PROJECT GAIA
ENERGY REVOLUTION

Gaia Brief:

Technical Introduction to the performance of the CLEANCOOK Stove

Performance of the CLEANCOOK Stove with Alcohol Fuels Compared with Traditional and Improved Solid Fuel Stoves, Kerosene and LPG Stoves

Aprovecho Research Center

June 2010

Reference:

Fuel Use and Emissions Performance of Fifty Cooking Stoves in the Laboratory and Related Benchmarks of Performance

Nordica MacCarty, Dean Still, Damon Ogle
nordica.maccarty@gmail.com, deankstill@gmail.com, monogle@oregoncoast.net
Aprovecho Research Center –
79093 Highway 99, PO Box 1175, Cottage Grove Oregon, 97424
(541)767-0287

MacCarty, N., Still, D., and Ogle, D., 2010. "Fuel Use and Emissions Performance of Fifty Cooking Stoves in the Laboratory and Related Benchmarks of Performance," Energy for Sustainable Development 14(3): 161-171.

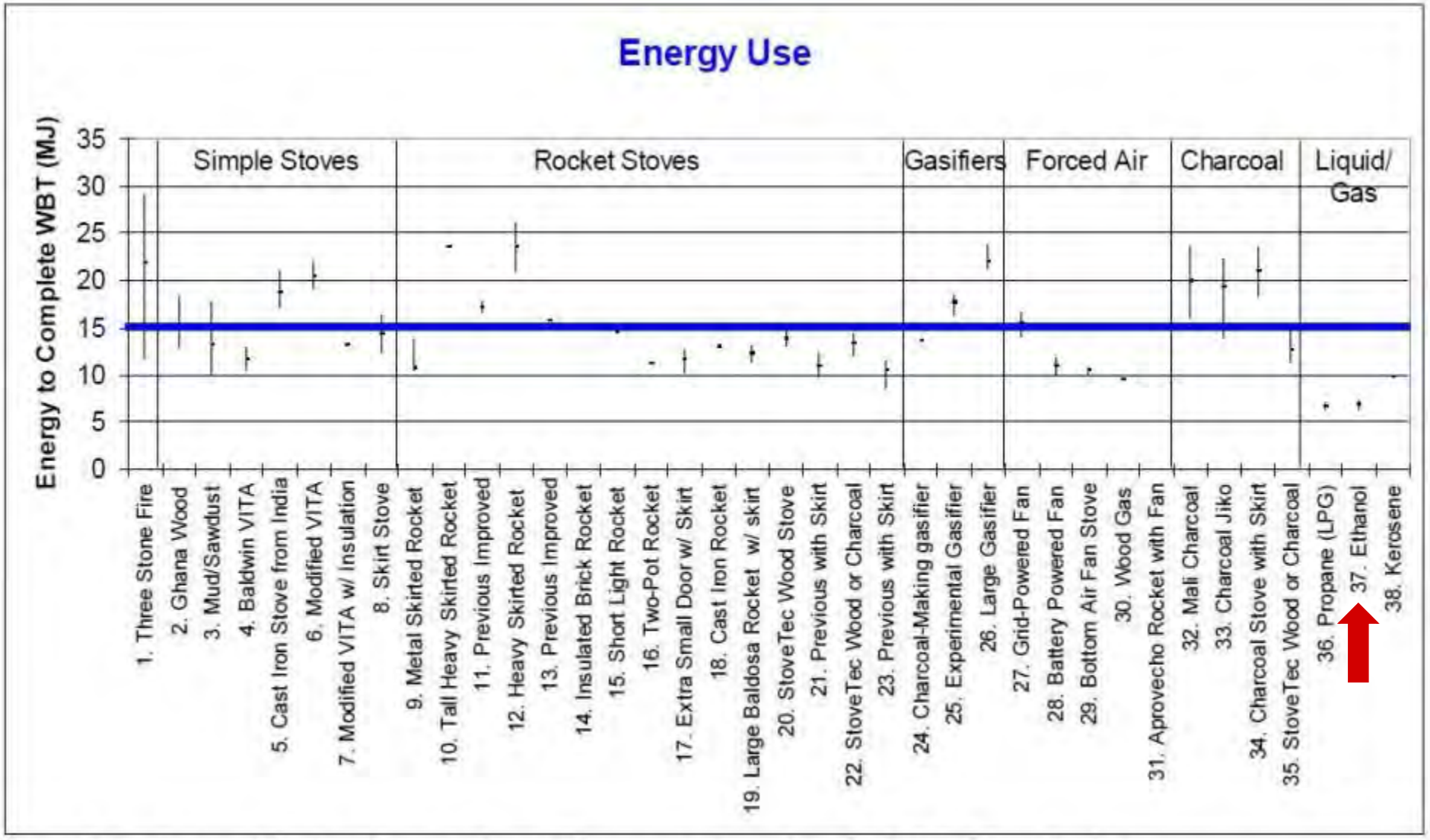


Figure 3.1 – Energy Use for Stoves without Chimneys to Complete the WBT (Mega Joules)

Suggested Fuel (Energy) Use Benchmark: *The improved cook stove should use less than 15 MJ of energy to complete the 5 liter WBT.*

Ethanol values were developed using the CLEANCOOK stove.

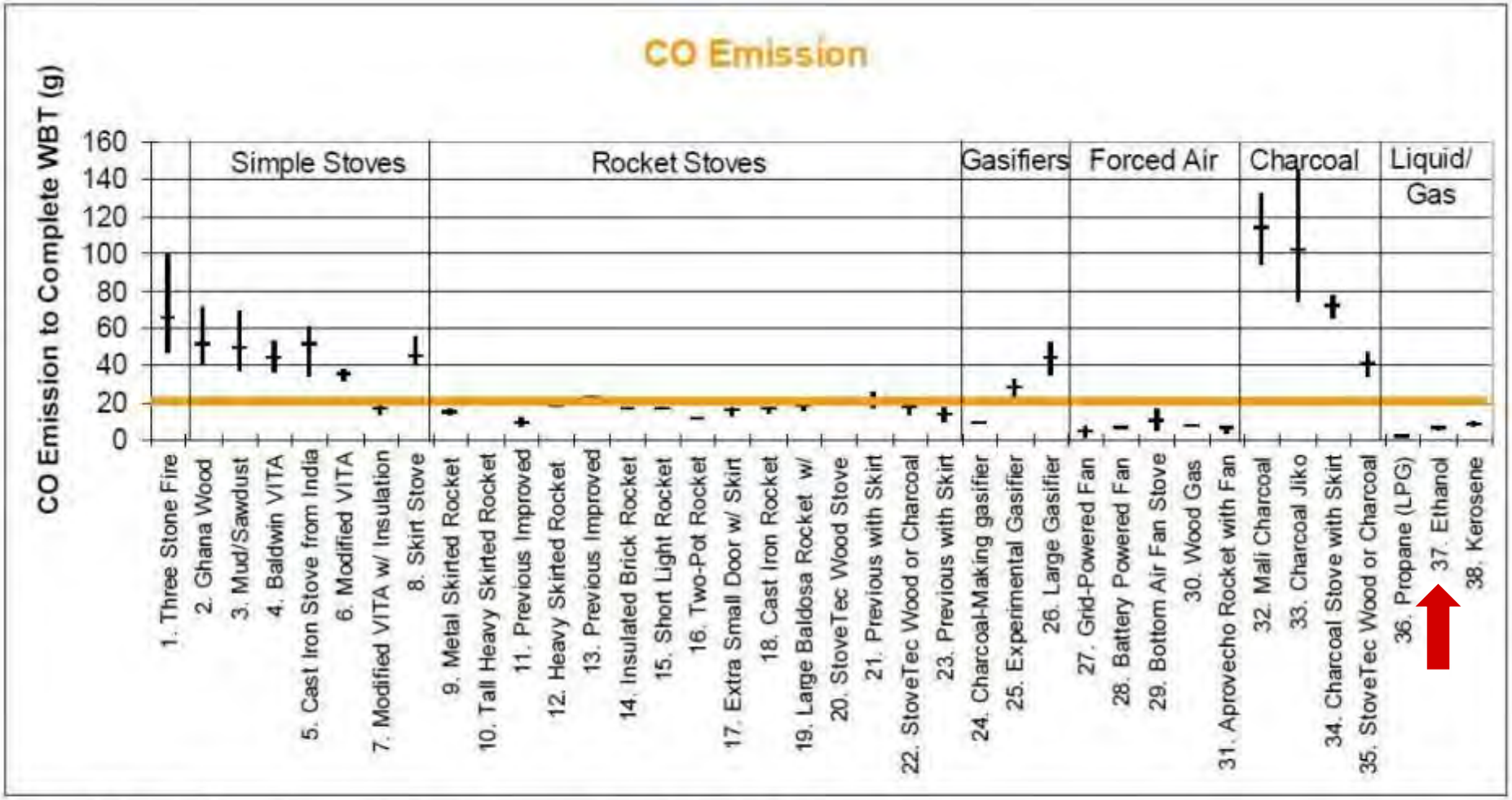


Figure 3.2 – Carbon Monoxide Emissions to Complete WBT (grams)

Suggested Carbon Monoxide Emission Benchmark: *The improved cook stove should emit less than 20 grams of carbon monoxide to complete the 5 liter WBT.*

Ethanol values were developed using the CLEANCOOK stove.

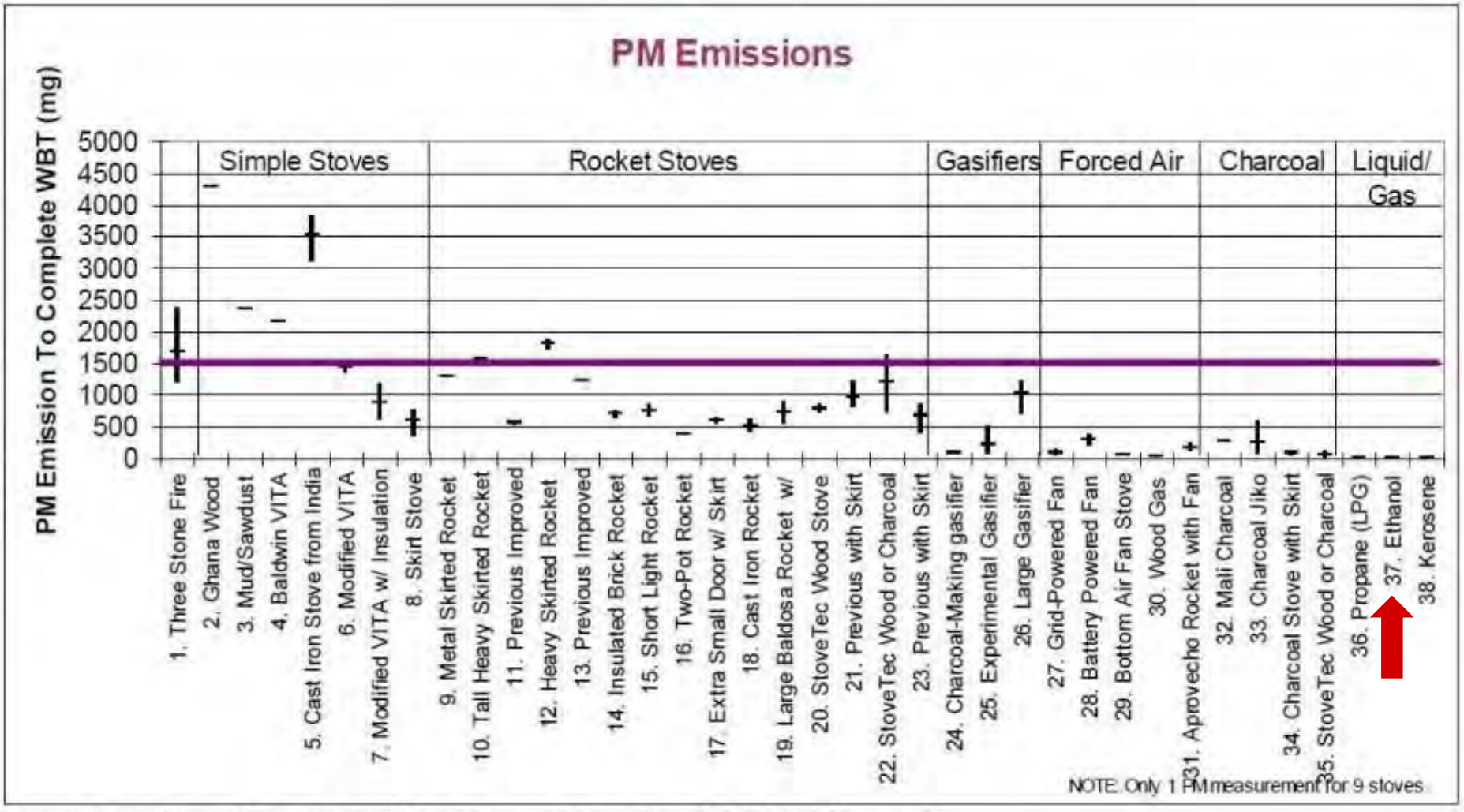


Figure 3.3 – Particulate Matter Emissions to Complete WBT (milligrams)

Suggested Particulate Matter Emission Benchmark: *The improved cook stove should use emit less than 1500 mg of particulate matter to complete the 5 liter WBT.*

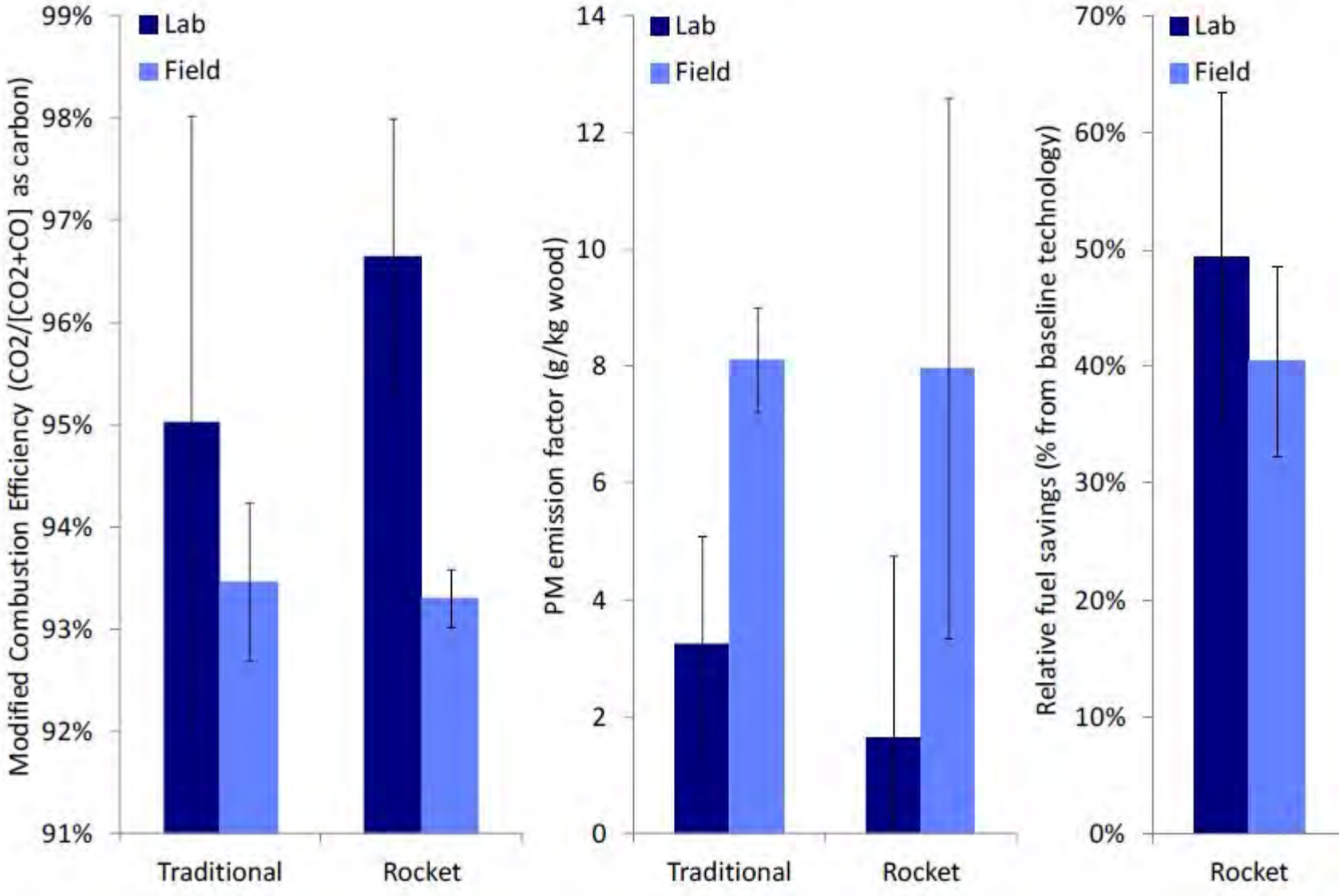
Ethanol values were developed using the CLEANCOOK stove.

	Gasifiers			Forced Air Stoves					Charcoal Stoves				Liquid/Gas Fuels		
	24. Charcoal-Making gasifier	25. Experimental Gasifier	26. Large Gasifier	27. Grid-Powered Fan	28. Battery-Powered Fan	29. Bottom Air Fan Stove	30. Wood Gas	31. Aprovecho Rocket with Fan	32. Mali Charcoal	33. Charcoal Jiko	34. Charcoal Stove with Skirt	35. StoveTec Wood/Charcoal Rocket	36. Propane (LPG)	37. Ethanol	38. Kerosene
Benchmarks Met?	YES	NO	NO	NO	YES	YES	YES	YES	NO	NO	NO	NO	YES	YES	YES
Energy Use (MJ)	13.6	17.6	22.0	15.3	10.8	10.5	9.4	15.0	19.8	19.1	20.8	12.6	6.7	6.8	9.7
PM Emission (mg)	70	225	1001	89	293	48	27	151	260	251	71	44	5	4	10
CO Emission (g)	8	27	43	4	6	9	7	6	113	102	71	41	1	5	8
Fuel Use (g)	741	961	1234	792	614	609	460	722	655	613	657	439	140	317	223
Time to Boil (min)	27.3	17.9	26.4	13.2	13.9	19.5	23.7	33.7	38.6	18.9	28.3	30.0	23.0	31.6	42.5

Looking at all of the stoves and comparing the improved solid fuel stoves to the clean fuel stoves, only the clean fuel stoves (LPG and the alcohols) meet and exceed the highest standards for efficiency, low PM emission, low CO production, and low trace emissions (methane, volatile organic compounds).

While pressurized kerosene stoves burn cleanly, kerosene wick stoves (and kerosene wick lamps) produce high PM, high CO and high VOCs, including aromatic compounds that are suspected carcinogens.

While improved solid fuel stoves may burn cleanly in the laboratory, *in the field under normal use their performance is subject to wide variation*. The CLEANCOOK stove performs consistently, virtually the same, under all conditions.



Variability in performance of rocket stoves between lab and field

Under field conditions, fuel savings in rocket stoves may be half of what is advertised. PM and other emissions may be higher than an open fire. (Berkeley Air Monitoring Group, 2012)

Aprovecho Research Center
Advanced Studies in Appropriate Technology Laboratory
79093 Highway 99, PO Box 1175
Cottage Grove, Oregon 97424 USA
541-767-0287
www.aprovecho.org

Results of Testing of the CleanCook Stove for Fuel Use and Carbon Emissions

Prepared for Project Gaia, Practical Action, and World Bank

By Nordica MacCarty
June 26th, 2009

In this round of testing, Global Warming Commitment (GWC) values were developed for the CLEANCOOK stove. Values were generated using the 5-liter water boiling test (WBT) with an uncovered pot.

Since the CLEANCOOK is powered at 1.5kW (as opposed to 2 or 3X that for a wood-burning stove), it takes longer to boil an uncovered pot of water. This results in heat loss from both water and pot, yielding a lower-than-actual efficiency value for the CLEANCOOK stove and slightly higher emissions values. Even with this bias in the test in favor of higher-powered stoves, the CLEANCOOK scored best of the stoves. If the test protocol is adjusted to use a covered pot, the CLEANCOOK test scores are even better.

The stove is powered at 1.5kW to cook fast, while also saving fuel. Computing efficiency using covered pots yields a higher value (64 %). Time to boil is less, thus emissions are lower.

Table 3.4 – Emission Factor Summary

	Ethanol Measured		Kerosene Default		Wood Default	
Measured Thermal Efficiency	52.5%		52%		20%	
Per MJ	Combusted	Delivered	Combusted	Delivered	Combusted	Delivered
CO_2	64	122	71.9	138	112	560
Methane	0.02	0.038	0.0022-0.023	0.004-0.044	0.3	1.500

From this data, ethanol is the clear choice in terms of lower global warming impact. In addition to the lower emission factors per MJ delivered than both wood and kerosene, a key advantage to ethanol for climate change is that the CO_2 emissions may be greenhouse neutral if the ethanol is "grown" sustainably, moving this figure essentially toward zero (not accounting for fuel processing).

Previous calculations of expected CO_2 emission factors based on a carbon balance for Ethanol, LPG, and Kerosene showed agreement with this study and the IPCC defaults.

Table 3.5 – Expected CO_2 emission factors based on Carbon balance

Fuel	Molecular Formula	Carbon Fraction	Energy Content (MJ)	Combustion Efficiency (estimated)	Stove Efficiency (reported)	gCO2/MJdelivered
Ethanol	C2H6O	52%	21	95%	64%	133
LPG	C3H8,C4H10	82%	50	98%	57%	103
Kerosene	CnH(2n+2)	85%	43	95%	50%	137

GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

ISO International Workshop Agreement Guidance for Clean Cookstoves

A collaborative effort of

The Partnership for Clean Indoor Air

The Global Alliance for Clean Cookstoves

and

The Cookstove Community

Performance Indicators…

Current Efforts

Fuel Use ✔	Is the stove efficient?
Emissions ✔	How much pollution is emitted by the stove?
Indoor Air Quality ✔	Does the stove reduce indoor pollutant concentrations with a chimney or have emissions so low that IAQ goals are achieved without a chimney?
Safety ✔	Does the stove reduce the risk of burns, poisoning, and other injuries?

Future Efforts

Climate Impact ✔	What affect will the stove have on the local and global environment?
Durability/Life ✔	How long is the stove going to last with normal use?
Field Testing ✔	How does the stove perform in the field? [This is especially important for built-in-place stoves .]

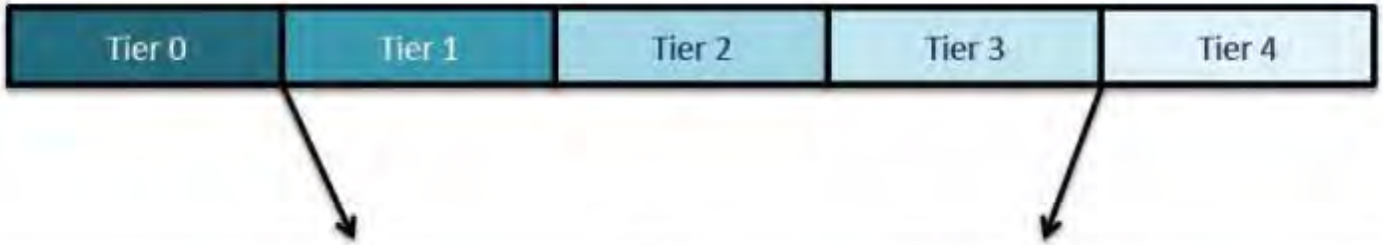
Tier Levels

Tier 0	No Improvement Over Open Fire / Baseline
Tier 1	Measureable Improvement Over Baseline
Tier 2	Substantial Improvement Over Baseline
Tier 3	Currently achievable technology for Biomass Stoves
Tier 4 ✔	Stretch Goals for Targeting Ambitious Health and Environmental Outcomes

✔ **The CLEANCOOK stove ranks in Tier 4 for all indicators.**

CLEANCOOK Stove – Tier 4. What this means:

Tier "Bookend" Numbers



Performance Indicator	3-Stone Fire	Aspirational Goal
Fuel Use	Low Power Specific Energy Consumption: 0.050 MJ/(min x L) High Power Thermal Efficiency: 15%	Low Power Specific Energy Consumption: 0.017 MJ/(min x L) High Power Thermal Efficiency: 45%
Emissions	Low Power CO: 0.20 g/(min x L) High Power CO: 16 g/MJ delivered Low Power $PM_{2.5}$: 8 mg/(min x L) High Power $PM_{2.5}$: 979 mg/MJ delivered	Low Power CO: 0.09 g/(min x L) High Power CO:8 g/MJ delivered Low Power $PM_{2.5}$: 1 g/(min x L) High Power $PM_{2.5}$: 41 mg/MJ delivered
Indoor Emissions	CO: 0.97g/min $PM_{2.5}$: 40mg/min	CO: 0.42g/min $PM_{2.5}$: 2mg/min
Safety	Iowa State University Rating System: 45	Iowa State University Rating System: 95

The CLEANCOOK and ISO Standards

The USEPA has now tested the CLEANCOOK Stove (Q4 2012) and confirmed that it is a *Tier 4* stove—able to achieve ambitious health and environmental outcomes. This latest round of testing confirms the field testing conducted in 10 countries to date as well as the extensive laboratory testing at Aprovecho Research Center and other labs.

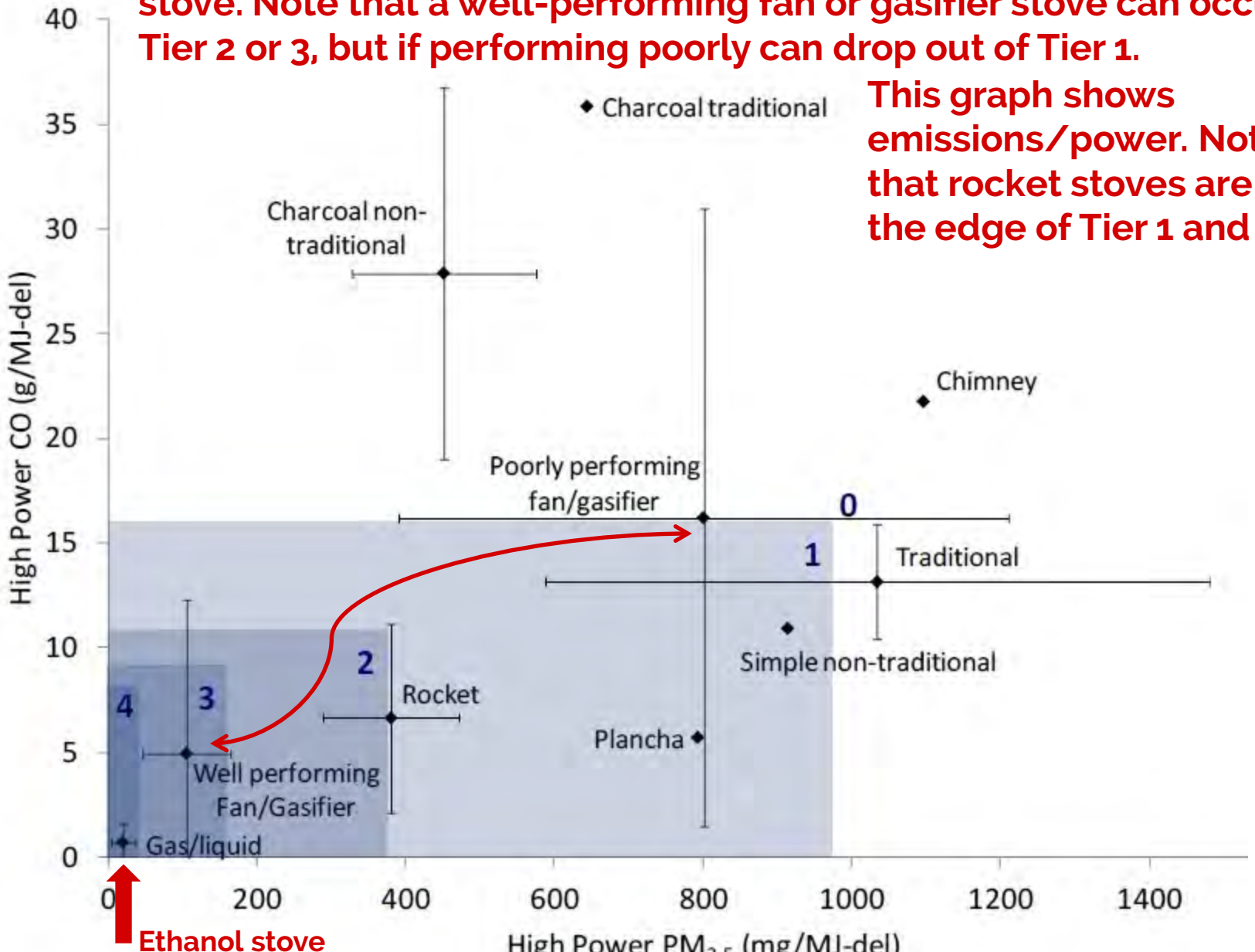
Impacts of ethanol intervention on personal exposure in household studies conducted in Madagascar (from a study by Practical Action Consulting, Project Gaia, Inc. and others in Madagascar for the World Bank, 2008-2011.*

Pollutant	Ambositra		Vatomandry	
	Mother	Child	Mother	Child
CO	-74%	-64%	-53%	-35%
PM2.5	-62%	-63%	-44%	-47%

* http://www.cleancookstoves.org/resources_files/ethanol-assessment-madagascar-a.pdf

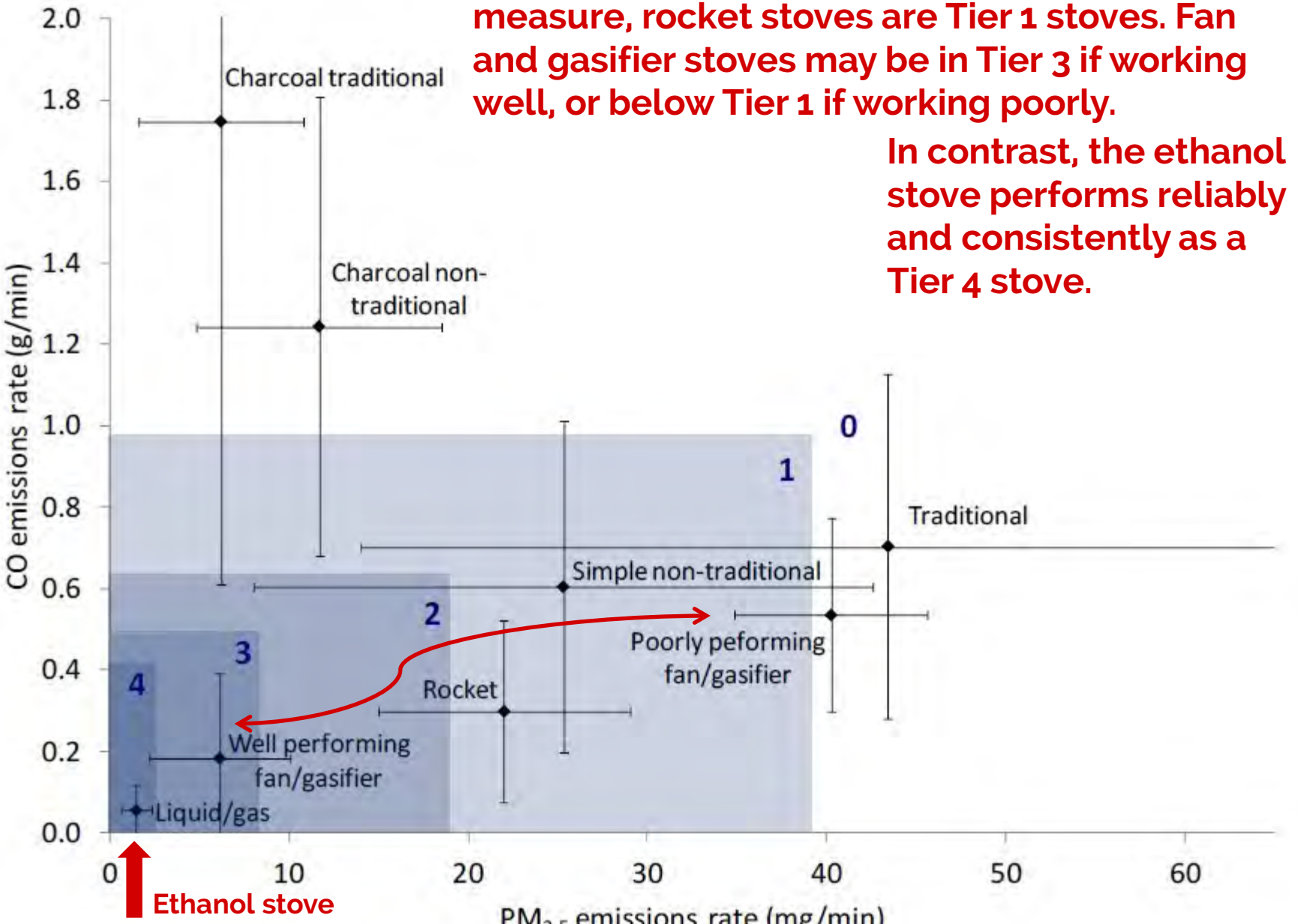
The Tier 4 stoves are the CLEANCOOK alcohol stove and the LPG stove. Note that a well-performing fan or gasifier stove can occupy Tier 2 or 3, but if performing poorly can drop out of Tier 1.

This graph shows emissions/power. Note that rocket stoves are on the edge of Tier 1 and 2.



Ethanol stove

Berkeley Air Monitoring Group, 2012


This graph shows emissions/time. By this measure, rocket stoves are Tier 1 stoves. Fan and gasifier stoves may be in Tier 3 if working well, or below Tier 1 if working poorly.
In contrast, the ethanol stove performs reliably and consistently as a Tier 4 stove.
CO emissions rate (g/min)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Charcoal traditional
Charcoal non-traditional
0
1
2
3
4
Traditional
Simple non-traditional
Poorly peforming fan/gasifier
Rocket
Well performing fan/gasifier
Liquid/gas
0
10
20
30
40
50
60
PM2.5 emissions rate (mg/min)
Ethanol stove
Berkeley Air Monitoring Group, 2012

How does the CLEANCOOK (CC) Stove perform relative to other improved or advanced stoves?*

Performance Gains of CLEANCOOK (CC) Ethanol Stove over Other Stoves (5-liter WBT; pot without lid)			
Baseline is 3-stone fire	**Reductions by CC Stove**	**Improvement in Performance**	**Conclusion**
Energy use	69.00%	321.00%	CC is 3 times more efficient
PM emissions	99.80%	41850.00%	CC is over 400 times cleaner
Carbon Monoxide (CO) emissions	93.40%	1300.00%	CC is 13 times cleaner
Baseline is StoveTec Rocket	**Reductions by CC Stove**	**Improvement in Performance**	**Conclusion**
Energy Use	50.80%	202.00%	CC is 2 times more efficient
PM emissions	99.50%	19575.00%	CC is 196 times cleaner
CO emissions	75.00%	400.00%	CC is 4 times cleaner
Baseline is Charcoal Jiko	**Reductions by CC Stove**	**Improvement in Performance**	**Conclusion**
Energy Use	64.40%	280.80%	CC is 2.8 times more efficient
PM emissions	98.40%	6275.00%	CC is 63 times cleaner
CO emissions	95.10%	2040.00%	CC is 20 times cleaner
Baseline is Wood/Charcoal Rocket Combo	**Reductions by CC Stove**	**Improvement in Performance**	**Conclusion**
Energy Use	46.00%	185.30%	CC is 1.8 times more efficient
PM emissions	91.00%	1100.00%	CC is 11 times cleaner
CO emissions	87.90%	820.00%	CC is 8.2 times cleaner

* Based on the data provided by MacCarty, Still, and Ogle, Fuel Use and Emissions Performance of Fifty Cooking Stoves in the Laboratory and Related Benchmarks of Performance, Energy for Sustainable Development (ESD), Volume 14, Issue 3, September 2010, Pages 161-171.

The test used was the 2003 University of California-Berkeley (UCB) revised Water Boiling Test (WBT) Version 3.0, using an uncovered pot (without lid). The CLEANCOOK stove showed superior numbers in all three benchmarks. Using a covered pot test (lid on), the gains by the CLEANCOOK stove are even greater.

Performance Gains of CLEANCOOK (CC) Ethanol Stove over Other Stoves (5-liter WBT; pot without lid)			
Baseline is Forced Air (Fan) Stove	**Reductions by CC Stove**	**Improvement in Performance**	**Conclusion**
Energy Use	44.30%	179.40%	CC is 1.8 times more efficient
PM emissions	96.70%	3040.00%	CC is 30 times cleaner
CO emissions	22.00%	128.00%	CC is 1.3 times cleaner
Baseline is Gasifier Stove	**Reductions by CC Stove**	**Improvement in Performance**	**Conclusion**
Energy Use	56.40%	229.40%	CC is 2.3 times more efficient
PM emissions	97.30%	3687.50%	CC is 37 times cleaner
CO emissions	71.50%	350.00%	CC is 3.5 times cleaner
Baseline is Kerosene Stove	**Reductions by CC Stove**	**Improvement in Performance**	**Conclusion**
Energy Use	29.90%	142.60%	CC is 1.42 times more efficient
PM emissions	60.00%	250.00%	CC is 2.5 times cleaner
CO emissions	37.50%	160.00%	CC is 1.6 times cleaner

These tests show that the CLEANCOOK uses fuel most efficiently and economically, that substantially less carbon monoxide is produced, and that soot and smoke are eliminated. In contrast, improved and advanced solid fuel stoves can emit high levels of CO and PM and perform unevenly in the field.

The CLEANCOOK stove has been designed around the properties of the simple alcohols. Here is how it works:

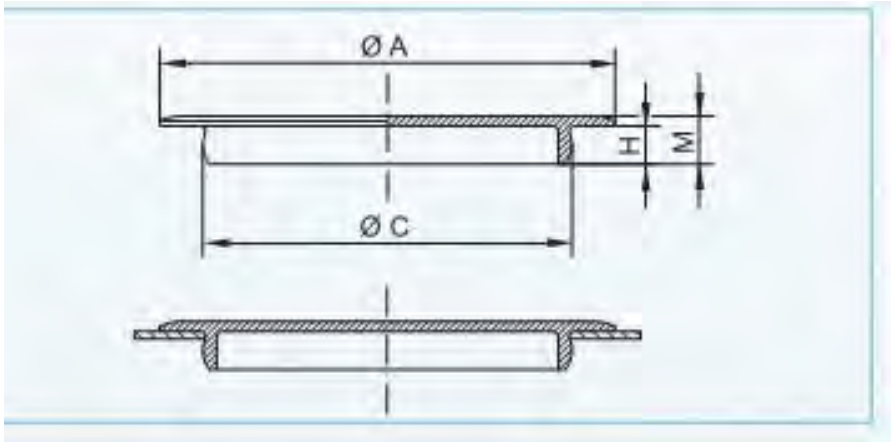
- Alcohol has low surface tension. The CC stove's fuel canister adsorbs alcohol fuel onto a refractory mass, holding the fuel as if it were a solid. It will not leak or spill out. Result: *safety*.
- Alcohol is volatile. It evaporates easily. The CC stove allows the alcohol to evaporate from the fuel canister into a chimney that controls fuel-to-air ratio for ideal combustion and a hot flame. Under optimal conditions, alcohol has a flame temperature similar to propane. Result: *performance*.
- Alcohol is a liquid at room temperature. As a result, the stove is fueled with a liquid fuel, not with gas that must be pressurized. Ethanol handles with the convenience of kerosene, and can be transported like kerosene. But since it is water-soluble, it does not pose a hazard to the environment. Result: *convenience*.

Safety, performance, convenience . . .

- The CLEANCOOK stove is not pressurized.
- The CLEANCOOK stove burns hot (~1.5 kW at full power).
- The CLEANCOOK stove refuels easily, burns for an extended period (4 ¼ to 8 hrs.) between refueling, and burns efficiently, therefore cleanly (very low CO and PM).
- To sum up, the CLEANCOOK stove uses a *liquid* fuel, but stores it as if it were a *solid*, and burns it as a *gas*. The expense and inefficiency of gelling alcohol and the difficulty of burning gel has been eliminated. The result is a more efficient and higher-powered stove.

The CLEANCOOK fueling system: The fuel is poured into the canister as a liquid and *adsorbed* by a fiber filling. It vaporizes in a combustion chimney. The fuel will not spill and cannot explode. The result is a very safe stove.

Gaia Assoc. Addis Ababa



Patented fuel canister is open and un-pressurized.

Canister with snap-on cap is shown.

Cross-section of cap design is shown.

CLEANCOOK Fuel Canister

The fuel canister serves as a fuel distribution system. The canister can be filled and sealed for distribution. Once empty, it may be returned for refilling.

Re-usable plastic cap

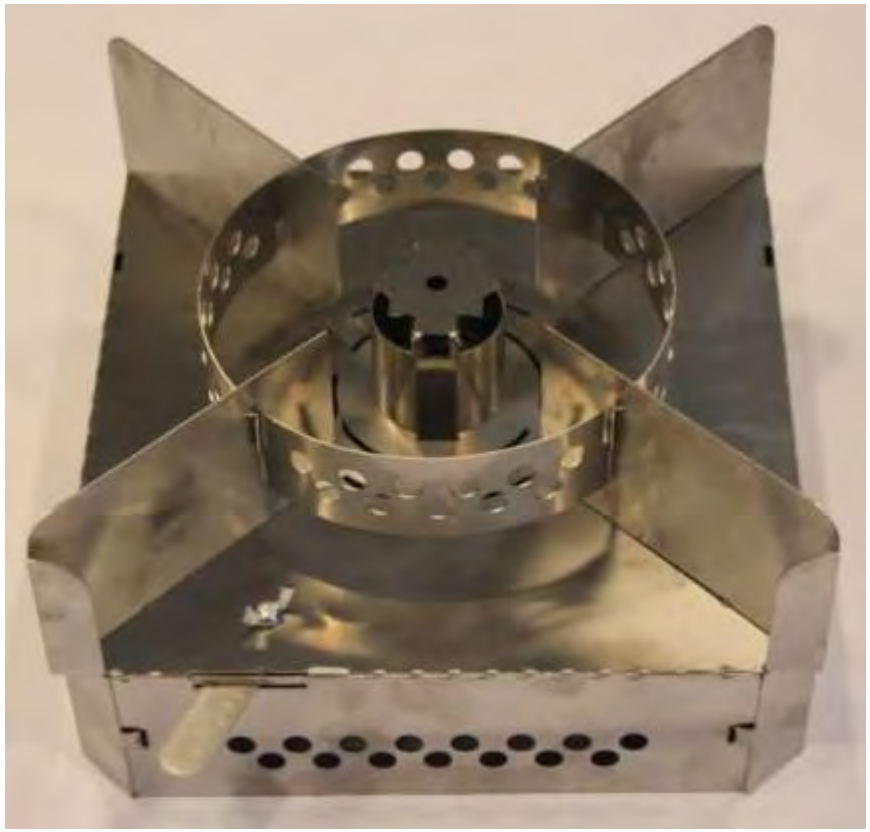
Capacity is 1.2 liters per canister, each giving 4.25 hours burning at full power, or 8 to 9 hours at low power settings.

NOVA 2

The CLEANCOOK stove comes as a very durable and long-lived aluminium body with galvanized and stainless steel parts. It is robust and durable.

NOVA 1

CLEANCOOK Star Stove



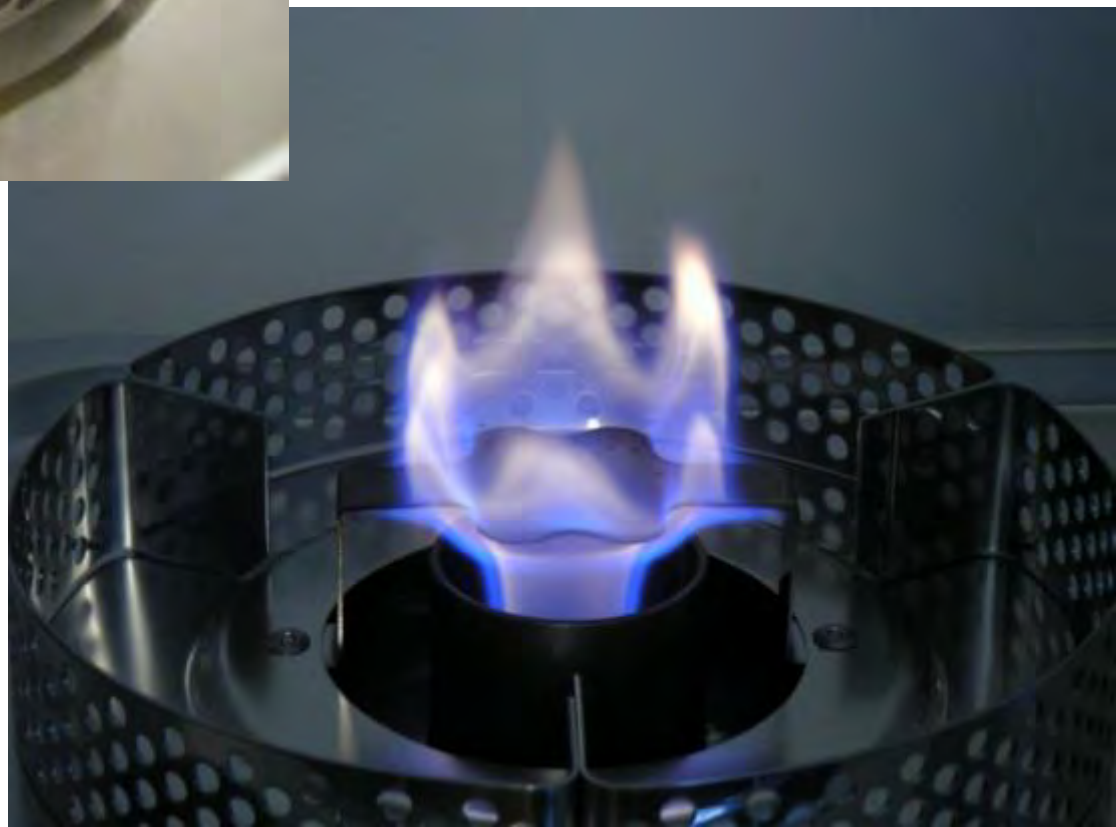
A new concept in production, the Star Stove ships flat and is assembled by hand on site with no tools required, making it less expensive. The Star Stove uses the same fuel canisters as the NOVA 1 and NOVA 2 and maintains the same standards of performance and safety.

This aluminium stove withstood a 100 kg deformation test.

The stove burns cool. Children are safer around this stove.

Flame color with different grades of alcohol.

Ethanol with impurities from higher alcohols (amyl alcohols or fusel oils) will tend to burn yellow. Very clean ethanol will burn blue. Addition of methanol, another simple alcohol, will clean up the burning ethanol.



This information is provided by Project Gaia on behalf of its partners. For more information please contact us at info@projectgaia.com. Additional information is available on our website at www.projectgaia.com.