A Summary Review of Global Standards and Test Protocols Relating to Product Quality Standard Development for Household Biomass Cookstoves

David Kaisel
Center for Entrepreneurship in International Health and Development (CEIHD), School of Public Health, University of California, Berkeley, 225 University Hall, Berkeley, CA 94720-7360 USA.
Email: dkaisel@gmail.com

Dana Charron
Berkeley Air Monitoring Group, 2124 Kittredege Street #57, Berkeley CA 94704

In recent years, there has been increasing interest and investment in developing sustainable, scaleable commercial approaches for the distribution and sale of improved biomass household cookstoves. Product performance, safety and quality standards at national and regional levels are an important tool for regulating markets and for establishing the credibility and comparability of various technologies and product offerings for end users. There are few national or regional standards specific to biomass cookstoves, though performance and emissions standards and test protocols for other biomass-fueled household appliances are more commonplace. This article provides historical background and a review of the most relevant current performance and emissions standards, as well as a discussion of key test protocols and air quality standards aimed at informing new product development and stove commercialization strategies.

1. Introduction

This article is a revised and updated version of a report first written as background for a national biomass stove competition in China. In 2005, the China Association of Rural Energy Industry (CAREI) in partnership with the Center for Entrepreneurship in International Health and Development (CEIHD) at the University of California, Berkeley, and with the financial and technical support of the Shell Foundation and Shell China, executed a national design competition to stimulate innovation and dissemination of improved biomass household cookstove technologies being developed by Chinese manufacturers.

The goals of the competition that were set out at the time included:

- Identifying the most promising high-efficiency, low-emissions biomass stove technologies and the best enterprises innovating in this field.
- Recognizing and publicizing these stoves and enterprises within China.
- Strengthening the capacity of the selected enterprises by providing management training, access to capital, and other business development support.
- Identifying export opportunities for these technologies and promoting the selected enterprises to fill appropriate market needs in other developing countries.

The scope of this document is to provide a high-level review of biomass-fueled[i] stove performance and emissions standards, and relevant test methodologies as adopted by standardization or regulatory authorities worldwide, with the objective of providing empirical reference points for the development of national stove evaluation criteria and product standards. While this summary does not intend to be an exhaustive survey, we believe it contains the standards and protocols most frequently cited in the stove design and performance literature reviewed. For brevity, the standards and methods cited are not appended, but are generally available directly from the issuing agencies.

In addition to the summary of stove standards and test methodologies, this article reviews independently published stove design guidelines that embrace pertinent aspects of product quality and safety.

2. Standards background

Among industrialized economies, the first national proposal to develop wood-fueled stove emission standards was launched in the early 1980's in the United States, followed by efforts in Canada, Europe, and Australia after a series of conferences and workshops raised concerns about the health hazards of residential woodstoves [Environment Australia, 2002]. The State Department of Environmental Quality in Oregon introduced the first compulsory testing of woodstoves in the U.S. in 1985 [Oregon State Department of Environmental Quality, 2006]. The U.S. Environmental Protection Agency introduced compulsory woodstove certification nationwide in 1988.

Stove performance standards have in general evolved independently from stove emissions standards, despite their interrelation. Additionally, stove emissions standards have dealt exclusively with outdoor stack emissions measured from flue exhaust. No standard or generally accepted test method has been developed to measure indoor emissions from domestic biomass stoves.[ii]

National standards establish targets for product quality, safety and performance. They are also used as by governments as descriptive references in the regulation of product attributes such as safe operation, harmful atmospheric emissions (though not indoor leakage), and efficiency measurement [National Resources Canada, 1999]. Standards address environmental as well as health impacts of household biomass combustion, and may be compulsory (in the case of regulated products) or voluntary.

In the developing world, environmental objectives have traditionally driven improvements and innovations in stove design more than health objectives. When stove test protocols were first developed in China thirty years ago, they were developed in order to provide a consistent means to assess the environmental impacts of the inefficient combustion of 250 million tons of firewood and 350 million tons of agricultural waste burned annually in household stoves [Hao and Jia, 2005]. This focus on environmental impacts is justified by the fact that in China alone, over 180 million rural households used improved biomass stoves in 2004 [Hao and Jia, 2005].

Relating stove performance to individual health risks associated with burning biomass fuel is a comparatively recent exercise. This is one reason why the majority of current standards and test methods evaluate wood-fueled appliance emissions under controlled laboratory conditions, rather than their performance (or better, effectiveness) under actual conditions of use. As noted, most standards are concerned with outdoor rather than indoor air pollution. China is one of the first countries to establish residential indoor air quality standards (GB/T 1883-2002) that specify limits for stove emission factors such as CO and particulates (PM_{10}), though compliance for biomass stoves is not yet compulsory [Edwards et al., 2007].

3. Standards summary tables

Stove standards and test methods published by national or regional governmental agencies are summarized in the following tables. Several stove standards and test protocols (such as China's NY/T 8) define targets for cookstove performance (efficiency) and emissions. However, there are no standards that address household biomass cookstove emissions alone. The emissions standards and protocols cited here apply either to biomass-fueled heating appliances in general (such as the U.S. New Stove Performance Standards Title 40), or to ambient air quality regardless of source (as is the case with China's GB/T 1883-2002).

As noted in the tables, some national stove emissions and performance standards such as the U.S. NSPS Title 40 serve as references for regulatory frameworks. In other cases, such as Canada, enforcing compliance with standards is left to state or local authorities. Overlapping requirements are also common, as in China where municipal emissions ordinances apply in addition to national standards such as GB/T 1883.

The tables below list test protocols and standards related to stove performance (more accurately, efficiency) separately from standards and test protocols relevant to stove emissions. As mentioned above, some test standards apply to both performance (efficiency) testing and emissions testing, and are listed in both tables.

"Type" in the column headers refers to whether the document cited defines a test protocol alone, or whether it is part of a national standard or regulation made up of multiple test protocols, such as US CFR Part 60, Subpart AAA. "Objective" describes whether the standard or method addresses principally efficiency, emissions or both.

Table 1. Standards or methods relating primarily to stove performance (efficiency)

Country	Designation	Type		Objective		Test method	Indicator	Limits	Comments
		Standard	Method	Efficiency	Emissions				
China	**NY/T 8-2005** Thermal testing method of household firewood stove and firewood kitchen range		X	X		Controlled Water boiling test	Rated cooking power (heat energy absorbed per unit time)	N/A	Test method (standard) first issued as GB4363 in 1984
China	**GB/T 16155-1996** Testing method for thermal performance of domestic cooking-water heating coal stoves		X	X		Water-boiling test	Starting rate, cooking power, heating power, thermal efficiency, restart rate after bank-up, CO concentration in smoke	N/A	Method specific to coal-burning stoves
China	"General technical specification for domestic biomass stove/boiler" (**Draft**)	X		?	?	Unknown	Unknown	Unknown	Beijing Municipal standard-scheduled for publication Q2 2008[iii]
China	"Standard for Biomass molded fuel" (**Draft**)	X		?	?	Unknown	Unknown	Unknown	Beijing municipal standard-scheduled for publication Q2 2008[9]
USA	**NSPS Title 40 CFR Part 60 Subpart AAA** (Phase I)	X		X	X	Methods 5H, 5G, 28, 28A (Dilution tunnel)	% efficiency, TPM (total particulate matter)	8.5g/hr, 5.5g/hr. (catalyst)	Efficiency measured along with emissions
USA	**NSPS Title 40 CFR Part 60 Subpart AAA** (Phase II- 1995)	X		X	X	Methods 5H, 5G, 28, 28A	Weighted avg.	7.5 g/hr 4.5 g/hr (catalyst)	Standards includes efficiency indicators

Country	Designation	Type		Objective		Test method	Indicator	Limits	Comments
		Standard	Method	Efficiency	Emissions				
USA	**NSPS Title 40 CFR Part 60** Appendix A Method 28A		X	X	X	Fuel and device operational specifications	Fixed-dimension fuel cribs from air-dried Douglas fir 2x4 or 4x4		Method stipulates operational parameters affecting efficiency
Canada	**CAN/CSA-B415.1**	X	X	X	X	EPA method 5G-1 equivalent	Weighted avg. TPM	7 g/hr	As with EPA standards, efficiency is measured
AS/NZ	**AS/NZS4012: 1999**		X	X		Calorimeter room, fuel and operating specifications	% efficiency at 3 power levels, heat output in kW	None, relative average performance reported	Standard emphasizes stove performance
India	**IS 13152 (CIS 1315 Z) (Part 1): 1991** Indian Specification on Biomass Chulha-Specification	X	X	X	X	Water boiling test (Thermal Efficiency), stove hood for emissions tests	Thermal efficiency, CO/CO_2 ratio, TSP	None defined	Only national test methodology designed specifically for cookstoves
AS/NZ	**AS/NZS4013:1999**	X	X	X		Dilution tunnel		4g particulates per kg. of oven-dry weight of fuel burnt	Emissions standard that incorporates stove performance indicators
ISO	**ISO 13336 (ISO/TC 116SC)** (Draft standard, currently on stand-by)		X	X	X	Emissions: Dilution tunnel/ constant flow sampling (CFS) Efficiency: calorimeter room	TSP (total suspended particles), optional CO, efficiency	NA	Stove performance is calculated along with emissions
CEN/TC[iv]	**CEN/TC 13240** (Draft standard)		X	X	X	Emissions: stack measurement Efficiency: calculated indirectly from flue loss	Flue gas temp, CO_2, CO	(proposed) 2500 mg/m^3 CO, 150 mg/m^3 particle mass, 100 mg/m^3 total hydrocarbons	Stove performance indirectly calculated, but included in standard

Country	Designation	Type		Objective		Test method	Indicator	Limits	Comments
		Standard	Method	Efficiency	Emissions				
Denmark	**DS887-2**	X	X	X	X	Stack measurement (flue gas)	Efficiency, CO, CO_2, surface temp stability, air leakage	<0.3% CO @7.5% CO_2 concentration, min. 70% efficiency	Standard includes performance criteria
Denmark[v]	"Swan" Nordic Eco-label	X		X	X	EN 13240 (CEN 13240), NS 3058/3059	Efficiency, materials compliance, manufacturing process compliance	≥73% efficiency (wood stoves and inserts), tested at nominal and 3 reduced power outputs	"Swan" certification includes multiple design, manufacturing and performance specifications
Germany	**DIN18891**		X	X	X	Stack measurement	CO, CO_2, temp	0.4% CO normalized to 13% O_2	Efficiency calculated along with emissions
Kenya	**KS 1814**	-	-	-	-	Unknown	Unknown	Unknown	Kenyan standard is referenced by several sources, but the document has not been obtained.
Uganda	**DUS 761:2007** (Draft)	X	X	X		Water boiling test	PHU (% heat utilized) of	>30% PHU @ 3kW power output, Thermal shock resistance, external temp. ≤ 45^{o} C	Draft standard is based on Kenyan Jiko design. Emissions not included in standard.

Country	Designation	Type		Objective		Test method	Indicator	Limits	Comments
		Standard	Method	Efficiency	Emissions				
South Africa	**SABS 1111-1976** (Coal burning domestic appliances)	X	X	X	X	Water boiling test, kitchen performance test (cooking test), stack measurement (smoke)	Time to reach temperature, heat distribution, obscuration (smoke)	Stovetop: 1L water to 90^o in 10-15 minutes. Oven: 200^o C in 90 min, 250^o C in 120 min. Cooking performance, < 40% obscuration 20 minutes after startup, < 10% obscuration for any 5 minute period otherwise	Standard includes detailed product safety and quality criteria. Performance test based on standardized recipes.
South Africa	**SANS 1243:2007**, Ed. 3 (Pressurized paraffin-fueled appliances)	X	X	X	X	Combustion efficiency test ($CO:CO_2$ ratio), thermal output (kW, calculated from fuel consumption), smoke hood and stack measurements	$CO:CO_2$ ratio (combustion efficiency), Power output (kW) averaged over 600 seconds burn time, (thermal output)	Min. 1kW output after 500 hours operation, $CO:CO_2$ ratio ≤ 1:0.02	Standard includes comprehensive safety and product quality criteria. No specific emissions standard ($CO:CO_2$ ratio)
South Africa	**SANS 1906:2006** Ed. 2.1 (Non-pressure paraffin stoves and heaters)	X	X	X	X	Fuel consumption (thermal efficiency), smoke hood and stack measurements (emissions)	Power output in kW averaged over 7.5 hours burn time, particulates and $CO:CO_2$ ratio	Test output of 1kW for at least 500 hours operation, ≤ 0.03g/min particulates, 1:0.02 $CO:CO^2$ @ 1.5 kW output	Standard includes comprehensive safety and product quality criteria.

Table 2. Standards relating primarily to stove emissions

Country	Designation	Type		Objective		Test method	Indicator	Limits	Comments
		Standard	Method	Efficiency	Emissions				
China	**GB/T 1883-2002** "National indoor air quality standards"	X			X	Not specified	Multiple (over 15) IAP species, including physical, chemical, biological and radiation	CO: < 10 mg/m^3 PM_{10}: <150 $\mu g/m^3$ Total volatile organic compounds (TVOC): <600 $\mu g/m^3$ (8 hr. avg.)	One hour averages, except as noted
China	**GB 3905-1996** "Ambient air quality standard"	X			X	Not specified	Limits listed, as well as Pb, F and B[a]P (Benzo[a]pyrene)	Class II: TSP <0.3 PM_{10} < 0.15 SO_2 < 0.15 NO_2 < 0.08 O_3 < 0.16 CO < 4.0 NO_x < 0.1	All limits mg/m3, daily average.
China	**GB/T 16157-1996** Determination of fixed source particulates and gaseous pollutant sampling method		X		X	Impinger/filter (particulates), absorption (CO, CO_2, O_2), pitot-tube sampling, balanced velocity tube and balanced static pressure tube sampling	Temperature, pressure, water content and composition of exhaust gas; Exhaust gas density and gas molecular weight; Exhaust gas velocity and flow rate; Particulates in the exhaust gas and discharge rate and concentration; Gaseous pollutants in the exhaust gas and discharge rates and concentrations		

Country	Designation	Type		Objective		Test method	Indicator	Limits	Comments
		Standard	Method	Efficiency	Emissions				
China	**GB/T 17095-1997** Hygienic standard for inhalable particulate matter in indoor air	X			X	Not specified	Particulates	Unknown	Indoor air standard
China	**GB 980488** Air quality-determination of CO		X		X	Non-dispersive infrared spectrometry	CO	Unknown	
China	**HJ/T 42, 43, 55, 56, 57, 75, 76**		X		X	Various	NOx, SO_2		Emission determination methods for (industrial) point sources
USA	**NSPS Title 40 CFR Part 60 Subpart AAA** (Phase I)	X		X	X	Methods 5H, 5G, 28, 28A (Dilution tunnel)	% efficiency, TPM (total particulate matter)	8.5g/hr, 5.5g/hr. (catalyst)	7/1/88, mandatory compliance after 7/1/90
USA	**NSPS Title 40 CFR Part 60 Subpart AAA** (Phase II- 1995)	X		X	X	Methods 5H, 5G, 28, 28A	Weighted avg.	7.5 g/hr 4.5 g/hr (catalyst)	Implemented 7/1/90, mandatory compliance after 7/1/92
USA	**NSPS Title 40 CFR Part 60 Appendix A Method 28A**		X	X	X	Fuel and device operational specifications	Fixed-dimension fuel cribs from air-dried Douglas fir 2x4 or 4x4		Requires testing at 4 burn rates
USA	**NSPS Title 40 CFR Part 60 Appendix A Method 5G**		X		X	Dilution tunnel sample location	Weighted average TPM		Device and operation per Method 28A
USA	**NSPS Title 40 CFR Part 60 Appendix A Method 5H**		X		X	Stack (flue) sample location	Weighted average TPM		Device and operation per Method 28A

Country	Designation	Type: Standard	Type: Method	Objective: Efficiency	Objective: Emissions	Test method	Indicator	Limits	Comments
USA	**NFPA 211**	X				Installation standards for solid-fuel burning appliances (residential and industrial)			Published by the National Fire Protection Association
USA	**UL 1482**	X				Safety and construction certification			Published by Underwriters Laboratories and ANSI
Canada	**ULC S628**	X				Wood and pellet stove safety testing. Sets minimum requirements for construction and clearances to combustibles			Equivalent to U.S. UL/ANSI standards
Canada	**CAN/CSA-B415.1**	X	X	X	X	EPA method 5G-1 equivalent	Weighted avg. TPM	7 g/hr	Provincial or local mandatory compliance
India	**CIS 1315 Z (Part 1): 1991** Indian Specification on Biomass Chulha-Specification		X	X	X	Stove hood, sampling, gas analysis method not specified, TSP using impinger and filter (Handy Sampler)	CO/CO_2 ratio, Total Suspended Particles (TSP)	No limits established	Specifies stove fuel preparation and firing protocol
AS/NZ	**AS/NZS3869:1999**	X				Specification of materials (type of steel and gauge) for components	Voluntary compliance (widely adopted)	Avg. 15-20 year lifetime for appliance	Development of AS standards is very well documented
AS/NZ	**AS/NZS4013:1999**	X	X	X		Dilution tunnel		4g particulates per kg. of oven-dry weight of fuel burnt	Use of emission factor vs. rate (g/hr) places more weight on slow burning

Country	Designation	Type		Objective		Test method	Indicator	Limits	Comments
		Standard	Method	Efficiency	Emissions				
AS/NZ	**AS/NZ4014:1999**	X		X	X	Physical parameters of test fuels: hardwood, softwood, 3 coal types	Density, moisture content, calorific value, piece size	NA	Virtually all testing done with hardwood test fuel
ISO	**ISO 13336 (ISO/TC 116SC)**		X	X	X	Emissions: Dilution tunnel/ constant flow sampling (CFS) Efficiency: calorimeter room	TSP (total suspended particles), optional CO, efficiency	NA	(Proposed standard) Appliances tested at 3 burn rates. Efficiency directly measured
CEN/TC[vi]	**EN 13240: 2001 Supplement DS/EN 13240/A2: 2004**		X	X	X	Emissions: stack measurement Efficiency: calculated indirectly from flue loss	Flue gas temp, CO_2, CO	(proposed limits) 2500 mg/m^3 CO, 150 mg/m^3 particle mass, 100 mg/m^3 total hydrocarbons	Test conducted at nominal burn rate
EN	**EN 12815: 2001**	X	X	X	X	Unknown	CO, Particulates	From 1/1/2008: CO 3000 mg/m^3, PM 110 mg/m^3, after 1/1/2011: CO 3000 mg/m^3, PM 90 mg/m^3	EU/Swiss standard for individual solid fuel stoves
Sweden	**SP 1425**	X	X		X	Flue gas sampling	CO, Hydrocarbons (tar), particles, Gaseous Organic Compounds (GOC)	Particulates: <40mg/MJ input, for combined aerosol refractory and tar. 250 mg. OGC per m^3 dry gas, at 10% CO2	Testing done at 3 fire output levels-low power, 3-5kW and high power.

Country	Designation	Type		Objective		Test method	Indicator	Limits	Comments
		Standard	Method	Efficiency	Emissions				
Denmark	**DS887-2**	X	X	X	X	Stack measurement (flue gas)	Efficiency, CO, CO2, surface temp stability, air leakage	<0.3% CO @7.5% CO2 concentration, min. 70% efficiency	Comparable to DIN 18891
Denmark[vii]	**"Swan" ecolabel**	X		X	X	According to EN 13240, SP 1695 (for THC), NS 3058-2 (particulates)	OGC, CO, Particulates	OGC: 150 mg/m^3 @ 13% O_2 CO 2500 mg/m^3 < 5 g/kg fuel (nominal), < 10 g/kg (per test)	Emissions limits include restrictions on use of specific materials (phthalates, chromium) in stove construction
Germany	**DIN18891**		X	X	X	Stack measurement	CO, CO2, temp	0.4% CO normalized to 13% O2	Local standards more restrictive-Stuttgart 0.2% CO @ 13% O2
Austria	**EN 303-5**	X	X	?	X	Unknown	CO, NOx, Hydrocarbons, "dust" (refractory aerosol particulates)	60mg/MJ "dust"~ 1.2g/kg, 1100 mg/MJ CO, 150 mg/MJ NOx, 80 mg/MJ HC	
Norway	**NS 3059**	X	X		X	Stack measurement (natural flue draft)	Particulates	Max 10 g/kg, avg. 5 g/kg (catalytic models), Max 20 g/kg, avg. 10 g/kg (non-catalytic models)	Measurements taken at 4 burn rates, enabling comparison to US EPA standards but not EN 13240

Country	Designation	Type		Objective		Test method	Indicator	Limits	Comments
		Standard	Method	Efficiency	Emissions				
Norway	**Method A-D (NS 3059)**	X	X		X	Aerosol mass using dilution tunnel (similar to EPA 5G)	Particulates, CO, CO2, temp, Polycyclic aromatic hydrocarbons (PAH)	5 g/kg TPM (catalyst), 10 g/kg (non-catalyst)	Values based on 4 test runs, firing procedures set in Method A
Sweden	**SP 1071**	X	X		X	Stack measurement	Particulates (tar)	40 mg/MJ input	Test method (likely superseded)
Sweden	**"P" Certification** (under development)		X	X	X	Not determined	Organic carbon, CO, efficiency	OC < 100 mg/m^3 @ 10% O_2, CO < 3000 mg/m^3 @ 10% O_2. Efficiency ≥ 75%	Voluntary certification, more stringent than national standards.
Switzerland	Swiss Stove Quality Seal (ASEB)	-	-	X	X	Unknown	Efficiency, CO, particulates	Unknown	Copy of certification requirements unavailable
UK	**BS 7256:1990**	X		?	X	Unknown	Unknown	< 5.5g/kg mass emissions	Emission of visible smoke prohibited in smoke control areas

4. Discussion

4.1 Comparability of standards and methods

The test protocol and sample methodologies described under NSPS Title 40 CFR Part 60, represent the most comprehensive attempt to develop a reliable and repeatable stove certification protocol on a national level, and as such, has served as a template for several other national stove testing programs (as in Canada and Australia/New Zealand). While there have been ongoing attempts to establish a common stove testing or certification protocol within the European Union, the two main proposed protocols (ISO/TC 116SC and CEN/TC 13240) represent different methodological approaches and are non-comparable. However, progressive emissions limits set forth in EN 12815 for individual solid fuel stoves have been adopted and will be enforced beginning in 2008 in EU countries.

The U.S. EPA protocol includes an operational methodology (Method 28/28A) and two alternative sampling routines (Method 5G and 5H). Method 28 strictly specifies stove fueling and firing procedures, using standardized cribs of air-dried Douglas fir to reduce test variations due to fuel differences. Methods 5G and 5H offer alternative emissions sampling techniques- 5G employs a dilution tunnel to sample emissions, 5H a flue-located mass flow sensor - but are not strictly comparable. Tests of a set of EPA phase 2 wood heaters by three independent laboratories comparing methods 5H and 5G produced significant differences in test results [Houck et al., 2001]. An important round-robin study [Skrieberg et al., 1997] reported that the degree of variance between emission test results for a single stove evaluated under relevant national protocols in nine different countries was between a factor of five and an order of magnitude. These findings suggest the difficulty in producing comparable quantitative test results even under controlled laboratory conditions.

There has been greater success at developing test methodologies that provide comparable functional performance data for diverse wood or biomass-fueled cookstove designs. Stove test methods that simulate household use, such as water boiling, controlled cooking or kitchen performance tests, can better predict real-world stove performance than analytic tests designed primarily to evaluate emissions from heating appliances. Some national stove efficiency test standards (such as Norway's NS 3059) seek to approximate real world operating conditions by testing devices at multiple power levels.

The Chinese State Standard Testing Method first published in 1985 as GB4363 [Chinese Academy of Agricultural Engineering Research and Planning, 1984] (and recently revised as NY/T 8-2005) was one of the first standardized stove performance test protocols to be adopted by national authorities. This water boiling test (WBT) evolved from the stove performance target called the "Three Tens" promulgated by the Ministry of Commerce in 1972 where qualifying stove designs would boil ten *Jin* (5kg) of water using ten *Liang* (0.5kg) of firewood in ten minutes [Hao and Jia, 2005]. Much of the Chinese WBT procedure was incorporated into the International Stove Performance Testing Standards published by VITA in 1985, validated by Professor Kirk Smith's Household Environment and Health Program at the University of California, Berkeley, and subsequently adapted by organizations such as Aprovecho Research Center[viii] and the Partnership for Clean Indoor Air[ix].

However, important caveats apply to the use of the WBT and other "functional" tests for comparative assessments of household cookstoves, due to the variability of biomass cookstove performance in the real world. Lab tests are, therefore, most appropriate for early-stage stove development and the optimization of stove dimensions and design details. Several studies [cited in Environment Australia, 2002] point out disparities between stove performance as evaluated under ideal laboratory conditions and performance assessed under operating conditions in the field [Correll et al., 1997 and

Fisher et al., 2000]. The authors of the modified water-boiling test developed for the Shell Foundation Breathing Space Programme discuss the matter in more detail:

> Fuel savings among users who have adopted improved stoves cannot be predicted from the results of the Water Boiling Test alone. […] (Field testing) is critical if project designers wish to make justifiable claims about real impacts on fuel consumption resulting from the stoves that they are promoting. ***Such claims cannot be based on lab-based tests alone.***
> […] While lab-based tests allow stove developers to differentiate between well-designed and poorly designed stoves, they give little indication of how the stoves are actually used by the people who are targeted by the stove projects. In order to know if stove projects are having the desired impact (whether it is fuel conservation, smoke reduction, or both), the stoves must be measured under real conditions of use [Bailis et al., 2004].

While early functional test methods such as the "Three Tens" were simple to execute and provided intuitively interpretable results, they allowed significant variation in too many parameters for reliable scientific analysis and comparison between stove designs. Development of the Thermal Testing Method of Household Firewood Stove/Range (GB4363) in China was a direct response to the need for a stove performance test that could be easily conducted in the field and that would provide clear empirical evidence of comparative stove efficiency to "farmer technicians" submitting new stove designs in a series of three national competitions in the 1980's [Hao and Jia, 2005]. Authorities in other limited-resource settings (such as India and Kenya, and potentially Uganda) have adopted similar field-based stove assessment methods.

In order to address the poor correlation between controlled laboratory-based stove testing and observed performance under field conditions, significant efforts have been made to develop methods to standardize stove performance testing under household conditions. The evolution of thermal testing methods exemplified by GB4363 (and its revision as the current NY/T 8 standard) has been paralleled by efforts among researchers to develop more specific and scientifically valid performance testing protocols that accurately assess not only a stove's ability to convert fuel energy to heat energy but more importantly how effectively it accomplishes the specific task of cooking food. These test methods include specific fuel consumption testing and kitchen performance testing.

Specific consumption testing measures the actual cooking efficiency of a stove in terms of the ratio of fuel energy to actual product produced (i.e., cooked food) rather than the more commonly measured ratio of fuel energy to the energy required to vaporize (boil) water, such as measured in water boil tests. Rather than measuring stove "efficiency" as a function of an amount of water vaporized, specific consumption measures the energy used to produce a measured quantity of final product (such as beans, bread, or liters of boiled water). In 1985, the VITA International Testing Standard recommended specific consumption as a more reliable measure of stove performance than efficiency measures alone, and this finding has been corroborated by numerous subsequent studies.

Kitchen performance testing (KPT) employs both quantitative and qualitative methods to compare the performance of improved and traditional stove designs under real-world use scenarios. While KPT provides the most detailed comparative data of actual stove performance, it is also the most complex methodology to employ and introduces a greater possibility of error due to the difficulty in controlling variables under field conditions.

4.2 Evolution of emissions standards and test protocols

Household biomass stove emissions standards have developed somewhat in the shadow of air quality standards developed to regulate large industrial point sources. Sampling methods and appropriate indicators and species appropriate for household stove emissions are the subject of ongoing research and debate. In some countries, such as the U.S., stove emissions test protocols have been developed specifically to evaluate household biomass combustion. In other countries such as China standards developed for coal-burning industrial sources (describing sampling of individual pollutant species such as CO, NO_x) have been applied for household biomass appliances. However, other than the proposed Beijing municipal regulations, no emissions standards specifically regulate household coal- or biomass-burning stoves in China [Hao and Jia, 2005].

International focus on industrial air pollution has delayed recognition of the impact of indoor air pollution from domestic biomass cookstoves. Existing stove emissions standards assess chimney emissions to the outdoor environment. No standards currently regulate indoor air pollution caused by biomass stoves. Despite the persistence of air quality standards determined by individual pollutant species such as CO, particulates or radon, there is a trend towards more comprehensive indoor air quality standards such as GB/T 1883-2002 in China.

As is apparent from the standards summary table, there is little harmonization among national standards and methods for measuring stove emissions. Where equivalent indicators do exist or could be contemplated, differences between test methodologies render comparisons among standards practically impossible. Furthermore, stove emissions may be regulated by local as well as national ordinances, especially in large industrial cities. In addition to the non-comparability of national or local testing protocols, differences in fuel types and species, fuel preparation, stove operation and location all have significant impacts on combustion conditions and results. This suggests the importance of generating emissions test data for all fuels that a particular stove is designed to use.

The quest for a more consistent indicator for health impacts has led to greater emphasis on particle emissions compared to other pollution factors [Smith and Jantunen 2002]. In an article discussing the influence of national standards, test procedures, and calculation procedures on the emission level of a wood stove submitted for round-robin testing, Skreiberg writes "Particle emission measurements were found to be the best method to evaluate the environmental acceptability of the tested stove, since the particle emission level was least dependent of (sic) the national standards, test procedures and calculation procedures used" [Skreiberg et al., 1997]. However, many national emissions standards continue to emphasize measurement of discrete gaseous pollutants such as CO, NO_x and SO_2 in addition to sampling particulates.

4.3 Efficiency testing

Measurement of stove efficiency follows two broad methodologies: 1) laboratory assessment of total thermal output (either calculated through stack-loss or directly via calorimetric methods) or fuel consumption during simulated cooking tasks and 2) evaluation of fuel consumption in the field through specific fuel consumption for cooking standardized meals or multi-day kitchen performance tests. Laboratory-based efficiency tests, while useful for evaluating modifications during the design phase of stove development, do not always correlate well with actual cooking performance, as actual cooks use stoves in different ways and often for multiple tasks.

There has been greater attention to the development of consistent and comparable efficiency assessments in developing countries, where fuel is at a premium than in industrialized countries, where biomass or wood are used almost exclusively for heating and rarely for cooking (other than "recreational cooking"). We have already noted the significant financial, organizational and political resources brought to bear in China over a thirty-year period to develop more efficient biomass cooking and heating appliances. Non-governmental organizations such as Aprovecho Research Center, PCIA and the FAO as well as governmental agencies such as the Ministry of Agriculture, Animal Husbandry and Fishery in China and the Bureau of Indian Standards[x] have promulgated stove efficiency testing protocols that simulate real-world use scenarios and that can be applied to a range of stove and fuel types.

4.4 Stove safety

Alarmed by a perceived increase in stove-related liability claims, the U.S. insurance industry promoted development of stove safety standards around the same time as emissions standards were being considered in the late 1970s and early 1980s. These standards address the operational safety of wood-fueled stoves and cooking appliances apart from their health risks, and cover such design features as stove surface temperatures, vents and chimneys, allowable proximity to combustible materials and installation procedures. It does not appear that U.S. (UL/ANSI) stove construction standards specifically address stove durability and ease of maintenance, though research has demonstrated considerable degradation of stove performance (especially for catalyst-equipped models) over time [Fisher et al., 2000 and Correll et al, 1997].

A recently published paper [Johnson et al., 2005] addresses the absence of safety standards or hazard evaluations for biomass cookstoves. Anecdotal evidence indicates that poor stove design is a significant factor in domestic injuries, especially burns and scalds which disproportionally affect young children and can result in lifelong disability and disfigurement. Using strict US standards governing design safety of indoor and outdoor gas cooking appliances as their model [ANSI, 2000 and ANSI, 1993], the authors developed simplified analytical guidelines to enable safety assessment in the field. A four-point scale from “Poor” to “Best” was used to indicate levels of safety and encourage design improvements. Ten tests make up the safety evaluation guidelines:

Table 3. Stove safety guidelines

1. Sharp edges/Points	*Exterior surfaces of a cookstove should not catch or tear any article of clothing or cut hands during normal use*
2. Cookstove Tipping	*Cookstoves should come back to rest upright after being slightly tipped from their original position*
3. Containment	*Flaming embers should rarely fall from the cookstove when it is overturned*
4. Expulsion of Embers	*Embers should have little chance of being expelled from the cookstove*
5. Obstructions near Cooking Area	*The area surrounding the cooking area should be flat*
6. Surface Temperature	*Burns should not occur if the cookstove surface is touched for a short duration*
7. Heat Transmission to Surroundings	*Cookstoves should not cause dangerously elevated temperatures on surrounding surfaces in the environment*
8. Cookstove handle temperature	*Cookstove handle temperatures should not reach a level where use can cause harm either directly or indirectly*
9. Flames surrounding Cookpot	*Flames touching the cookpot should be concealed and not able to come into contact with hands or clothing*
10. Flames Exiting the Fuel Chamber	*Flames should not protrude from the fuel loading area*

The Nordic “Swan” appliance certification program stipulates a comprehensive set of safety and quality standards in addition to stove efficiency and emissions targets. Above and beyond requiring stoves to meet applicable regional and national regulations, the certification limits the use of materials such as phthalates, heavy metals (cadmium, lead and mercury), certain flame-retardants, and metal surface treatments including chrome-plating and metals-based paints. Certified stoves must also include complete installation manuals with detailed operating instructions, fuel specifications, recommendations to use qualified installers, and labels presenting stove performance figures [Nordic Ecolabeling, 2006].

4.5 Stove design guidelines

Several non-governmental organizations and academic groups have published comprehensive and field-tested design guidelines for domestic biomass cookstoves that take into account broader issues of marketplace acceptance, local production capacity, user costs, ergonomics, safety and specific fuel consumption under real-world conditions. The Partnership for Clean Indoor Air has developed both a set of ten key stove design principles [PCIA, 2004] and a more comprehensive design and performance guidance document[xi] that offer empirically validated design attributes of efficient stoves. The ten design principles are:

1. "Whenever possible, insulate around the fire using lightweight, heat resistant materials."

2. "Place an insulated short chimney right above the fire."

3. "Heat and burn the tips of the sticks as they enter the fire."

4. "High and low heat settings are created by how many sticks are pushed into the fire."

5. "Maintain a good fast draft through the burning fuel."

6. "Too little draft being pulled into the fire will result in smoke and excess charcoal."

7. "The opening into the fire, the size of the spaces within the stove through which the hot air flows, and the chimney should all be about the same size."

8. "Use a grate under the fire."

9. "Insulate the heat flow path."

10. "Maximize heat transfer to the pot with properly sized gaps."

4.6 Challenges to standards adoption

4.6.1 No universal performance or emissions indicators

The challenge of developing valid, reliable, and reproducible measurement and evaluation tools for biomass-fueled cookstoves is an ongoing process among academic and industry experts as well as regulatory authorities, as witnessed by the plethora of non-comparable yet highly specific stove standards and test methodologies adopted around the world.

4.6.2 Compliance testing vs. functional testing

In order to assess the relevance or applicability of the stove testing methodologies summarized in section 2, it is necessary to differentiate analytical test methods designed for certification under ideal conditions from task-based methods designed to model stove use in the real world. For example, the language in U.S. Title 40 CFR Part 60 states clearly that it is a certification methodology to verify compliance with woodstove performance standards, and not, as stated by one reviewer, "designed to provide real-world particulate emission values" [Tiegs and Houck, 2000]. Task-based stove performance evaluations (such as the Chinese State Standard for testing firewood stoves, a water boiling test [FAO, 1993]) are able to characterize stove performance more realistically, but they are more complex, and conducting them correctly requires specialized skill in order to avoid introducing significant procedural variability.

4.6.3 Design vs. Performance-based Standards

Design-based technical standards (India and Kenya) risk promoting outdated technologies and causing harmful constraints in the marketplace. Promoting performance-based standards (US EPA, CEN/EN, China) is another means to encourage design and technical innovation that addresses qualitative as well as quantitative performance targets.

4.7 Opportunities for Independent Certification

Developing demand-based commercial mechanisms for improved stove dissemination, particularly in limited resource settings, implies a need for a more comprehensive approach to stove evaluation and standardization than the laboratory-based performance and emissions methods that currently prevail. The emergence of independent or regional certification programs, such as the Nordic Swan certification, is one approach being embraced by manufacturers and consumers in developed markets. Given the unlikely situation of achieving harmonization between national and regional stove assessment methods and approaches in the foreseeable future, independent certification may be one of the only means to establish stove performance and emissions standards that provide comparability across markets and geographic regions.

4.8 Incorporating Qualitative Design Parameters

The following table offers some examples of user-centered design criteria that could have a significant impact on the market viability of a successful biomass cookstove.

Table 4. User-centered stove attributes

Evaluation parameters (criteria)	Justification	Common indicators
Fuel consumption	Fuel savings is a key customer criterion	Specific consumption: mass of fuel required to cook a standard meal.
Stove controllability	Equates to consumer's perception of stoves utility.	- Cooking speed - Heat retention and radiation - Consistent temperature - Turn-down ratio
Emissions	Proxy for health impacts and important to consumer comfort and well-being.	- Stack emissions
Room concentrations	A more intuitive measure of "healthiness" for consumers	- Particulates, CO
Performance using varied fuels	Consumers rarely use a single biomass fuel source	- Specific consumption using different fuels
Ease of use/attractiveness	A key factor for both stove performance and consumer preference	- ease of lighting/startup - ease of maintenance/repair - attractive appearance
Ergonomics and safety	Affects consumer preference as well as access to overseas markets	- surface temperatures - stove stability - well-labeled controls - projections/sharp corners - platform for hot pots - reachover height - cleanability
Durability/reliability	Predictor of consistent performance, indicator of quality, market reputation and total operating costs	- expected service life of key components - service intervals - parts availability - user-serviceability
Market appeal	Indicates how well designs address both explicit and implicit market needs	- positive user test results - price - size, footprint - installation requirements - materials and finish - purchase incentives - sales volume - warranties

As scalable business models for biomass stoves evolve, both marketers and stove designers will have an increasing need to identify experiential attributes such as those above that influence the purchase and use of improved stoves (as well as other novel technologies). As users become more familiar with improved stoves, their purchase decisions will be increasingly based on experiential attributes as well as performance and emissions criteria.

5.0 Conclusions

Assessment and testing of wood or biomass cookstoves with the objective of increasing distribution and adoption of more efficient and less harmful technologies requires evaluation of a complex set of design attributes. While combustion efficiency alone can be a baseline indicator for a well engineered stove, it does not necessarily correlate with effective operation in the home. Nor do common analytical measures of stove performance (emissions and % efficiency) reflect the many product attributes, such as perceived value, price, ease of use, turn-down ratio, ease of installation, safety features, color and styling, and brand identity, that determine product success in the consumer market. Effective methodologies for evaluating these "subjective" product attributes may be as important as accurate testing of quantitative performance indicators. Indicators of stove usability and functionality, and their relationship to cultural preferences are particularly important when contemplating export markets.

The strategic objectives of any stove scale-up initiative need to be kept in mind. Task-based tests such as the water boiling or controlled cooking test appear more predictive of stove performance in the household, and by extension, of market demand, than analytic tests such as those used for heating stove certification in the U.S. and Europe. These latter methods may be appropriate for certifying home heating appliances but do not accurately assess the performance of biomass cookstoves under actual use conditions.

Market success and consumer demand are a function not only of sound engineering and design, but also of effective business management. For this reason, it is important to address aspects of management, production and distribution that reflect on product quality, enterprise sustainability and customer satisfaction.

In the end, effective evaluation of innovative stove technologies may depend less on the actual test methodologies employed, than on how well the methodologies employed provide a reliable means to compare how well each stove meets performance criteria expected by end-users in the household. The implication is that no single design or performance indicator is independent of the others, and that the validity of testing will depend on the relevance and breadth of design parameters assessed.

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Notes

[i] "Biomass fuel" as used in this report is understood to include wood, charcoal, agricultural waste and other organic fuels not produced through geologic processes.
[ii] Personal correspondence, Dr. Kirk Smith
[iii] Reported by personal correspondence with CAREI, January 2008.
[iv] European Normalization Committee Technical Committee (CEN/TC). This proposed standard is also referred to as CEN/TC 295.
[v] Nordic Eco-label signatories include Denmark, Norway, Sweden, Finland and Iceland.
[vi] European Normalization Committee Technical Committee (CEN/TC). The draft standard was also referred to as CEN/TC 295, and has been accepted as EN 13240.
[vii] "Swan" ecolabel certification for Nordic countries: Denmark, Norway, Sweden, Finland, and Iceland.
[viii] www.aprovecho.net
[ix] www.pciaonline.org
[x] Indian Standard on Solid Biomass Chulha- Specification CIS 1315Z (Part 1): 1991
[xi] Draft document available for comment at: http://www.pciaonline.org/resources.cfm

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