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THE BOTTOM LINE

Clean cooking promises substantial benefits for human health, environmental protection and climate change. The first generation of fuel-efficient cookstoves, motivated by deforestation concerns, focused primarily on improving heat transfer so as to improve energy efficiency. More recent concerns about human health and black carbon have turned toward advanced-combustion cookstoves, the goal of which is to reduce harmful emissions by boosting combustion efficiency.


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Understanding the Differences Between Cookstoves

Why is this issue important?

Clean cooking offers important health, environmental, and climate-change benefits

The growing interest in clean cooking, with its potential benefits for human health, environmental protection, and climate change, has prompted development specialists to reconsider the quality and performance of cookstoves. Governments, donors, and development organizations want to ensure that the cookstoves they promote meet standards that will yield the greatest possible benefits over time, when adopted and used properly. Households need to understand differences in cookstove performance if they are to select those that represent the best value for money.

The performance of a cookstove is characterized by three processes:

- *Heat-transfer efficiency,* or how much of the heat is absorbed by the pot
- *Combustion efficiency,* or how much of the energy and carbon in the fuel is converted to heat and carbon dioxide
- *Overall thermal efficiency,* or how much energy in the fuel is absorbed by the pot (Venkatraman and others 2010).

These aspects of efficiency are influenced by different cookstove design features. Heat-transfer efficiency depends primarily on the geometry of the cookstove and the flow of hot gases around the bottom and sides of the pot. Combustion efficiency, by contrast, depends primarily on the temperature in the cookstove and the characteristics of the combustion chamber that affect the circulation of air.

Overall thermal efficiency can be raised by improving either combustion efficiency or heat-transfer efficiency. Polluting emissions, however, are most strongly influenced by changes in combustion efficiency. In fact, relatively small improvements in combustion efficiency have relatively large effects on emissions. Yet so-called fuel-efficient stoves (commonly referred to as "improved cook-stoves") are designed to raise overall thermal efficiency by improving heat transfer (Venkatraman and others 2010), with comparatively little focus on combustion efficiency. Advanced-combustion stoves (or "advanced cookstoves"), on the other hand, increase airflow to boost combustion efficiency and reduce emissions.

What is the problem?

Traditional cookstoves are highly polluting and hazardous to health

Across much of the world, the traditional method of cooking is over a three-stone fire. The three-stone fire is inefficient in transforming solid fuels to energy and, although its performance varies greatly dependent on the cook, it generally yields only 5–20 percent overall thermal efficiency. Traditional cookstoves, locally made from mud or metal, are slightly more fuel-efficient than the three-stone fire, yielding as much as 15 percent fuel savings. For example, traditional cookstoves in Bangladesh are usually made of mud in a cylindrical form (either underground or above ground), with three raised points on which cooking utensils are placed. One of the spaces between these raised points is used as the fuel port and the other two as exits for flue gases. Wood, logs, dry leaves, hay, straw, jute sticks, rice husks, twigs, dung, and bamboo serve as fuel. Users of such traditional cookstoves must collect or purchase large quantities of fuel to cook their meals.

The reliance on solid fuels for cooking and heating has drawn attention lately because of the role of black carbon in global

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warming. Black carbon originates from incomplete combustion of fossil fuels, particularly diesel, but also of biomass and other fuels. There is a growing body of evidence that black carbon alone may be the second-most-important factor affecting the rise in global temperatures after carbon dioxide (CO_2) (Ramanathan and Carmichael 2008; Gustafsson 2009; Bond and others 2013).

In terms of health, exposure to household air pollution from the inefficient combustion of solid fuels in low-quality stoves operated in poorly ventilated kitchens is a significant public health hazard. The resulting pollution is a mixture of particulate matter, carbon monoxide, hydrocarbons, formaldehyde, and benzene that significantly exceeds safe levels to humans (Smith and others 1999 and 2000; Venkataraman and others 2010). Current estimates from the World Health Organization (WHO 2014) have tied indoor air pollution to 4.3 million deaths in 2012 in households cooking over coal, wood, and biomass stoves.

What are the benefits of fuel-efficient cookstoves?

Fuel-efficient cookstoves were designed to reduce deforestation

A critical goal of promoters of the first generation of fuel-efficient cookstoves was to help slow the pace of deforestation by reducing the volume of fuelwood needed for cooking. Fuel-efficient cookstoves were designed primarily to improve the efficiency of heat transfer to the cooking pot, thereby saving fuel and reducing pressure on forest resources. Fuel-efficient cookstoves can reduce fuel use by 20–50 percent relative to the three-stone fire.

There are various types of fuel-efficient cookstoves. Many are designed with the cook in mind and aim not to change cooking practices but to accommodate a cook's habits, fuel choice, and traditional cuisine. So-called rocket stoves use rocket design principles. Rocket stoves are defined by improvements to an insulated, L-shaped combustion chamber that allows for partial combustion of gases and smoke inside the cookstove. Rocket stoves follow 10 design principles to improve heat transfer using insulation and narrow channels that direct the flow of hot gases closer to the pot or griddle. 1 Stoves that incorporate a griddle for cooking flat breads are most prevalent in Latin America, and throughout this region are referred to as plancha stoves. The plancha stove is designed to enclose the fire to heat the griddle surface and to expel through a chimney the particulate matter and toxic vapors resulting from incomplete combustion.

Although fuel efficiency was the main concern of designers of fuel-efficient cookstoves, in some parts of the world—notably Latin America and South Asia—some cookstoves were also provided with chimneys or hoods. These help reduce indoor air pollution by diverting wood smoke out of the kitchen, though they do nothing to curb outdoor pollution or climate change (Smith 2010). The reduction of indoor emissions varies significantly. Some fuel-efficient cookstoves deliver little or no reduction, whereas others can reduce particulates and carbon monoxide by up to 90 percent in laboratory testing. Stoves with a well-fitted chimney kept in good condition and regularly cleaned can dramatically reduce indoor air pollution.

What are the potential benefits of advanced-combustion cookstoves?

Advanced-combustion cookstoves eliminate nearly all pollutants harmful to health

In contrast to fuel-efficient cookstoves, advanced-combustion stoves focus primarily on cleanliness. In other words, the task of designers of advanced-combustion cookstoves is to maximize combustion efficiency, defined as how much of the energy and carbon in the fuel is converted to heat and carbon dioxide.

Advanced-combustion cookstoves perform at varying levels of combustion efficiency depending on the efficiency of the fuel used. Emerging types are *forced-air cookstoves* and *gasifier cookstoves*. Forced-air biomass cookstoves use a fan powered by a battery, electricity, or a thermoelectric couple that blows jets of air into the combustion chamber. With a fan, the jets of air induce superior mixing of flame, gas, and smoke and can be extremely clean. Gasifier cookstoves force the gases and smoke that result from incomplete combustion back into the cookstove's flame, where the heat of the flame continues to combust the particles until combustion is nearly complete, resulting in few emissions. Each type of advanced-combustion cookstove has its own fuel requirements. Some use

[1] More information is available at: http://www.pciaonline.org/design-principles.

"The best advanced-combustion cookstoves reduce indoor air pollution to levels close to those of cookstoves using liquefied propane gas or other clean fuels."

unprocessed fuelwood; others require processed fuels in the form of pellets or small cuttings.

In laboratory tests, advanced-combustion cookstoves show fuel savings of 45 percent or more. They also reduce carbon monoxide and particulate matter by 95 percent or more and nearly eliminate black carbon. The best advanced-combustion cookstoves reduce indoor air pollution to levels close to those of cookstoves using liquefied propane gas or other clean fuels. This is done by raising the combustion efficiency of the stove to the point where only a negligible amount of fuel is left unburned (Mukhopadhyay 2012). Realizing all these benefits depends, of course, on proper, sustained use of the cookstoves.

The cost of fuel-efficient and advanced-combustion cookstoves can vary drastically, but the cost depends largely on the type of fuel used in the stove (charcoal, wood, other), the material from which the stove is made (metal, ceramic, cement, clay), and how the stove was made (artisanal, semi-industrial, industrial). In Kenya, for example, the cost of a basic (artisanal) improved stove can range from $5 to $12; a stove produced in a semi-industrial or industrial fashion ranges from $15 to $50; and an advanced stove (a Philips, for example), between $80 and $120. The plancha stove in Latin America, in part due to its size and the metal plancha required for tortillas, generally costs more ($150 or more). Costs and cost drivers vary widely by stove design and local conditions, however, and additional costs are associated with providing the necessary electricity supply needed for fans or other accessories. The price paid by the consumer may be influenced by still other factors, such as import tariffs or the availability of effective subsidies from carbon financing.

Can cookstove performance be measured?

New standards allow for a precise taxonomy of cookstoves

The 2011 Lima Consensus called for the establishment of testing standards for biomass cookstoves. In response, more than 90 stakeholders from 23 countries met in The Hague in February 2012 to reach consensus on an ISO International Workshop Agreement (IWA) to provide interim guidance for rating cookstoves on four performance indicators: (i) efficiency, (ii) indoor emissions of fine particulate matter (PM 2.5) and carbon monoxide (CO), (iii) overall emissions, and (iv) safety (table 1).

The tiered system specified in the IWA builds in enough flexibility to reveal the strengths and weaknesses of each stove and to allow for the coordinated use of multiple tiers. The tiers range from 0—the equivalent of a three-stone fire—to 4, which expresses aspirational targets for future improvements, based on WHO guidelines.

Some additional advantages of the tiered system are the ability to accommodate multiple protocols regarding performance, emissions,

Table 1. GACC tier-based performance standards for cookstoves

		Tier				
Indicator	Measure	0	1	2	3	4
Efficiency	HPTE[a] (percent)	<15	>15	>25	>35	>45
	LPSC[b] (MJ/min/L)	>0.05	<0.05	<0.039	<0.028	<0.017
Indoor pollution	CO (g/min)	>0.97	<0.97	<0.62	<0.49	<0.42
	PM (mg/min)	>40	<40	<17	<8	<2
Overall pollution	HPCO (g/MLd)	>16	<16	<11	<9	<8
	LPCO (g/min/L)	>0.2	<0.2	<0.13	<0.1	<0.09
	HPPM (mg/MJd)	>979	<979	<386	<168	<41
	LPPM (mg/min/L)	>8	<8	<4	<2	<1
Safety	Iowa protocol	<45	>45	>75	>88	>95

Source: Global Tracking Framework 2013.

Note: HPTE = high power thermal efficiency; LPSC = low power specific consumption; CO = carbon monoxide; PM = particulate matter; HPCO = carbon monoxide (in grams per megajoule delivered to the pot) at high power, that is, operation of the stove at the maximum (or nearly maximum) rate of energy use; LPCO = carbon monoxide in grams per minute per liter at low power, that is, operation of the stove at the minimum (or nearly minimum) rate of energy use); HPPM = particulate matter in milligrams per megajoule delivered to the pot at high power; LPPM = particulate matter in milligrams per minute per liter at low power.

"The 2011 Lima Consensus called for the establishment of testing standards for biomass stoves."

and safety and to allow for standardized reporting across those protocols. The IWA specifies tiers of performance for a water boiling test and for a biomass stove safety protocol. It also provides a framework for establishing tiers of performance for additional test protocols.

As of mid-2013 the stove performance tiers were still in draft form. Efforts to establish a formal ISO classification are continuing (PCIA and GACC 2011).

To measure fuel efficiency, the tiers in the draft agreement consider the thermal efficiency of the stove on high power and the specific fuel consumption (in MJ/min/L) of the stove on low power. To be rated as fuel efficient under the Clean Development Mechanism, a stove must reduce fuel consumption by 20 percent. This equates roughly to tier 2 in the present system. In order for a stove to quality for carbon credits under the CDM, it must be rated tier 2 or better.

The IWA tiers evaluate indoor emissions relative to small particulates (PM2.5)[2] and carbon monoxide emission rates. WHO guidelines specify that over a 24-hour period, the average level of PM2.5 should not exceed 35μg/m^3 and that of carbon monoxide should not exceed 7mg/m^3. A stove that met those standards would fall into tier 4 of the draft system.

Although significant progress has been achieved in designing cookstoves that are efficient and clean, much remains to be done to develop high-performing technologies that are also affordable, durable, and easy to use, while also meeting international guidelines for indoor air quality. Tables 2 and 3 provide an overview of the fuel efficiency, health effects, and emission-reduction levels of the cookstoves mentioned in this note.

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[2] Particulate matter, or PM, is the term for particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. Particles smaller than 2.5 micrometers in diameter (PM2.5) are referred to as "fine" particles. Because of their small size, they can lodge deeply into the lungs.

"Much remains to be done to develop high-performing technologies that are also affordable, durable, and easy-to-use, while also meeting international guidelines for indoor air quality."

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Live Wire 2014/8. "Widening Access to Nonsolid Fuel for Cooking," by Sudeshna Ghosh Banerjee, Elisa Portale, Heather Adair-Rohani, and Sophie Bonjour.

Table 2. Characteristics and impacts of fuel-efficient cookstoves

Cookstoves	Characteristics	Fuel type	Efficiency (as determined by lab testing)	Health impact	Climate impact
Plancha (griddle) stoves 	Specialized stoves designed for areas where common cooking practices require a hot flat surface. Designed to enclose the fire and to exhaust the particulate matter and toxic vapors from combustion through chimneys. Designs vary from built in to modular stoves that are prefabricated and easy to install.	Charcoal or biomass (agricultural waste including corn stalks and dung; natural debris like twigs, branches, and pinecones; and firewood).	Design differences result in a large variation in efficiency, with claims ranging from 50 to 70 percent reduction in fuel use. Variations include internal geometry of the stove that moves the hot gases through the systems; the inclusion or lack of pot rings to provide direct heat transfer to pots; density and thermal characteristics of materials used for combustion chambers, griddle, and insulation; and diameter and length of the chimney. The physical characteristics of the fuel will also create differences in consumption, as well as the option to remove (and reuse) fuel that has not been consumed.	Significant positive impacts. Burn injuries greatly reduced. Health issues associated with smoke (respiratory illness, cataracts, low birth weight) potentially reduced. When chimneys are used, indoor emissions are almost completely eliminated (compared with an open fire). With reduction in fuel use, other health problems are lessened (hernias, back and neck pain).	Combustion-chamber designs that burn fuel efficiently may reduce outdoor emissions by 30 percent or more compared with open fires, as long as the fuel is dry and dense. Well-designed stoves have been shown to mitigate 1.5 to 3.6 tonnes of carbon dioxide equivalent, thus reducing emissions of greenhouse gases.
Rocket 	Defined by improvements to an insulated, L-shaped combustion chamber that allows for partial combustion of gases and smoke inside the stve.	Raw or processed biomass	Performance varies from *increasing* fuel use for poorly designed, high-mass models to fuel savings of 20–50 percent.	Can achieve emissions reductions of roughly 70 percent or more in carbon monoxide, and more than 50 percent in particulates (in a laboratory setting). Wide variety in performance, even in laboratory settings, depending on the stove, fuel quality, and user.	Some of the insulated, mass-produced versions reduce net warming impact by nearly 60 percent; may have little to no impact on emissions of black carbon.

Source: Adapted from Global Alliance for Clean Cookstoves; available at: http://www.cleancookstoves.org/our-work/the-solutions/cookstove-technology.html.

Note: Climate change impact also depends on how the biomass fuels are collected, whether they are renewable or nonrenewable, and how a stove economizes on nonrenewable fuels.

Table 3. Characteristics and impacts of advanced-combustion cookstoves

Cookstoves	Characteristics	Fuel type	Efficiency (as determined by lab testing)	Health impact	Climate impact
Forced-air cookstove 	A fan powered by a battery, external source of electricity, or a thermoelectric device that captures heat from the stove and converts it to electricity blows high velocity, low volume jets of air into the combustion chamber, resulting in more complete combustion of the fuel.	Raw or processed biomass	Reductions in fuel use ranging from 37 to 63 percent (relative to a three-stone fire).	Indicative potential to reduce emissions by as much as 98 percent. Advanced stoves optimized for and fueled by a processed (uniform) fuel will very likely have much better results in field conditions.	Reduction of net warming impact by nearly 60 percent (with regard to CO_2). If the biomass is harvested sustainably, fan stoves reduce overall warming impact by about 95 percent.
Gasifier cookstove 	Gases and smoke from incomplete combustion of fuels such as biomass are forced back into the cookstove's flame, where heat continues to combust the particles in the smoke until almost complete combustion has occurred, resulting in very low emissions. Typical gasifier stoves are called top-lit updraft stoves because some fuel is lit on top of the stove, forcing combustible products to pass through the flame front before being emitted into the air. In a gasifier stove with a fan, jets of air create superior mixing of flame, gas, and smoke and can be extremely clean.	Raw or processed biomass	Gasifier stoves save on fuel, though generally less than fan stoves.	Indicative potential to reduce emissions by as much as 98 percent. Advanced stoves optimized for and fueled by a processed (uniform) fuel will very likely have much better results in field conditions.	Reduction in net warming impact by nearly 40 percent (with regard to CO_2). If the biomass is harvested sustainably, gasifier stoves reduce overall warming impact by about 66 percent.

Source: GACC 2013.

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