ratios and it is not permissible to average ratios. The total net heat gained is divided by the total heat available in the fuel to give the average efficiency. Also note that this value is not the peak heat transfer efficiency, which can be obtained by using a different set of approved 'tools'.

7.1. The Technical Test is an HFR test performed using the pot-swapping method throughout. It is performed three times always using fuel remaining from a previous replication provided the stove can burn 'fuel remaining'. Total emissions and fuel consumption are recorded and the thermal and emission performances are calculated. As with the other HFR tests, the "fuel remaining" used in the first replication[11] is compared with the fuel remaining after the last in order to adjust the total heat available in the raw fuel ($\sum MJ_f$).
The same final metrics are calculated:

$\sum CO/\sum MJ_{NET} = CO/MJ_{NET}$
$\sum PM_{2.5}/\sum MJ_{NET}. = PM_{2.5}/MJ_{NET}$
$\sum MJ_{NET}/\sum MJ_f \times 100 = \eta$ (%)

8. Validation of the Technical Test

8.1. The values Average ∑CO, Average ∑PM2.5 and Average ∑MJNET are compared with the values obtained in the Technical Test. If the Technical test values are within the range of 80%-120% of the Average values, the Technical Test is validated as a test method.[15]

9. Testing of water boiling appliances
The performance of candidate technologies is determined while bringing 5 or more litres of water to a boil. There is no other operational requirement.

The metrics are CO g/MJ_{NET}, $PM_{2.5}$ mg/MJ_{NET}, and system efficiency based on the net heat gained (including heat gained by the pot) divided by the energy available in the raw fuel consumed in MJ.

The water boiler capacity is expected to be in the range of 5 to 20 litres.

[15] The accuracy of this method is limited by the quality of the equipment available. The target range may be more restricted in future as better equipment becomes available.

Section 3 Determination of Results

10. Performance Rating

The performance values achieved are compared with the requirements of the performance tiers and a rating assigned for each performance category.

3-Star Rating system for Clean Cookstoves

	Overall Thermal Efficiency		Emissions		Safety, Environment and Durability	
	Cooking Stove	Water Boiler	CO (g/MJ_{NET})	PM2.5 (mg/MJ_{NET})	Safety Enviro[1/]	Durability
One Star	≥25%	≥45%	≤12	≤300	Expert	1 Yr.
Two Stars	≥30%	≥55%	≤10	≤200	Expert	1 Yr.
Three Stars	≥40%	≥ 65%	≤ 8	≤100	Expert	1 Yr.

Note 1: Expert will determine the safety and environmental aspect of stoves

11. Ownership of test results
    - 11.1. The results of performance tests belong to WB CSI Indonesia.
    - 11.2. The results are provided to the product owner in full.
    - 11.3. Anonymized results may be used for reporting and comparison in documents related to the CSI project.

Section 4 Examples of Test Results

12. Sample test results for a baseline stove in Central Java, Indonesia

12.1. Cooking Cycle 1: Steam 500g of rice and boil 3 litres of water

19' HIGH	30' MEDIUM	10' HIGH

Total PM2.5	2259 mg
Total CO	31.9 g
Total Fuel Consumed	26.5 MJ
Heat Flow Rate (Max)	3.5 W/cm^2 (determined during a pot-swapping test)
HFR Minimum	1.6 W/cm^2 (determined during a pot-swapping test)
Turn Down Ratio	2:1 (determined from the HFR Max and Min)

12.2. Cooking Cycle 2: Make *Opor* (chicken with coconut milk soup) with fried *sambal*

9' HIGH	0' MEDIUM	58' LOW

Total PM2.5	2062 mg
Total CO	31.6 g
Total Fuel Consumed	25.0 MJ
Heat Flow Rate (Max)	4.4 W/cm^2 (determined during a pot-swapping test)
HFR Minimum	1.0 W/cm^2 (determined during a pot-swapping test)
Turn Down Ratio	4.4 (determined from the HFR Max and Min)

12.3. Average Cooking Cycle results:

Total PM2.5	2161 mg
Total CO	32.0 g
Total Energy Used	25.8 MJ
Heat Flow Rate (Max)	4.4 W/cm^2 (highest value noted)
HFR Minimum	1.0 W/cm^2 (lowest value noted)
Turn Down Ratio	4.4 (determined from the HFR Max and Min)

12.4. Technical Test

14'	15'	29'	5'

Total PM2.5	2170 mg
Total CO	30.0 g
Total Energy Used	26.9 MJ
System Efficiency	15.9%
MJ delivered to the pot	4.28
PM emissions	507 mg/MJ_{NET}
CO emissions	7.1 g/MJ_{NET}
Heat Flux (Max)	2.9
HF (Min)	1.0
Turn Down Ratio	3.0

12.5. Baseline Keren Stove Rating:

PM2.5	= 0 Stars	x
CO	= 3 Stars	***
Overall Thermal efficiency	= 0 Stars	x

Reported to producer:	Heat Flux (Max)	2.9
	HF (Min)	1.0
	Turn Down Ratio	3.0
	Cooking power	1660 Watts (Max)
	Cooking power	553 Watts (Min)