Clean Technologies and Fuels

"Burn the gas, not the biomass!"

Indicators

- How can clean be measured? Visibility, odor and clean pots are sensory indicators; but one can't see respirable particles like $PM_{2.5}$ and PM_{10}, and CO has no smell – these air pollutants need to be measured.

User interactions

- Have clean practices and improved technologies and fuel been considered (integrated cooking, hayboxes, solar, pressure cooker, soaking beans ahead of time, larger community-level cooking)?
- Has adequate pre- and post-installation education and training been provided to user on proper use and maintenance of clean technologies and practices?
- Does user value clean energy?
- Is there an appropriate mix of fuels and technologies available to user?

Kitchen design

- Does the kitchen incorporate ventilation, such as a gap between wall and roof, or roof ridge vents?
- Are smoke hoods an option?
- Are chimneys being used?
- Has a raised cooking platform been considered?
- If families cook indoors and use wood burning stoves, they should position the front of the stove (combustion chamber) towards an opening in the kitchen so as to ensure unobstructed and satisfactory airflow directly to the opening of the combustion chamber.

Fuel

- Are cleaner-burning fuels an option? (e.g. methane (biogas), alcohol, biomass gasifiers)
- Is there an option to move higher up the energy ladder, including using LPG where available and accessible?
- Are fossil fuels a cleaner option?
- Is solar an option?
- Is using biomass to make electricity a possibility? What kind of fuel is being used?
- Are briquettes, pellets, charcoal a possibility?
- Is the biomass dry?
- Does the biomass have a low amount of pitch?
- Is the fuel adequately cut?
- Is the fuel standardized?

Operation

- Goal: pyrolysis via wood-gas or methanation via bio-gas.
- Is complete combustion taking place?
- Is there a suitable ratio of secondary air/primary air (6:1)?

- Is a catalytic converter a possibility?
- Have clean design options been considered (e.g. Jotul stove—S-draft concentrates combustion gases and provides air for secondary combustion)?
- Are cleaner more expensive stoves (e.g. forced air with meter controls) affordable to user?
- If a clean combustion technology is being used, might it emit inside for space heating? (e.g. gas, ethanol)
- Has preheating air with a vortex been considered?
- What is the radiation conservation/insulating refractory value of the stove?
- Does the stove leak?
- Is the draft optimal?

Maintenance and Repairs

- Is the chimney easily maintainable?
- Is the chimney built-in? Can the bottom be removed to clean it (e.g. with corn husk "Q-tip" brushes)?
- How durable is the chimney (how long does it last)?
- How durable is the smoke hood (how long does it last)?

Reliable Technology & Fuels

Consistency

- Consistent supply and quality of fuel (fire wood, solar, bio-gas, liquid). Otherwise, provide multiple devices or multi-fuel stove to meet the need.
- Every time you use it, it should work the same.
- Consistency in manufacturing (standardization, mass production, molds, quality control).
- Are the stove production materials consistently available?
- Is manufacturing expertise available?
- Manufacturing system that supports reliability of supply (especially crucial in large expansion plans).
- Constant technical performance within the household context.
- Consistent cooking time.
- Emissions remain constant over the lifetime of the device.
- Product quality remains consistent irrespective of time and volume.

Operation

- Long-term availability.
- Ignites easily and consistently with the same procedure.
- Ignites in a variety of weather conditions (i.e., windy, wet, cold).
- Ignites even if wood is not perfectly dry.
- Does the device use a variety of available fuels (i.e., pinecones, corn husks)?
- Is the heat generation/cycle predictable and replicable?
- Does the device remain safe over time (especially for children)?
- Is the device simple to operate? How much training is needed?
- Does it meeting local cooking styles (i.e., pots, griddles, food)?
- How much is the operation influenced by the user?
- Can the fuel use be controlled (turned down)?

Maintenance and Repairs

- How often does the device need to be maintained?
- Is the device easy to clean?
- Easily repairable by users and/or local artisans.
- Is maintenance expertise locally available?
- Are the parts easily replaceable?
- Are the replacement parts affordable?
- Is installation and maintenance profitable?
- Are the replacement parts easily available and accessible?
- Is the device easy to clean?
- Can you see the parts that need to be maintained?

Fuels

- Fuel preparation (drying, splitting, processing).
- Are fuels available in all seasons?

- Are fuels readily available and affordable?
- Is the quality of the fuels consistent?

Durability

- How long does the device last (according to the manufacturer)?
- How long do the materials and individual parts last?
- Components should last 2 –3 times as long as it takes to pay for the device.
- Portable device has 1 – 2 year lifetime.
- Stable device has 10-year lifetime.
- Will the device withstand usual wear and tear?

Training

- What kind of training do you provide on maintenance?
- What kinds of follow-up visits/information are needed to ensure reliability?
- Comprehensive and easy to understand instructions for use and maintenance.

Culturally Appropriate

- People must want to and understand how to use it (acceptability).
- Meets the needs of the cook consistently.
- Is the device user-friendly?
- Is the device attractive (i.e., does not deteriorate, fits in, gives pride)?
- Does the performance match induced and implied expectations?
- Does the device cook most common food dishes well?
- Is the device convenient and comfortable to use?

- Insulate, particularly the combustion chamber, with low mass, heat resistant materials in order to keep the fire as hot as possible and not to heat the higher mass of the stove body.

- Within the stove body, above the combustion chamber, use an insulated, upright chimney that has a height that is 1.5 times higher than the diameter of the combustion chamber. In other words if the combustion chamber diameter is 100 mm than the height of the internal chimney should be 150 mm. The total height then of the entire combustion chamber and the chimney would then be 250mm. This is the optimal height for overall stove efficiency. If you want to improve the combustion efficiency (i.e. reduce the amount of smoke) we recommend a combustion chamber that has a total height of 30 cm.

- Heat only the fuel that is burning. Burn the tips of sticks only as they enter the combustion chamber. The object is NOT to produce more gasses or charcoal than can be cleanly burned at the power level desired.

- Maintain a good air velocity through the fuel. The primary Rocket stove principle feature is using a hot, insulated, vertical chimney within the stove body that increases draft.

- Do not allow too much or too little air to enter the combustion chamber. We strive to have stoichiometric (chemically ideal) combustion: in practice there should be the minimum excess of air supporting clean burning.

- The cross sectional area (perpendicular to the flow) of the combustion chamber should be sized within the range of power level of the stove. Experience has shown that roughly twenty-five square inches will suffice for home use (12 cm in diameter or 10 cm square). Commercial size is larger and depends on usage.

- Elevate the fuel and distribute airflow around the fuel surfaces. When burning sticks of wood, it is best to have several sticks close together, not touching, leaving air spaces between them. Particle fuels should be arranged on a grate.

- Arrange the fuel so that air largely flows through the glowing coals. Too much air passing above the coals cools the flames and condenses oil vapors.

- Throughout the stove, any place where hot gases flow, insulate from the higher mass of the stove body, only exposing pots, etc. to direct heat.

- Transfer the heat efficiently by making the gaps as narrow as possible between the insulation covering the stove body and surfaces to be heated but do this without choking the fire. Estimate the size of the gap by keeping the cross sectional area of the flow of hot flue gases constant. EXCEPTION: When using an external chimney or fan the gaps can be substantially reduced as long as adequate space has been left at the top of the internal short chimney for the gasses to turn smoothly and distribute evenly. This is tapering of the manifold. In a common domestic griddle stove with external chimney, the gap under the griddle can be reduced to about one 12mm for optimum heat transfer.

Efficiency and Effectiveness

- Cooking effectiveness is a function of: stove + fuel + food + pot + practice + cook
- Effectiveness also depends on the training of the users for fuel preparation, stove use, and maintenance.
- Have you considered the willingness of the cook to attend to the needs of the device? (For example, continuous versus periodic monitoring, and using the most efficient shape, size and condition [dry versus wet] of fuel.)
- An effective system will accommodate various locally appropriate cooking surfaces and vessels.
- Consistency in production will ensure that similar stoves have similar efficiency.

Verifying Efficiency

- Has efficiency been tested in a field setting? Lab results do not always correlate to field results; field-testing is necessary to get in-use results from the standard cooking cycle**.**
- Have follow-up field tests been carried out to ensure efficiency over time? At what intervals were they conducted?
- Have you tested the device during the wet and dry seasons?
- What is the expected life span efficiency of your technology?

Integrated Approach to Maximizing Efficiency

- Consider minimizing fuel consumption and emission production by using complimentary devices/fuels, such as: solar cookers, hay boxes or baskets, retained heat cookers, pressure cookers, heating rocks, biogas and other liquid fuels in combination with any fuel and device.
- Pre-cooking measures can reduce cooking time/intensity (e.g. soaking beans).
- Training of cooks: The need for training should be minimized where possible; however, it is recommended that cooks should be trained as needed.
- Scale of cooking: institutional cooking is more efficient (bigger is better); household stoves should be scaled to average household needs.
- Insulation: home insulation should be utilized for space heating purposes.
- Waste heat: this may be ‘captured’ for more productive uses.

Production and Distribution Efficiency

- Ensure efficiency when devices/fuels are produced at large scale during manufacturing.
- Ensure efficiency of distribution system, which includes packaging, volume transported, role of middlemen etc.

Efficiency of Biomass Stoves = Oxygen + Time + Temperature

Basic principles of capturing heat

- Is the gas *retaining* heat?
- Is the heat *released* at cooking chamber? (gaps, baffles, flow)
- Is the heat *maintained* in the cooking chamber? (hay box)

Combustion efficiency

- Has the stove configuration been taken into account (oven vs. flat plats vs. pot)?
- Is the combustion chamber insulated? (Example)
- Is the chamber made of low-density materials? (Example)
- Is the size of the chamber optimized? (Smaller the better)
- Are the gaps controlled?
- Are the gas and air mixing in proper proportions?
- Is the air preheated? (Recommend using a vortex for preheating air.)
- Does the combustion chamber have a small flame with vortex?
- Does the primary airflow have velocity? There should be sufficient high velocity draft; forced air is the best option.
- Is the chamber protected from wind?
- Do pyrolysis products pass through the burning charcoal layer?
- Is the turn down ratio 6:1 for simmering?
- Can the stove be started easily/efficiently?
- Can the stove be turned off/shutdown easily?

Heat Transfer Efficiency

- Does the available heat match the cooking task (i.e., power, temperature, distribution, location, and time of delivery)?
- Is the hot gas at appropriate proximity to the cooking vessel? What is the appropriate gap size? The distance of the flow path around the pot or cooking surface should be monitored.
- Is there a convective shield?
- Is there an insulated path flow?
- Are the pots used with lids?
- Does the improved stove match the user's pot size? Does the stove need to allow for a range of pot sizes?
- Using thinner cooking vessels may improve heat transfer.
- The heat transfer efficiency should be adaptable to the cooking task although, this may be problematic at times.

Efficiency for Biomass Ovens

- Is the gap tapered to maximize heat transfer?
- Does the draft or chimney have a removable ash tray?
- Is the fuel opening adjustable to control the air intake?

Efficiency Issues for Biogas and Solar Technologies

- For biogas plants, shorter duct distance may increase efficiency.
- Solar energy can offset fuel needs if it is a good match for the cooking task involved.
- Efficiency should be addressed in terms of both price and fuel.

Fuel Use

- Ensure that fuel utilization is most cost effective by using a combination of heat sources.
- Are the fuels appropriately sized (small)?

- Are the fuel inputs metered?
- Are the fuels well prepared (dried, split)?
- While processing fuel, remove undesirable components that interfere with combustion.
- Processed fuels are easier to meter and have cleaner combustion.

Affordable Technologies & Fuels

Value

- What is the consumer's ability to pay for the improved technology/fuel?
- How do users perceive the benefits of using the improved technology/fuel?
- What are the 'intangible/desirable' aspects of the improved technology/fuel (status; appeal; storability; multiple-use; etc.)?
- Are consumers prioritizing adoption of the improved technology/fuel (vis a vis other needs)?
- Are both women and men accepting/desiring the improved technology/fuel?
-
- Is the sale of the improved technology/fuel demand driven?
- Is the improved technology/fuel associated with a brand?
- Is there quality assurance?
- Is the improved technology/fuel durable, reliable?

Availability

- Is the improved technology available in the marketplace? Is the improved fuel consistently available? Is the fuel price stable?
- Is the improved technology/fuel mass-produced?
- Can you lower the cost of production and distribution to make the improved technology/fuel more affordable?
- Is the production system decentralized?
- Is there a transport system for distribution of the improved technology/fuel?
- Do users have a range of improved technologies and fuels to choose from?
- Is there competition between producers?
- How can a change in the supply and cost of raw materials impact prices; distribution and adoption of improved technology/fuel?
- How might trends in the type and uses of various fuels be considered?

Awareness

- Do the consumers (women and men) have accurate information (costs, the full range of benefits – health, time, cost savings, etc…) about the improved technology/fuel and the choices available to them?
- Do the consumers have accurate information about the high prices that they often pay for unclean energy, services, and products?
- Are community leaders and other key stakeholders (including improved technology/fuel producers and distributors) involved in the outreach/extension process?
- Is there a marketing strategy? Has a market analysis been conducted?
- Are producers/distributors given training on salesmanship?
- Are social marketing tools used for to promote the improved technology/fuel?

Financing

- What is the payback period (discount rate)?
- Are there adequate incentives for producers and consumers?
- Are there various payment options (full price; time payments; barter)?
- Is there a micro-banking system to finance the production?
- Has a revolving fund been established?
- Has the availability of disposable income (which often varies by season - especially for rural and migrant communities) been considered?
- Are the devices subsidized? Are any donated for charitable purposes?
- Are there donor and/or corporate backing for this venture?

Income generation

- Has the production and distribution of the improved technology/fuel created new jobs and enterprises?
- Have franchises and cooperatives been established?
- Is there a range of products and competition between producers? (Note: competition may lead to decreased employment in the sector.)
- Is the device used as a source of light?

Working Stove Surface and Cooking Platform

- ❑ Are there any protrusions (trip points for pots)?
- ❑ Are surfaces sufficiently smooth to avoid pot spillage?
- ❑ Are there any sharp edges? When a thin piece of cloth is rubbed firmly on all edges and surfaces of the stove surface or cooking platform,
  Best: The cloth does not catch or cut.
  Poor: The cloth catches or cuts.
- ❑ Is the cooking surface flat? What is the griddle design?
- ❑ Is the cooking platform at appropriate height? Has an elevated cooking platform been considered?
- ❑ Is the cooking platform level (e.g. on the floor or a table)?
- ❑ Is the stove safely installed, and not leaning?
- ❑ Is the stove located in a 'safe' location (e.g. not where children will be running, playing)?
- ❑ Does fuel extend out from the cooking platform, where it could be knocked out of the stove?
- ❑ Are there any unsafe projections on account of stove design/operation?

Surface Temperature

- ❑ What is the temperature of the cooking surface, and is it within an acceptable range for the material being used? The ranges of acceptable temperatures are based on the surface temperature plus the room temperature. The following procedure is recommended for measuring cooking surface temperature:
  - First, the room temperature should be measured with a thermometer.
  - Next, a grid with 4" by 4' squares should be chalked out on the exterior of the stove.
  - The stove should then be fully loaded with fuel and ignited.
  - Temperature should be measured when the fire is at it peak and the stove is fully heated. This can be accomplished by using a hand-held thermocouple at the intersections of the crossing lines on the grid. Measurements should not be averaged and the highest temperature found should be used to estimate stove safety.
  - If the stove consists of more than one material then temperature readings should be taken for each material and the poorest rating used for safety measurements.

The following table has been proposed* for judging acceptable temperature ranges. The table represents the amount of degrees Fahrenheit the surface temperature is greater than that of the room temperature. For example, if the room temperature is 88.5º F then the Good rating for metal would be 153.5º < T < 163.5º F.

<u>Surface Temperature + Ambient Temperature for Three Materials</u>

	Metal	Glass	Porcelain
Poor	T > 95º F	T > 115 ºF	T > 125 ºF
Fair	75º < T < 95º F	95º < T < 115 ºF	105º < T < 125 ºF
Good	65º < T < 75º F	85º < T < 95 ºF	95º < T < 105 ºF
Best	T < 65º F	T < 85 ºF	T < 95 ºF

Suggested revisions to recommended Surface Temperatures

- Revise ‘fair’ temperature to where they are safe for children, who burn more easily
- A broader scale of temperatures might be considered
- Are surface temperatures near the stove within an acceptable range (180º F or below)?
- The following procedure is recommended for measuring nearby structure or combustible temperature for stoves placed against a wall or within 2” of a combustible.
  - First, the stove should be placed at a distance from the structure or combustible (hereafter referred to as the ‘structure’) to be measured.
  - Next, using a stick of chalk, a silhouette of the cookstove should be drawn onto the structure while looking from the direction perpendicular to this structure. Then, a grid with 4” by 4” squares should be chalked out inside this silhouette.
  - The stove should be returned to its original position, loaded with an adequate quantity of fuel and ignited. Once a sustained peak temperature has been reached for about 30 minutes, the stove should be pulled away and temperature readings taken at each intersection on the chalk grid. The stove should be placed back against the wall within 30 seconds of removing it. In 5 minutes the structure will warm up again and the temperature test should be repeated. The highest temperature will be used to rate the safety of the stove.

The following table has been proposed for estimating acceptable temperature ranges for nearby structure or combustible.

Metric for Temperature of Nearby Structure or Combustible

	Temperature (ºF)
Poor	T > 210
Fair	190 < T < 210
Good	180 < T < 190
Best	T < 180

Chimney
- Is the chimney a safe distance from combustible surfaces?
- Is the chimney equipped with burn protectors? If not, is chimney (especially metal) in a safe location to prevent burns?
- Is the chimney compatible with the roof (e.g. grass roof)?
- Is the chimney built out of safe (non-combustible) materials?
- Has the possibility for chimney falling been addressed?

Stove Operation
- Are flames enclosed or controlled?
- Are screens installed to avoid sparks?

- Do flames cover the entire pot/pan and billow up over the rim? Following are the recommended safety ratings developed by Mark Bryden:
  - *Poor*: When flames cover the entire pot and rise over the rims
  - *Fair*: Flames envelop the bottom of the pot but do not rise above the pot handle; rims or cooking utensils.
  - *Good*: Flames cover the bottom of pot and do not exceed 1" around the diameter.
  - *Best*: The flame comes into direct contact with only the bottom of the pot
- Are there any openings on the stove (other than fuel and pot openings) that are 1.5 inches or wider? If yes, sparks and other pieces of wood – along with smoke – can escape and injure the user. Recommended procedure for rating fuel safety of stove:
  - The stove should be fully loaded however not ignited.
  - The pot/pan should be placed in its usual position. Ratings can then be taken by inserting objects (fingers; large and small ends of standard pencil/pen) in the open spaces of the stove through which the fuel can be viewed.

Metric for Fuel Safety

	Width of open spaces of cook stove
Poor	Two fingers (approx. 1.5")
Fair	One finger (approx. 0.75")
Good	The large (erasing) end of a standard pencil/pen)
Best	The small (writing) end of a standard pencil/pen

Safety for Solar

- Has the problem of glare been addressed?
- Have parabolic solar collectors been configured so as to not cause fire (hazards at focal point of solar collectors)?
- Keep in mind solar cookers are hot after 2/3 hours in sun.
- Mirrors/glass panel in cookers can be fragile.

Occupational Issues

During stove construction, are worker safety issues considered and addressed?

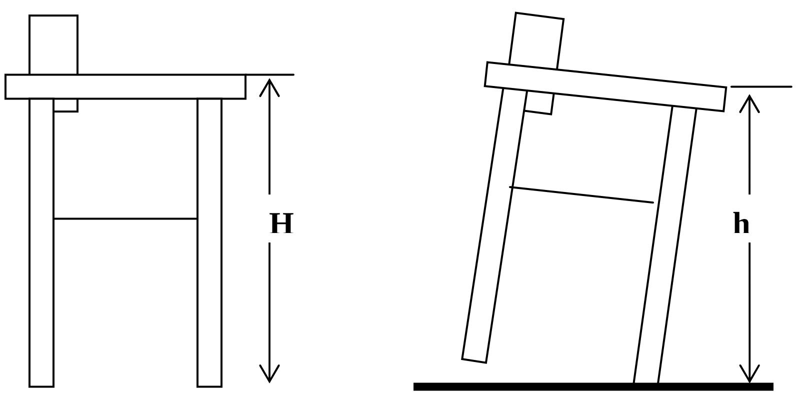
User Safety

- Have users been educated on burn prevention?
- Burnability of individual, especially children, is more important than simply the temperature.
- Is a CO detector present? Do CO emissions exceed safe levels? Have users been warned of dangers of CO poisoning, and how to avoid it?
- Are the gas paths accessible for cleaning?
- Are chimney-cleaning methods safe?

Stove Stability

- How stable is the stove? Does it maintain its stability with various pot shapes/sizes?

- Does the stove have secure pot support?
- Will the likely mode of cooking (e.g. vigorous stirring) affect stability?
- Does the stove allow for adequate isolation of handles from hot surfaces/sources?
- How ‘securable’ are moving parts (e.g. over doors), fuel door/port?
- Is the stove structurally damaged by repeated minor jostling? (i.e. by pushing or pulling an eight pound pot filled with food/water directly on the stove)
- Is the angular displacement of the stove at or less than 12 degrees? Displacement range is calculated by taking the inverse cosine of the ratio of the tipping height (h) to that of the starting height (H). Refer to ‘Angular Displacement of Stove’ below for more information. Recommended procedure for calculating angular displacement of stove:
  - For this test, the stove should be left as is, that is with chimneys, cover and lids in their usual positions. The fuel magazine should be fully loaded however not ignited. A cooking pot, used regularly, should be filled with water and placed on the stove.
  - The highest point on the side being tipped over should be measured in relation to the ground. Now, the stove should be tilted on one side and at the point where the device begins to tip over, the new height should be measured in relation to the ground. With the two heights (H and h respectively), the angular displacement can be calculated.



Metric for Angular Displacement

	Angular Displacement Degrees (radians)
Poor	Φ < 12 (0.14)
Fair	12 (0.21) < Φ < 16 (0.21)
Good	16 (0.21) < Φ < 20 (0.28)
Best	Φ > 20 (0.28)

Fuel Safety

- ❑ Have the risks for leakage/explosion been addressed for liquid/gaseous fuels?
- ❑ Is solid fuel stored safely? This will reduce chances of accidents and keep fuel out of the reach of children.
- ❑ For gas fuels—has line/connector tightness been checked (problem if material deteriorates)?
- ❑ What safety concerns are present in fuel preparation (e.g. hatchets, axes)?
- ❑ How safe is transportation of the fuels?
- ❑ Are there safety concerns related to fuel additives?
- ❑ Does ignition sequence present safety risks (e.g. having to put face close to igniting fuel to blow on it)?
- ❑ Have potential safety risks involved in processing briquettes from polluted wood (treated wood) been addressed?
- ❑ Have potential safety risks involved in charcoal production been addressed?
- ❑ Have provisions been made for keeping coals off the ground?
- ❑ Do pieces of fuel exit the fuel magazine when it is jostled while fully loaded?
  Recommended procedure for testing stove safety in terms of fuel stability:
  - The stove should be fully loaded and the final piece of fuel should be lightly placed on top of the stack. The fuel should *not* be ignited.
  - All hatches or protective covering for the fuel magazine (if applicable) should be closed.
  - Next, a piece of fuel should be gently knocked off the top of the pile in the direction of the fuel magazine entrance. Enough force should be applied to start the piece of fuel into motion, at the same time allowing for adequate free movement. This procedure should be repeated 5 times, each time with a different size and shape of fuel. In the event that topmost piece of fuel is not accessible, the stove should be gently jostled (by pushing or pulling an eight pound force directly on the chimney/cage).

Best: if no pieces of fuel exit
Poor: if any fuel comes out of the magazine