Indonesian Clean Stove Initiative Pilot Programme

Water Boiling Test Methods and Product Evaluation Criteria

SeTAR Standard Operating Procedure: SOP 30.03.02

Contents

Section 1: Objectives, Testing Principles and Definitions

1. Objectives of the stove evaluation process are:

1.1. To evaluate biomass fuel burning cooking appliances in a realistic manner such that their future performance in the hands of a given community is reasonably predicted. The performance prediction is based on key metrics that can be obtained by applying the testing method, described in Section 2, under controlled conditions;

1.2. To evaluate all such product 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 stove performance using metrics that are appropriate for communicating to all interested parties the product's key performance metrics, 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) expressed as a percentage of 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[1];
- the mass of carbon monoxide (CO) emitted per MegaJoule of useful heat energy accumulated by a cooking vessel when completing such standardised proxy cooking tasks, expressed in mass of CO per MegaJoule [g CO/MJ] [2];
- the mass of fine particulate matter ($PM_{2.5}$) emitted per MegaJoule of useful heat energy accumulated by a cooking vessel when completing such standardised proxy cooking tasks, expressed in mass of $PM_{2.5}$ per net MegaJoule [g $PM_{2.5}$/MJ] [3];
- a product safety rating will provided by a suitably qualified expert reviewer using culturally appropriate methods.

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

1.4.1. To qualify for inclusion in the Indonesian Clean Stove Initiative Pilot Project, the minimum performance targets for carbon monoxide and fine particulate matter **Emission Factors** and **System Efficiency** must be achieved. In addition, additional requirements of **Safety** and **Durability** must be met by any proposed product (cooking stove or water heater). With respect to other performance parameters such as maximum power and turn-down ratio, it is up to the product proponents to convince the public their cooking technology is worth buying. Some of these use-based metrics are reported as part of this test procedure but do not form part of the qualification criteria.

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[1] The useful heat H_{NET} equals the heat gained by the pot material H_P plus the heat gained by the pot contents H_C. The total heat available from the fuel H_F is in the denominator. System Efficiency = $H_{NET}/H_F \times 100$.

[2] Some of the potential fuel heat H_F is lost to combustion inefficiencies and the stove body h_S. The heat transferred h_T includes the accumulated cooking heat H_{NET} plus the heat transferred to the pot but subsequently lost into the surrounding environment h_E. The h_E heat losses are not measureable nor useful for cooking. The total mass of CO divided by H_{NET} in MJ gives the CO emission factor EF_{CO} CO/MJ.

[3] The total mass of PM divided by H_{NET} in MJ gives the $PM_{2.5}$ emission factor $E_{PM2.5}$ $PM_{2.5}$/MJ.

1.4.2. Energy efficiency will be based on the heat energy potentially available in the raw fuel consumed per cooking cycle H_F and the heat gained by the cooking vessel or vessels/surfaces H_{NET}.

1.4.3. The energy consumption rating, whether expressed in MegaJoules [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 fuel left over from a previous replication. This protocol requires the use of the number of MegaJoules of energy theoretically available from the fuel consumed, as received (AR)[4]. This approach is taken to avoid using a mass of fuel consumed as a metric.[5] 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 of 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. 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 (refer to Paragraph 2, Definitions), will include this because it is tuned for cultural relevance.

1.4.5. 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.

1.4.6. 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 which metrics are chosen to report product performance. Stoves with unequal performance must receive an unequal rating.[6]

1.4.7. 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.

1.4.8. The test methods used for rating the performance of domestic stoves must therefore be culturally relevant and implemented so as to reasonably predict field performance in

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[4] As Received means the moisture content of the fuel is considered.

[5] Identical masses of different fuels usually contain different amounts of potential combustion energy. Expressing the energy consumption on a "dry fuel" basis allows inter-comparison between {stove plus fuel} combinations only if the fuel is always the same. To compare stoves burning different fuels, the net energy available in those fuels is considered and the appropriate metric is MJ.

[6] The meaning of this is that one might find a way 'cheat' in a test by exploiting a loophole in the methodology to get an enhanced but undeserved rating. When such a problem is identified, the test method should be adjusted which may include the use of more appropriate metrics and calculations.

typical use.[7] "The scientific method requires that a physical model fulfills two conditions: it has to reconstruct and predict (or forecast) physical observations."[8]

2. Definitions

2.1. **3-Star Rating system**: A system for classifying product performance into one of three categories (tiers) according to a set of performance targets, as defined in Table 1 (Paragraph 10 below). To qualify on a performance tier, the performance ratings for CO, PM emissions and overall thermal efficiency must each meet or exceed the respective requirements for that tier.

2.2. **As Received (H_{AR})**: The specific heating value of the **Fuel Consumed** expressed in unit [MJ/kg]. This specific heating value considers the Higher Heating Value (HHV) of dry fuel obtained by bomb calorimeter testing, a deduction for the combustion of fuel hydrogen to give the Lower Heating Value (LHV) and a further deduction to consider the fuel moisture content. A synonym is **Effective Heating Value (EHV).**

HHV of dry fuel by direct measurement using a bomb calorimeter		[MJ/kg]
LHV of dry fuel	= **HHV**(Dry) - 25.911 * 9h	[MJ/kg]
H_{AR} of fuel	= **HHV**(Dry) - 25.911 * (w + 9h)	[MJ/kg][9]

where h = the Hydrogen mass fraction of the dry fuel expressed as a percentage
w = the water mass fraction of the fuel (WWB) **As Received** expressed as a percentage

2.3. **Baseline Emission Factor:** When comparison is being made between a candidate technology and a product stove already in common use, the qualifying performance improvement may be expressed relative to the 'baseline product' rather than in absolute form.

2.4. **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.

2.5. **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.

2.6. **Compliant products** are defined as those products that are capable of delivering adequate heat into one or more cooking vessels without exceeding the **emission factor** or **fuel consumption** thresholds necessary to achieve at least a 1-Star rating. Cooking stoves must deliver the heat in a controllable manner as required by the selected **Technical Test**.

2.7. **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

[7] 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.
[8] Scarfetta, N, 2011, p. 12, http://www.fel.duke.edu/~scafetta/pdf/Scafetta_models_comparison_ATP.pdf
[9] This formula, converted to other units [BTU/lb], [kCal/kg], is in common use, i.e. by the US-EPA and China.

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.

2.8. **Cooking Power Maximum (P_{MAX}):** The measured maximum rate of heat gained by the pot during a high power section of the **Technical Test**, expressed in Joules per second or Watts. It is calculated as the differential maximum **Net Heat Gained** and includes the heat gained by the pot material.

2.9. **Cooking Power Minimum (P_{MIN}):** The measured minimum rate of heat gained by the pot during a low power section of the **Technical Test**, expressed in Joules per second or Watts. It is calculated as the differential minimum **Net Heat Gained** and includes the heat gained by the pot material.

2.10. **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 geographical area of interest, in this case Central Java, Indonesia.

2.11. **Cooking Test #**: Any particular cooking cycle of food preparation, water heating or other home industry task that is typical of behaviour in the geographical area of interest each of which is given a different number. Common tasks are characterised, numbered and replicated in the laboratory using typical pots, fuels and behaviours and the performance measured. A **Technical Test** is a combination of **Cooking Tests**.

2.12. **Density of Heat Flow (HFR)**: Used as a synonym for **Heat Flow Rate** or **Heat Flux** expressed in units [J/cm^2/sec].

2.13. **Effective Heating Value (EHV):** Specific heat energy available from fuel containing moisture; synonym for **As Received (H_{AR})**, unit [MJ/kg].

2.14. **Emission Factor (EF)**: The **mass of CO** (*x*) in grams or **mass of $PM_{2.5}$** (*y*) in milligrams emitted during a burn cycle are determined and divided by the **net heat gained H_{NET}**, yielding emission factors **EF_{CO}** and **$EF_{PM2.5}$ respectively** in units mass of emissions per net MegaJoule:

EF_{CO} = x grams of CO/H_{NET} [g/MJ]
$EF_{PM2.5}$ = y milligrams of $PM_{2.5}/H_{NET}$ [mg/MJ]

2.15. **Energy Consumed (H_F):** The heat energy available [MJ] in the **Fuel Consumed**.

$$H_F = H_{AR} * F_C \text{ [MJ]}$$

where **H_{AR}** = the specific heating value of the fuel **As Received** and
F_C = the mass of **Fuel Consumed**

2.16. **Fuel Consumed (F_C):** The fuel consumption of a biomass burning stove is defined as the mass [kilograms] of new fuel drawn from a supply that is sourced outside the cooking system needed to conduct any one of a series of identical replications of a burn cycle, save the first.

2.17. **Fuel Remaining:** Fuel which is unburned, partially or almost completely burn remaining after a burn cycle is complete, and which can be used in the same stove during the next replication of the cycle, is considered to be unburned fuel and is deducted from the amount of **Fuel Consumed**. If the properties of the fuel remaining after a test (to be re-used in the next fire) are substantially the same, there is no need to determine for the energy contained in such fuel. It is simply put into the subsequent fire. If local practice is to discard all **Fuel Remaining**, this behaviour may be copied if no behaviour change is expected in this regard.

2.18. **Geographic Community of Interest:** A region, however defined, which is identified as a stove improvement area in which marketing and other activities are initiated. The cooking habits of the communities in the region are studied so that a laboratory test can be created which will predict whether and to what extent a candidate stove is an improvement over current products. The test will be reflective of an amalgam of local practices thus the evaluations vary from one place to another. Variations include the fuels, stoves, pots, foods and meal preparation methods. There may be several evaluation methods required for one area when multiple or specialised cooking appliances are in common use.

2.19. **Heat Available in the Fuel (H_F):** The total heat available from the perfect combustion of the **Fuel Consumed** calculated from the heating value per unit mass **As Received** (AR). H_F is expressed in unit [MJ].

2.20. **Heat Flow Rate (HFR)**:[10] 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.[11] It is a measure of cooking power per unit area expressed in units [J/s/cm^2] or [W/cm^2]. The measurement may be made for any diameter of pot used during a test cycle but is usually reported for the largest diameter. The diameter should be reported together with the **HFR** value, or indicated by clear implication in the body of the report.

2.21. **Heat Flow Rate Cooking Test (HFR Cooking Test):** The burn cycle (including power variation and duration) of a **Cooking Test** is conducted without cooking food, but rather heating water in the same pot or pots normally used. The heat gained by these pots is determined, swapping the pot for another one if the water reaches 70°C. The **HFR Cooking Tests** are conducted for each of the selected **Cooking Tests** that make up the **Technical Test** (which are always HFR tests). The **Technical Test** result is then validated by comparing it with the sum of the **HFR Cooking Tests**.

2.22. **Heat Flux (HFR)**: Heat flow per unit Time per unit Area expressed in units [J/s/cm^2] or [W/cm^2]; used as a synonym for **Heat Flow Rate** and **Density of Heat Flow**.

2.23. **Net Heat Gained (H_{NET})**: This variable is the heat retained by a cooking vessel during a burn cycle and is expressed in units of MegaJoules. It includes the heating of the pot and its contents plus the heat of evaporation of water, but excludes other heat flows through the pot, specifically radiative and convective losses from the pot sides and top.

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[10] 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 and Плотность теплового потока both mean the latter and are in common use. The ultimate meaning is the same: Joules per second per square meter [J/s/m^2]. Using CGS it can be written [Watts/cm^2].

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

2.24. **Overall Energy Efficiency (η):** Refer to **System Efficiency.**

2.25. **Overall Thermal Efficiency (η):** Refer to **System Efficiency**

2.26. **$PM_{2.5}$:** Fine particulate matter, such that the aerodynamic diameter of the particles is less than 2.5 μm.

2.27. **Pot-swapping method:** Water is heated in a series of pots which are replaced if the water reaches a predetermined temperature selected to avoid evaporation, normally 70°C. The pots and water masses and the change in temperature of both, and considering the Specific Heat of each, are used to calculate the total heat gained during a **Burn Cycle** or **Cooking Cycle**. This is a high precision[12] variant of a **Water Boiling Test** that avoids the measurement complexities related to the evaporation of water. It can be used to precisely determine the **Heat Flow Rate**, the **System Efficiency** and **Cooking Power** at high and low fire power.

2.28. **Stove Testing Toolbox:** This is an approach to testing whereby the methods for making individual measurements and calculation procedures **(Tools)** are agreed and published as validated procedures. Any test that is built up using a series of validated **Tools** from the **Toolbox** is accepted as producing valid results. Depending on the requirements of the customer, a laboratory is free to use any validated **Tool** or **Tool** combination without having to have the combined set of procedures externally reviewed as a separate method. The concept can be extended to cover all performance measurements including safety and social acceptability.

2.29. **System Efficiency (η):** The ratio of the useful heat energy gained by a cooking vessel[13] divided by the energy originally available in the **Fuel Consumed** (as defined in 2.13) expressed as %. Synonyms include O**verall Thermal Efficiency** and **Overall Energy Efficiency**.

2.30. **Technical Test:** A water heating test conducted under controlled conditions wherein the power and duration of two or more **Cooking Tests** is duplicated. The purpose of the **Technical Test** is to reproduce, without cooking and without bringing water to a boil, a burn cycle that is representative of an amalgam of cooking cycles used in the geographic community of interest. A **Technical Test** is created by combining several **Cooking Tests**. A **Technical Test** is a combination, by simple average or weighted for frequency, of the durations and fire power(s) of two **Burn Cycles** within which the cooking takes place. The sum of the emissions and fuel consumption of two **Technical Tests** should be the same as the combined results of the component **HFR Cooking Tests** which, strictly speaking, are **Technical Tests** for a single cooking task.

2.31. **Turn Down Ratio (TDR)**: During the cooking of foods typical in the community of interest, the **Cooking Power Maximum P_{MAX}** and **Cooking Power Minimum P_{MIN}** are determined. These are the upper and lower limits of cooking power required in the **Geographic Community of Interest** to produce the meals. The ratio between these power levels is defined as the **Turn**

[12] Using a 1 gram scale and a 0.1 degree thermometer it is ≈500 times more precise to determine performance by measuring water heating than water evaporation.
[13] See para 1.3 above and its footnote for the definition of heat gained.

Down Ratio. Specialised water heaters are not required to demonstrate any capacity to control the **Cooking Power** and thus do not have a **TDR**.

2.32. **Water Boiling Test (WBT):** Any test of a stove or water heater that uses a pot or pots of water heated from an initial to a final temperature (sometimes but not necessarily the boiling point) as a surrogate for cooking and for determining the quantity of heat delivered by the product to the cooking vessel or cooking surface.

2.33. **Water Heater**: Any **Biomass Fuelled** water heating appliance which can deliver heat at an acceptable rate into one or more water containers.

Section 2: Testing Methods

3. **Performance evaluation** applies the concept of the **Stove Testing Toolbox**. The **Toolbox** is a set of approved[14] measurement methods (**Tools**) that can be combined in various ways to give a performance evaluation based on the diverse cooking requirements a community of interest. Not all **Tools** are used on all occasions as the cooking cycles differ from project to project. Provided the test is conducted and analysed using a combination of accepted **Tools**, the result is deemed to be valid.

4. The five stages in the development of a validated **Technical Test** for a **Performance Evaluation**:
   - evaluation by social scientists of typical C**ooking Cycles** and the selection of representative **Cooking Tests**, then determining baseline emissions and fuel consumption;
   - conducting **(HFR) Cooking Tests** to establish the **cooking power**, **system efficiency** and **emission factors** for each cycle;
   - the creation of a **Technical Test** by mathematically combining two or more **Cooking Tests**;
   - the application of approved methods to measure and calculate the performance of the product during the **Technical Test**;
   - comparison of the **Technical Test** results with the **HFR Cooking Test** results to show that the laboratory test can reproduce and therefore predict actual cooking performance.

   Each element used in this process is a **Tool** and has its rules, procedures 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.[15] These are chosen on the basis that the cooking power patterns are in common use and distinctly different from each other. Typically one cycle requires a predominantly high cooking power and the other predominantly low. Also considered is the need to control the cooking power during the session. The chosen cooking tasks, pots and fuels should be common in the community of interest and cover the required **Cooking Power** range. In order to ensure agreement about the cooking and fire management processes, a focus group should be observed replicating these processes in the laboratory. The focus group should be very familiar with the cooking cycles and the stoves used. The baseline product performance (**Fuel Consumption**, $\mathbf{EF_{CO}}$ and $\mathbf{EF_{PM2.5}}$) is determined during these demonstrations.

5.1. **Cooking Test 1, Central Java**

The task comprises two stages – steaming 0.5 kg of dry rice in a traditional manner using a water boiling pot (*soblok*–rice steamer), followed by bringing 3 litres of cold 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

Time needed 9 minutes

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

[15] 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 demonstrated in the first two tasks.

Replace the pot with the soblok containing 2 litres of water in the bottom section

Bring the water to boiling

Time needed 10 minutes

Put the par-boiled rice into the soblok

When the rice is done remove the soblok

Time needed 30 minutes

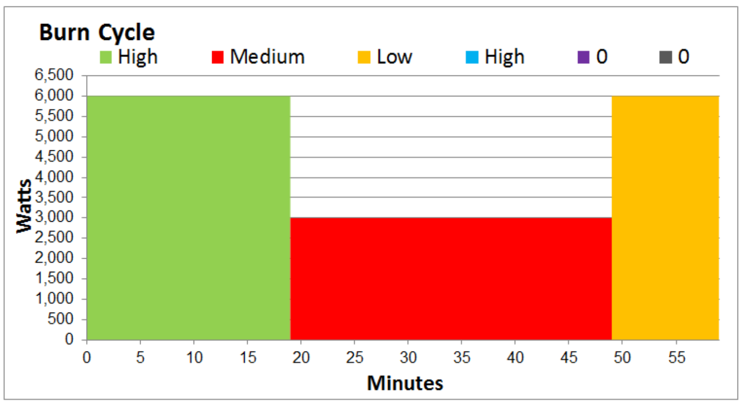
Place a pot (with lid) containing 3 litres of water on the stove

When the water is boiling, the cooking cycle is complete

Time needed 10 minutes

Total time: 59 minutes.

Cooking power	High	Medium	Low	High	**Total**
Minutes	19	30	None	10	**59**



5.2. Cooking Test 2, Central Java

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

Time Zero

Ignition

Place a pot with lid containing 365 g of coconut milk, 600 g of chicken, 60 g of seasoning and 1.4 litres of water on the stove

Bring everything to a boil

Time needed 9 minutes

Simmer and stir as needed

Time needed 57 minutes

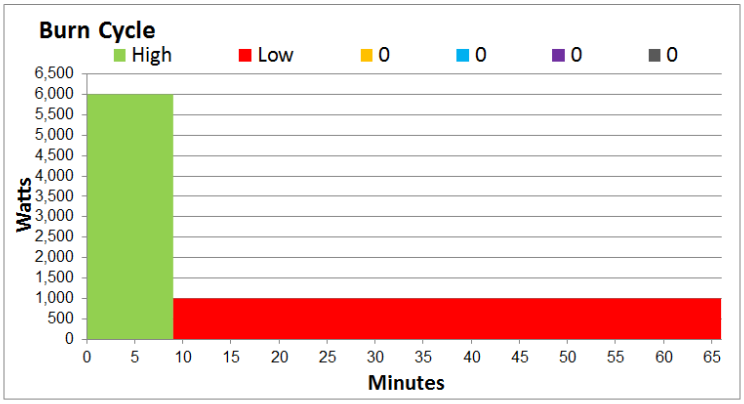
Remove the pot and replace it with a wok containing 60 g of oil

Cook the chillies at low power

Time needed 9 minutes

Total Time 66 minutes

Cooking power	High	Medium	Low	High	**Total**
Minutes	9	None	57	None	**66**



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

6. HFR Cooking Tests

Having established which of the cooking cycles will be used and having measured the overall CO, PM emissions and fuel consumption 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. For cultural reasons, this target is not the same in all communities. The information is relevant to the selection of technologies the market aggregators will promote.

6.1.3. The formula for calculating the **HFR** is:

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

6.2. The **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, pots of water identical to those used when cooking[16] 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** [Joules per second per square centimeter] is calculated – for each pot, if there is more than one – at each fire power level used.

6.3. The total emissions, emission factors, fuel consumption, energy efficiencies, heat flow rates and cooking powers for all three replications are tabulated. As before, fuel remaining from a previous identical burn cycle is included[17] in each test when applicable.[18]

6.4. The total potential energy in the fuel consumed during **Cooking Test 1** ($\sum H^1_F$) and the useful cooking energy ($\sum H^1_{NET}$) are determined. If there is a difference between the mass of 'used fuel' added during the first replication and the mass remaining after the third replication, an adjustment is made to the $\sum H^1_F$ figure to give the total energy available in all the consumed fuel.[19] For stoves that cannot reuse any of the fuel remaining, this correction is not required as all fuel is considered consumed.

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

6.6. The $\sum CO^1$ and $\sum PM^1_{2.5}$ values for **Cooking Test 1** are divided by the total useful heat gained $\sum H^1_{NET}$ to yield the **baseline Emission Factors** for Carbon monoxide and PM2.5 particulate matter:

$$\mathbf{EF^1_{CO}} = \sum CO^1 / \sum H^1_{NET} \quad [\text{g CO/MJ}]$$
$$\mathbf{EF^1_{PM2.5}} = \sum PM^1_{2.5} / \sum H^1_{NET} \quad [\text{g } PM_{2.5}\text{/MJ}]$$

The total useful heat gained during all three replications of **Cooking Test 1** $\sum H^1_{NET}$ is divided by the total energy available in the **Fuel Consumed** $\sum H^1_F$ to yield the **System Efficiency,** expressed in %.[20]

$$\eta^1 = \sum H^1_{NET} / \sum H^1_F \times 100 \quad [\%]$$

where η is the efficiency and the superscript [1] indicates the cooking test number.

6.7. **HFR Cooking Test 2** is conducted in triplicate yielding:

CO emission factor for Test 2: $\mathbf{EF^2_{CO}}$

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[16] There may be different pot sizes used during cooking and this variation is also reproduced.
[17] This implies that 4 replications are required to get the performance from three tests if fuel remaining is reusable.
[18] 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 comprises 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.
[19] The fuel remaining does not necessarily have the same heating value as raw fuel. The energy available is adjusted accordingly.
[20] 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'.

$PM_{2.5}$ emission factor for Test 2: $\mathbf{EF^2_{PM2.5}}$
System efficiency for Test 2: $\boldsymbol{\eta^2}$

These results are used to validate **HFR Cooking Test 2**.

6.8. The values for the two tests are averaged as follows:

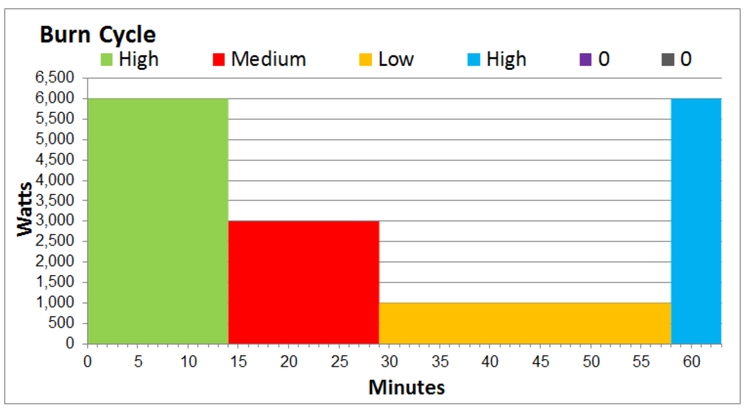
Average $\mathbf{EF_{CO}}$ $= (\sum CO^1 + \sum CO^2) / (H^1_{NET} + H^2_{NET})$
Average $\mathbf{EF_{PM2.5}}$ $= (\sum PM^1_{2.5} + \sum PM^2_{2.5}) / (H^1_{NET} + H^2_{NET})$
Average $\boldsymbol{\eta}$ $= (H^1_{NET} + H^2_{NET}) / (H^1_F + H^2_F)$

7. Technical Test Construction

The burn cycles of the two **Cooking Tests** are combined to create a single **Technical Test** that averages the test segment duration at each power level, rounding up:

Cooking power	**High**	**Medium**	**Low**	**High**	**Total**
Average minutes	(19+9)/2 =14	(30+0)/2=15	(0+57)/2 =28.5	(10+0)/2=5	62.5
Rounded values	14	15	29	5	63

This **Technical Test** has four separate cooking power sections with a total duration of 63 minutes.



7.1. The **Technical Test** is a **Heat Flow Rate** 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 mass of **Fuel Remaining** used in the first replication[11] is compared with the **Fuel Remaining** after the last to adjust the total energy available in the raw fuel (H_F).

The same final metrics are calculated:

Technical Test emission factor: $\mathbf{EF_{CO}} = CO / H_{NET}$ [g CO/MJ]
Technical Test emission factor: $\mathbf{EF_{PM2.5}} = PM_{2.5} / H_{NET}$ [g $PM_{2.5}$/MJ]
Technical Test system efficiency: $\boldsymbol{\eta} = H_{NET} / H_F \times 100$ [MJ/MJ, %]

8. Validation of the Technical Test

The combined emission factors for CO and $PM_{2.5}$ and system efficiency of the **Cooking Tests** are compared with the values obtained in the **Technical Test**. If the **Technical Test** average values are within the range of 80%-120% of the average values of the **Cooking Tests**, then the **Technical Test** is validated as a test procedure.[21]

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. In some geographic communities of interest the specified water load may be different. It is already known that the water boiler capacity will range from 5 to 20 litres.

The metrics used are **Emission Factors EF_{CO}** [g CO/H_{NET}], **$EF_{PM2.5}$** [mg $PM_{2.5}/H_{NET}$] and **System Efficiency η** [%] based on the net heat gained (including heat gained by the pot) divided by the energy available in the raw fuel consumed **H_F** [MJ].

Section 3: Determination of Results

10. Three-Star Performance Rating System for the Indonesian Clean Stove Initiative

The average performance values determined by the **Technical Tests** are compared with the requirements of the stove performance tiers specified in Table 1. A rating is assigned for each performance category.

Table 1. Clean Cookstoves 3-Star Rating Criteria for the Indonesian Clean Stove Initiative

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

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

A tier is assigned to a product (cooking stove or water boiler) on the basis of the highest tier for which all three parameters System Efficiency, EF_{CO} and $EF_{PM2.5}$ meet the relevant criteria.

If a product qualifies for a tier on the above criteria, the product report will contain a statement: **"This product has been assigned a *one/two/three star rating* under the Indonesian Clean Stove Initiative."**

[21] 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.

If a product fails on one or more of the criteria at the **One Star** tier, then the product report will contain the statement:
"**This product has not been assigned a *star rating* under the Indonesian Clean Stove Initiative.**"

Safety: To receive endorsement under the Indonesian Clean Stove Initiative, a product shall comply with minimum safety standards, irrespective of the tier rating based on **Emission Factors** and **System Efficiency**. The methods and criteria for safety standards are contained in a separate document (to be developed) or determined by the Government of Indonesia.

Durability: To receive endorsement under the Indonesian Clean Stove Initiative, a product shall comply with minimum standards of durability which will be taken as the equivalent of one year of normal use irrespective of the tier rating based on **Emission Factors** and **System Efficiency**. The methods and criteria for determining durability are contained in a separate document (to be developed) or determined by the Government of Indonesia. Evaluation of durability may take into account evidence of durability tests provided by the product owner.

11. Ownership of Test Results

11.1. The results of performance tests belong to World Bank Clean Stove Initiative Indonesia.

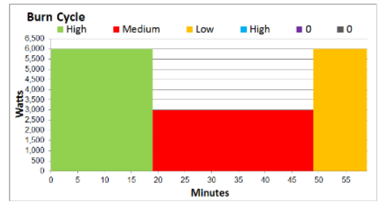
11.2. The results are provided to the product owner in full, who may use, distribute or publish results for their own purposes

11.3. Anonymized results may be used for reporting and comparison in documents related to the Indonesian Clean Stove Initiative project.

Section 4: Examples of Test Results

12. **Sample test results** for a baseline stove in Central Java, Indonesia are presented below:

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

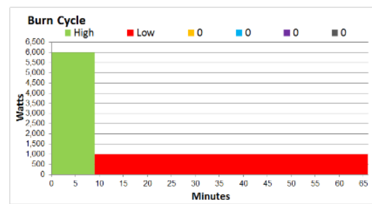


'Soblok' rice steamer: 27.2Ø x 18 cm high aluminium
Water boiling pot: 22Ø x 13.5 cm high aluminium

Total PM2.5	2 259 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)
Heat Flow Rate (Min)	1.6 W/cm^2 (determined during a pot-swapping test)
Turn Down Ratio	2:1 (determined from the HFR Max and Min values)

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

Cooking pot: 27.2 Ø cm x 18 cm high aluminium

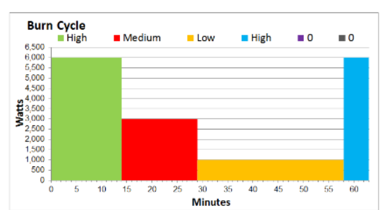


Total PM2.5	2 062 mg
Total CO	31.6 g
Total Fuel Consumed	25.0 MJ
Heat Flow Rate (Max)	4.4 W/cm^2 (determined during a pot-swapping test)
Heat Flow Rate (Min)	1.0 W/cm^2 (determined during a pot-swapping test)
Turn Down Ratio	4.4 (determined from the HFR Max and Min values)

12.3. Average Cooking Cycle results:

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

12.4. Technical Test



Total PM2.5	2,170 mg
Total CO	30.0 g
Total energy used	26.9 MJ
System Efficiency	15.9%
Heat delivered to the pot	4.28 H_{NET} [MJ]
PM Emission Factor	507 mg/H_{NET}
CO Emission Factor	7.1 g/H_{NET}
Heat Flow Rate (Max)	2.9 W/cm^2
Heat Flow (Min)	1.0 W/cm^2

Turn Down Ratio 3:1

12.5. Baseline Keren Stove Rating:

$PM_{2.5}$ Emission Factor	→	0 Stars	Not compliant with minimum one star criterion
CO Emission Factor	→	3 Stars	Compliant with three star criterion
System Efficiency	→	0 Stars	Not compliant with minimum one star criterion

Overall rating:
"This product has not been assigned a *star rating* under the Indonesian Clean Stove Initiative."

Additional information reported to producer or market aggregator in order to assist them in determining the most suitable products for each market segment:

Heat Flow Rate (Max)	$\mathbf{HFR_{MAX}}$	2.9 W/cm^2
Heat Flow Rate (Min)	$\mathbf{HFR_{MIN}}$	1.0 W/cm^2
Turn Down Ratio	**TDR**	3:1
Cooking power (Max)	$\mathbf{P_{MAX}}$	1,660 W
Cooking power (Min)	$\mathbf{P_{MIN}}$	553 W

The report may also include the pot size the stove can heat adequately according to local opinion, a tipping test result, a pot stability test result, a load bearing test result, an exploration of the maximum practical TDR and other information deemed relevant by the testing authority.

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