An Overview of the Paper "A Laboratory Comparison of the Global Warming Potential of Six Categories of Biomass Cooking Stoves"

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While most work in the cook stove community has been focused on the health affects of improved stoves, data is emerging supporting possible benefit that improved cookstoves could have on the health of the climate as well. Some of the major greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), hydrocarbons, nitrous oxide (N_2O), carbon monoxide (CO), and oxides of nitrogen (NO_x), are present in the emissions from biomass cooking stoves. Particulate matter emissions from traditional biomass cooking stoves are also significant and have strong effects on the climate. An August 2007 headline in the online BBC NEWS stated "Clouds of pollution over the Indian Ocean appear to cause as much warming as greenhouse gases released by human activity [19]*." These clouds are composed primarily of soot, or black carbon particles. An article found in Scientific American on that day stated "the dominant source for all this black carbon is cooking fires [20]."

The gaseous and particulate matter emissions from six cooking stoves were measured by a team of researchers from the Aprovecho Research Center, The University of Illinois Urbana-Champaign, and at Colorado State University. The stoves were tested in an effort to examine four common methods of wood combustion: open burning, "rocket" combustion chamber-type combustion, gasification, and forced draft. The emissions from a charcoal stove and a rice-hull burning stove were also investigated.

The six stoves are shown below:


Three-Stone Fire


Rocket Stove with Skirt


Karve Gasifier


Philips Prototype Fan Stove


Jiko Type Charcoal Stove


Mayon Turbo Rice -Hull Stove

A modified University of California at Berkeley 2003 Water Boiling Test was used to test each stove three times [8]. 2.5 L of water was used in a standard 3 L pot. Gas measurements were analyzed at Colorado State University using a Fourier-Transform Infrared (FTIR) system for measurement of 23 different species. Particles were collected for one test of each stove at the Aprovecho Research Center. A portable pump-and-filter system to collect and later analyze mass and elemental carbon/organic carbon ratios using a Sunset Laboratories Carbon analyzer by the University of Illinois Bond Research Group.

Sustainable Harvesting of Biomass

The manner in which fuel is harvested has a large influence on the climate-change potential when cooking with biomass. If biomass is harvested sustainably, the CO_2 released in combustion is theoretically reabsorbed by the biomass growing to replace it. If biomass is not harvested sustainably, then the CO_2 released when burned is contributing to the build-up of CO_2 in the atmosphere. The products of incomplete combustion (PICs) such as carbon monoxide, methane, and particulate matter contribute to the changing of the climate in both cases.

Dr. Kirk Smith has pointed out the importance of PICs. “Simple stoves using solid fuels do not merely convert fuel carbon into carbon dioxide (CO_2). Because of poor combustion conditions, such stoves actually divert a significant portion of the fuel carbon into products of incomplete combustion (PICs), which in general have greater impacts on climate than CO_2. Eventually most PICs, are oxidized to CO_2, but in the meantime they have greater global warming potentials than CO2 by itself. Indeed, if one is going to put carbon gases into the atmosphere, the least damaging from a global warming standpoint is CO_2, most PICs have a higher impact per carbon atom.” [2].

Emissions

The following table presents the gaseous results in tabular format. Percentages are relative to CO_2 on a molar basis.

High Power						
	Three Stone Fire	Rocket	Philips Fan	Gasifier	Charcoal	Rice Hull
CO	3.80%	1.67%	0.35%	3.01%	36.0%	17.8%
CH4	0.13%	0.11%	0.02%	0.27%	3.99%	0.87%
NMHC	0.22%	0.22%	0.36%	0.67%	1.29%	1.71%
N2O	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
Nox	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
Formaldehyde	0.04%	0.03%	0.01%	0.06%	0.04%	0.10%
Low Power						
	Three Stone Fire	Rocket	Philips Fan	Gasifier	Charcoal	Rice Hull
CO	11.8%	3.2%	0.4%	4.7%	20.9%	15.7%
CH4	0.29%	0.17%	0.07%	0.42%	0.35%	0.57%
NMHC	0.18%	0.10%	0.08%	0.54%	0.05%	0.85%
N2O	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
Nox	0.07%	0.11%	0.08%	0.06%	0.06%	0.15%
Formaldehyde	0.08%	0.04%	0.02%	0.06%	0.03%	0.10%

Particulate matter emissions must be broken down into the type of particles for global warming analysis. Elemental carbon (EC), or black particles comprised of soot generated in flaming fires, are strongly warming in the atmosphere. Organic Carbon (OC) and Organic Matter (OM), or white particles produced in smoldering fires, has a cooling effect on the atmosphere. Since the manner in which the fire is tended (whether smoldering or flaming) can have a significant effect on the type of particles produced, user tendencies should be considered. Local practice, as well as wood species and moisture content, are also important variables. However, the type of stove also plays a substantial role.

Particle Emission Factors (g/kg) and Ratios

	Cooling Particles from Smoldering Fire		Warming Particles from Flaming Fire	
	EF OM (g/kg)	%OM	EF EC (g/kg)	%EC
3 Stone	1.45	**62%**	0.88	**38%**
Rocket	0.55	**32%**	1.16	**68%**
Karve	0.82	**74%**	0.28	**26%**
Fan	0.14	**71%**	0.06	**29%**
Charcoal	1.54	**88%**	0.20	**12%**

* Particle analysis was not performed on the rice-hull stove due to a lack of rice-hull fuel during the testing series.

The three-stone fire typically consists of a larger bed of charcoal under the flaming fuel, resulting in both black and white particles. The rocket stove has a stronger draft and higher temperature, resulting in less charcoal and higher flame and thus a higher fraction of warming particles. On the other hand, the smoldering gasifier stove created little flame, but more charcoal, which produced more cooling than warming particles. Finally, charcoal burning produced almost all white particles, which is typical of a smoldering fire.

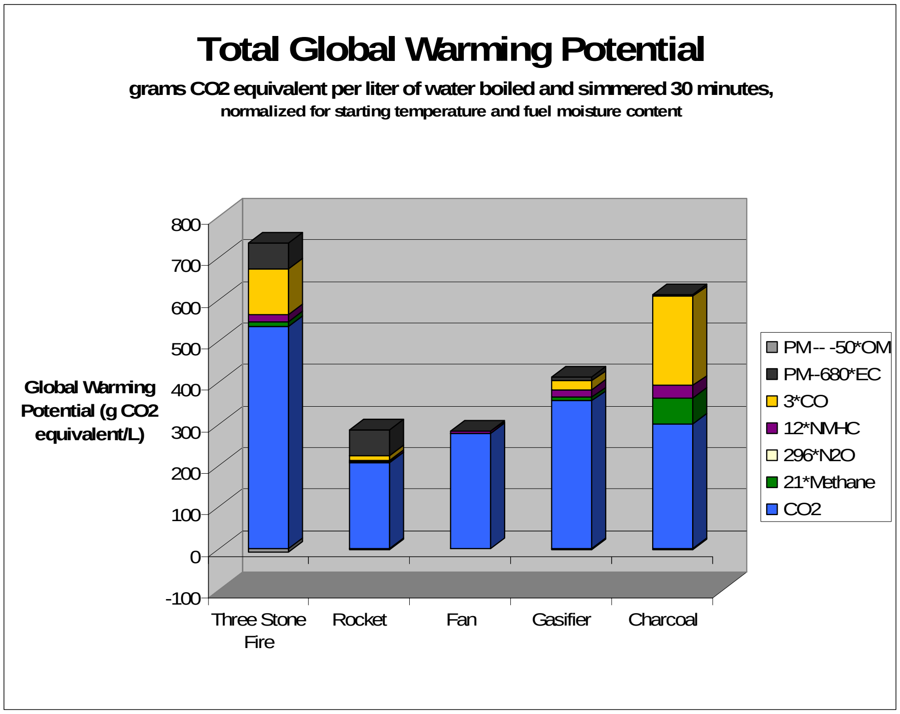
Global Warming Potential

When the Global Warming Potential (GWP) for each pollutant is applied to all the emissions, including particulate matter, all emissions are combined onto the same scale as grams of CO_2 equivalent. The GWP of each pollutant is as follows:

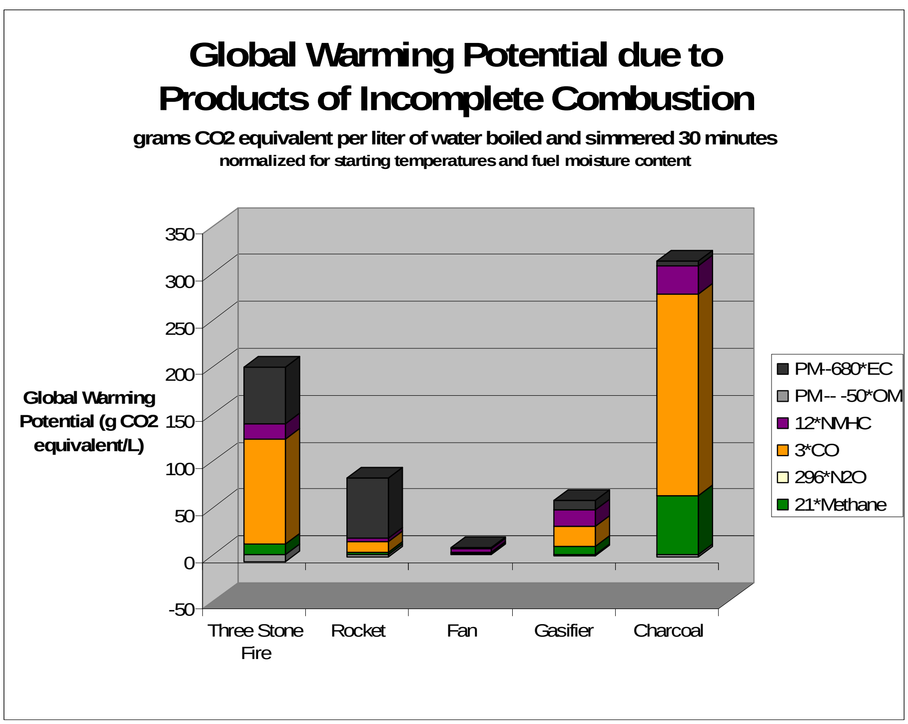
Emission	Global-Warming Potential, 100-year CO_2 Equivalent	Source
CO_2	1	IPCC [4]
CO	3	IPCC [4]
CH_4	21	IPCC [4]
THC	12	Smith [5]
N_2O	296	IPCC [4]
PM – EC	680	Bond [7]
PM -- OM	-50	Estimate – Bond [6]

(*It should be noted that the GWP of OC and OM is still uncertain. Research is ongoing to determine the effects of these particles based on their behavior in the atmosphere. Better estimates will likely result from this research. [6])

The following graph presents the overall GWP, including CO_2 as if the biomass was not harvested sustainably:



Alternately, when biomass is harvested sustainably, the CO_2 emissions from biomass burning are considered to be greenhouse-neutral. The following chart shows the warming potential of the PICs only:



Discussion

Reduced fuel use and improved heat transfer can significantly decrease the global warming potential of a cooking task. In these laboratory tests, several improved biomass stoves (the rocket stove, fan stove, and gasifier stove) displayed substantially reduced global-warming potentials compared to the three-stone fire. When fuel is harvested sustainably the fan stove (which produced much less particulate matter) far outperformed the rocket and gasifier stoves. If wood is not harvested sustainably the fan stove and rocket stove have approximately equal effects due to the lower fuel use in the rocket stove.

The products of incomplete combustion (PIC) contribute 26% to the overall GWP of the open fire, 28% of the rocket stove, and 51% of the charcoal stove. This suggests that estimates of carbon reductions based on fuel use alone would not be accurate.

Further field studies will be necessary to quantify the carbon savings from the use of specific stoves. Laboratory data can identify which stove types look promising. However, follow up studies in the field need to be conducted to quantify the levels of emissions found in the real-world.

Both burning wood, charcoal, and rice hulls and using various combustion methods have been found to create different patterns of emissions. The data presented suggests that there are stoves that can be designed to 1.) Reduce the fuel used to cook, 2.) Reduce health damaging emissions and 3.) Address climate change. The considerable difference in climate changing emissions from the stoves in this study should be noted. Large scale use of cleaner burning stoves could reduce global warming effects. Further study seems warranted.

*For further details on the procedure, results, and references of this study, please refer to the full report found on the Aprovecho Research Center website, www.aprovecho.org.

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