FdS Gasifier Improved Cookstoves vs. Traditional Haitian Charcoal Cooking

Air Impurities Emissions and Personal Exposure in Households

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***Abstract*—**Haiti burns 400,000+ tons of charcoal annually, destroying 4,000,000 tons of trees. Previous studies confirm charcoal's destructive effect on Haiti's forests; however, charcoal-cooking's health risks require further evaluation. Social-Eco Enterprise, Fuego del Sol Haiti SA (FdS) herein measures traditional charcoal-cooking's health risk exposure levels in comparison to the FdS Gen-8 Gasifier Stove. FdS compared the $PM_{2.5}$ and CO air-impurity levels of the FdS Gen-8 Gasifier (improved non-carbonized biomass briquette cookstove) v. charcoal stoves in use in actual Haitian households. FdS followed the manufacturers' recommended protocols for the DYLOS 1700 $PM_{2.5}$ and the LASCAR EL - USB – CO air-impurity monitors. FdS compared the results with WHO and EPA maximum recommended air-impurity exposure levels. Results: During cooking, the FdS stove recorded zero (0) measurable impurities for $PM_{2.5}$ and CO. In contrast, the traditional charcoal stoves' CO results exceeded 300 ppm, or six-times the EPA's 50 ppm "EVACUATE" level. For $PM_{2.5}$, the charcoal stoves registered up to 125 µg/m3, or 12.5 times the WHO Annual Threshold. FdS encourages further study and offers recommendations for ecological sustainable biomass development in Haiti, including introduction / adoption methods for FdS stoves and a scalable indigenous fuel-forest / job implementation plan.

Keywords - Improved cookstoves; Haitian charcoal stoves; carbon monoxide (CO); particulate matter$_{2.5}$ ($PM_{2.5}$); household air pollution ("HAP"); deforestation; gasification; biomass.

Introduction

Haiti burns over 400,000 tons of charcoal annually (USAID 2011); that amount translates to over 4,000,000 tons of trees destroyed since it takes 10 tons of wood to produce one ton of Haitian charcoal (ESMAP 2007). Regional environmental studies in Haiti, including Ghilardi, *et al* 2018, have confirmed that the Haitian charcoal industry has a destructive effect on the forests of Haiti. However, recent studies in Haiti have not focused on the health risk factors of charcoal cooking. International studies that explored the negative health effects of traditional stoves, including Mortimer, *et al* 2016, have focused on $PM_{2.5}$ emissions. Charcoal stoves also release CO emissions in dangerous concentrations (WHO 2014).

Fuego del Sol Haiti SA (FdS) is a Social-Eco Enterprise that has implemented ecological cooking solutions in Haiti and the Dominican Republic since 2006. Fds Haiti implements the FdS Eco-Cooking System including: the FdS Gen-8 Gasifier Stove (Fig. 1) and non-carbonized recycled fuel briquettes (made from recycled paper, cardboard and

sawdust / woody-biomass) (Fig. 2). FdS has been a partner in the Global Alliance for Clean Cookstoves (GACC) since 2010.

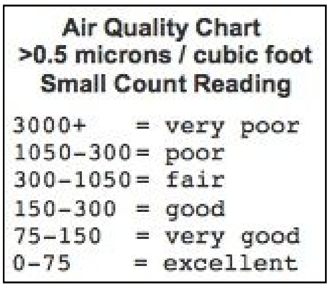
The FdS stove incorporates a chimney, and GACC research indicates that a biomass stove with a chimney is greatly superior to stoves without them. (PCIA 2012): "If a chimney is added to an indoor biomass stove, indoor air pollution drops to almost zero." Since 2012, FdS Haiti has recycled over 130 tons of material, offset over 13,000 trees, and sustainably fueled over 850,000 meals, mostly for homes, schools, orphanages and community centers.

The objective of this study is to monitor, measure, record and compare the $PM_{2.5}$ and CO air-impurity levels of the FdS Gen-8 Gasifier Stove (a locally-manufactured improved non-carbonized biomass-briquette cookstove) v. traditional charcoal stoves currently in use in actual Haitian households.

Methodology

FdS followed the manufacturers' recommended protocols for the DYLOS 1700 $PM_{2.5}$ (Fig. 3) (Left) and the LASCAR EL - USB – CO (Fig. 4) (right) air-impurity monitors.

The DYLOS 1700 measures the quantity of particulate matter impurities (smoke, dust, etc.) in the air per cubic foot, a.k.a., "particle concentration". "Small particles" range in size from 0.5 microns up to 10 microns. "Large particles" range in size from 2.5 microns up to 10 microns. The DYLOS corporation rates air-quality based on the small particles per cubic foot of air by the chart to the right.

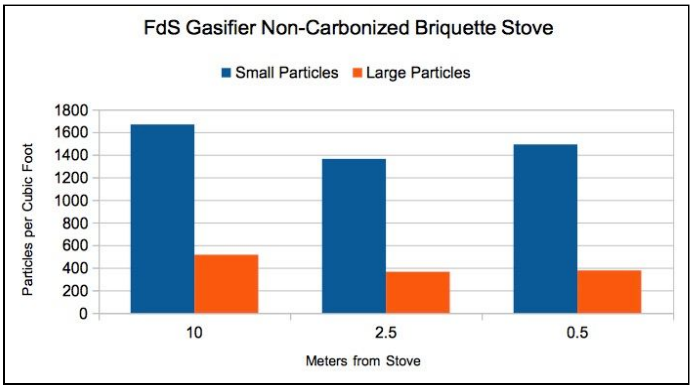


All ambient indoor and outdoor air has a basic "background" particle concentration. To account for that background number the FdS research team began each test-trial with a DYLOS particulate matter reading at least 10m from the nearest cookstove. The DYLOS 1700 was then powered-off and relocated to a second testing location 2.5m away from the nearest cookstove and powered-on for a second reading. Then, the DYLOS unit was powered off again and relocated to within 0.5m of the stove (at a sufficient distance that researchers were not in danger of burns). The DYLOS 1700 takes one (1) sample of the small and large particulate matter every second and averages the readings every sixty (60) seconds. When the DYLOS 1700 data were downloaded, the averaged readings were reported for each of the three test-trial distances for each household. The $PM_{2.5}$ monitors and the CO monitors where held closely together for the readings to assure that the data they recorded were consistent for each location.

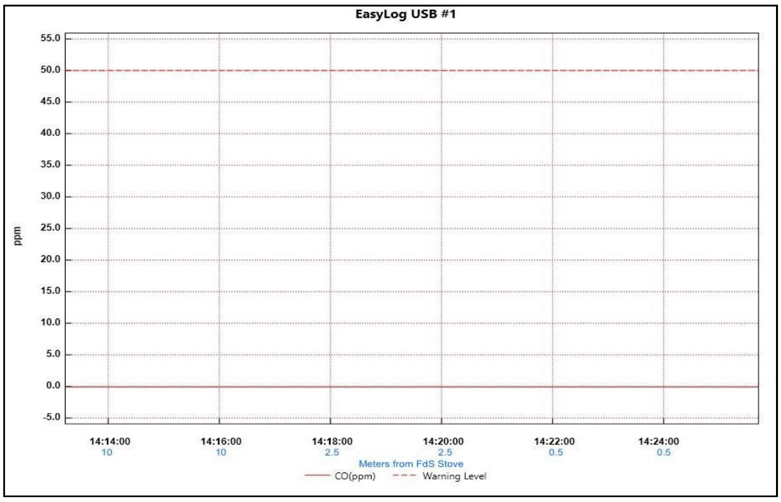
THE FDS GEN-8 GASIFIER STOVE AND FDS BRIQUETTES, TESTING FOR $PM_{2.5}$ AND CO

The testing team monitored $PM_{2.5}$ and CO for the FdS Gen-8 Gasifier Stove, burning 18 FdS Briquettes while boiling water. Readings were conducted at 10m, 2.5m and 0.5m distances. Since the study was designed to compare FdS stoves with random home-based charcoal stoves, the team tested an FdS Gen-8 Gasifier Stove that was over 1-year old. The FdS stove tested is designed to fit a typical Haitian bean-pot; FdS builds stoves which are customized to all sizes of Haitian cookpots.

The DYLOS 1700 measured $PM_{2.5}$ levels that were marginally lower nearer the stove than at 10m. Since background impurity levels are already very high in the air of Port-au-Prince, Haiti, having no measurable increase in PM levels nearer the FdS stove can only be considered the optimum result in any air impurity test-trial. (Fig. 5)

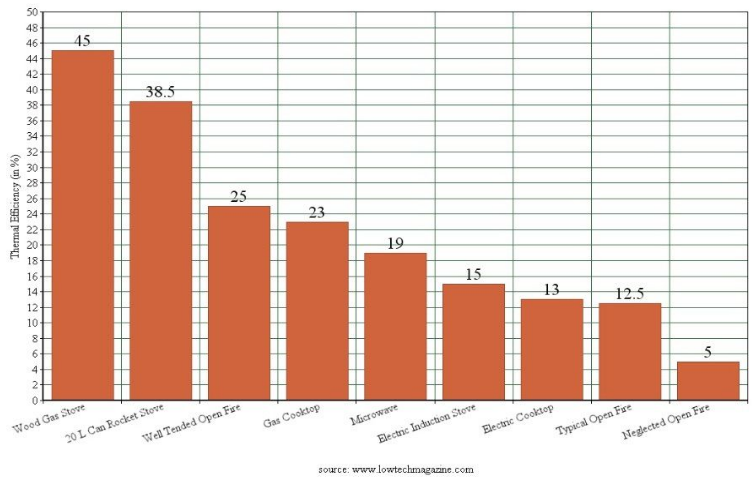


Consistent with the DYLOS 1700 measuring no measurable increase in $PM_{2.5}$ over the background readings in Port-au-Prince, the LASCAR EL - USB – CO monitor also recorded zero (0) ppm CO for the FdS Gen-8 Gasifier Stove at 10m, 2.5m and 0.5m (Fig. 6).



The Fig. 6 EasyLog was generated automatically by the LASCAR software, based on the data recorded when testing the FdS Gen-8 Gasifier Stove's carbon monoxide emissions. The solid red line at 0.0 ppm reading was the level of CO detected from the FdS stove at the 10m, 2.5m, and 0.5m distances. The dotted red line at the "50.0" ppm level is the "Warning Level" at which point persons exposed to 50.0 ppm of CO must, by EPA standards, evacuate to seek fresh air. Clearly, the FdS consistent CO emissions level of 0 ppm would never cause an "evacuation" level of CO exposure.

CO quickly breaks down in the atmosphere, so the LASCAR unit only registers a measurable reading near active CO sources. Therefore, the results from the monitors of both $PM_{2.5}$ and CO indicate that while cooking, the FdS Gen-8 Gasifier Stove is not a source of air-impurities in measurable amounts. These results support the findings of GACC that chimney biomass stoves tend to have extremely low Household Air Pollution (HAP) emissions. These results can also be attributed to the ultra-high efficiency independently identified in Low Tech Magazine (Fig. 7).



The study determined that Wood Gas Stoves (left most column), which are also known as Top-Lit-UpDraft or TLUDs (the core design of the FdS Gen-8 Gasifier Stove), recorded the highest efficiency of 45%. Propane / Natural Gas Cooktops (4th column from left), which are common in the US, recorded a comparatively inefficient 23% and a "Typical

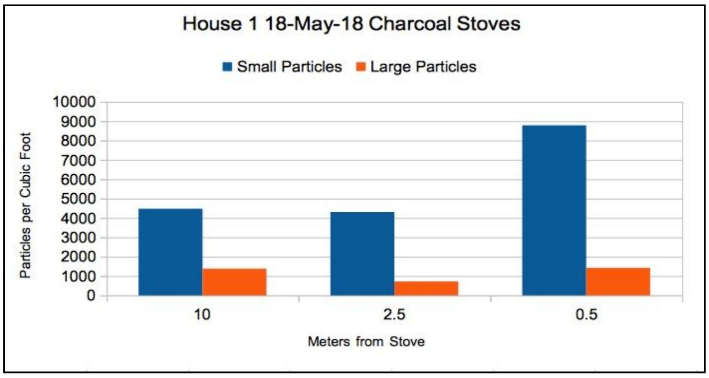
Open Fire" charcoal stove scored only 12.5%. Crucial in analyzing this low 12.5 efficiency percentage is that it is calculated *after* 90% of the fuel-value of the original wood is lost in the process of producing the charcoal (ESMAP 2007). The resulting aggregate percentage of only 1.25% efficient reveals Haitian charcoal as one of the least efficient fuels in the world.

The FdS team next tested Haitian charcoal stoves currently in use in Port-au-Prince households to determine if the measurements of (health risk-factor) air-impurities indicate that charcoal may actually be as detrimental to the health of local cooks as the charcoal industry is to the forests of Haiti.

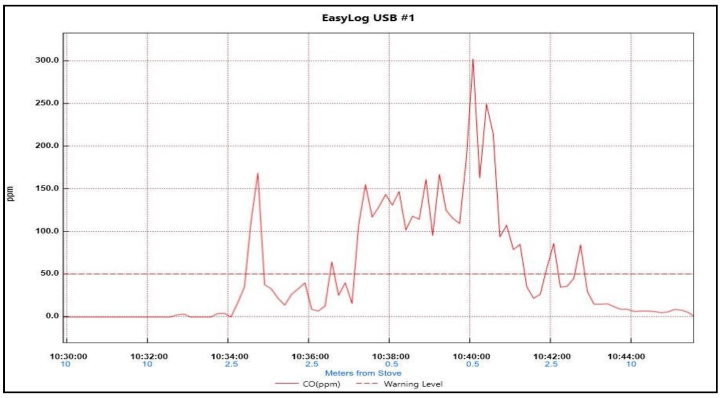
House 1. Multiple Charcoal Stoves in a House's Yard

The FdS researchers repeated the consistent 10m, 2.5m and 0.5m testing-distance sequence for several local charcoal-cooking household sites in Tabarre / Delmas, P-a-P, Haiti. In the yard of the first house (Fig. 8), several family members were cooking food to sell as noon-meals on basic charcoal stoves, for their home-based business.

Emission results showed dangerous $PM_{2.5}$ levels (Fig. 9).



A $PM_{2.5}$ count above 3000 particles-per-cubic-foot is rated as very poor air-quality. The P-a-P background PM levels are very poor, and at 0.5m from the charcoal stoves the $PM_{2.5}$ were 3x the "very poor" level. CO results are below (Fig. 10).

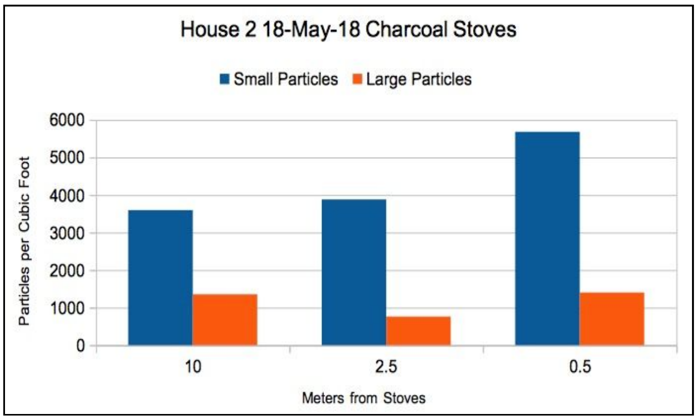


In contrast to $PM_{2.5}$, background CO levels are below a detectable level. However, upon approaching the charcoal stoves, CO levels already reached twice the "evacuate" level when 2.5m away from the stove. CO levels at 0.5m reached 300 ppm or 6x the "evacuate" level. These levels carry large health risks and would be illegal for any US workplace.

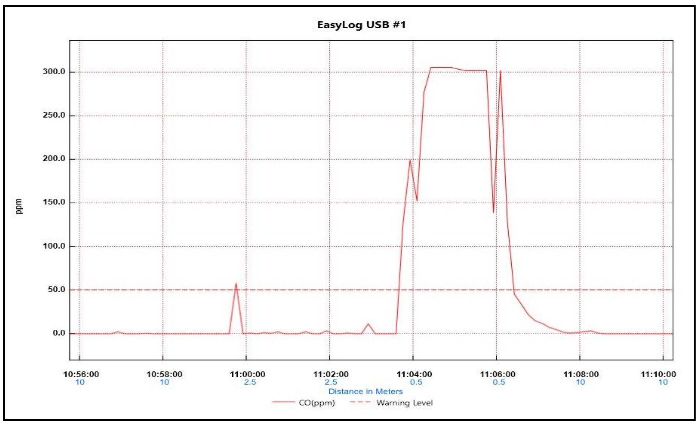
House 2. Three Charcoal Stoves, Cooking a Noon-Meal

A second home in the same neighborhood was also burning charcoal, on one 2-burner stove and one 1-burner stove, to cook the noon-meal for the household (Fig. 11).

The DYLOS 1700 recorded nearly 2X a "very poor" $PM_{2.5}$ level at the 0.5m distance from the stoves (Fig. 12).



The LASCAR CO monitors only register up to 300 ppm; the CO emissions graph (Fig. 13) for House 2 is flat-topped



because CO levels exceeded 300 ppm, which is 6-times an "Evacuate" level for carbon monoxide exposure.

House 3. The Orphanage Charcoal-Cooking Household

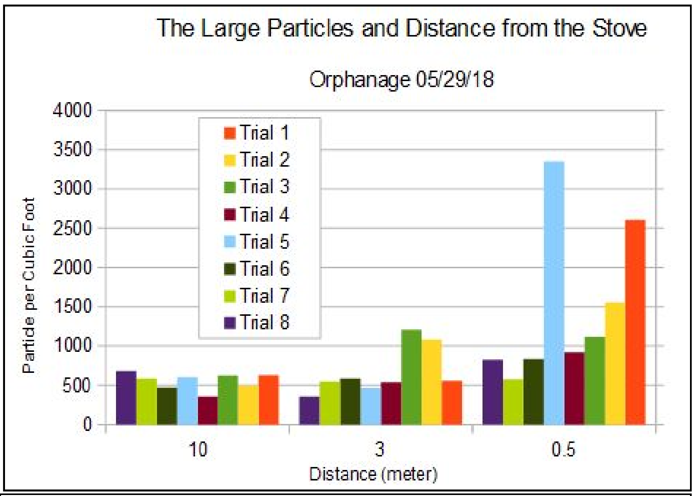
The third charcoal-cooking house holds a small orphanage operation that cares for 50 children. Food is prepared in a small cinder-block cookhouse (Fig. 14). In-home businesses are extremely common in Haiti, including: orphanages, welders,

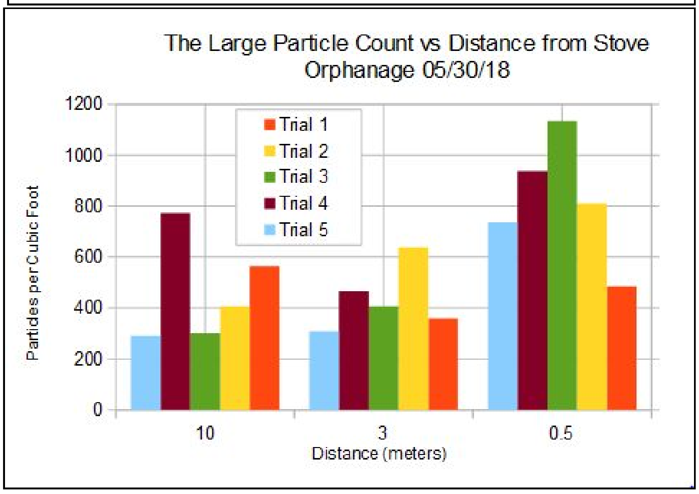
mechanics, merchandise and food sales.

Charcoal stoves in Haiti are basic and extremely inefficient. They nearly all follow the same rebar-rack design (Fig. 15). The consistency of Haiti's charcoal stoves increases the likelihood that the results of this study can be generalized throughout Haiti.

PM Large Particles -- 2.5 to 10 Microns (Two Days of Trials)

This house was the first location to reflect an increase in PM large-particles, as the researchers sampled air-quality at locations that were closer to the stoves (Figs. 16 – 17).

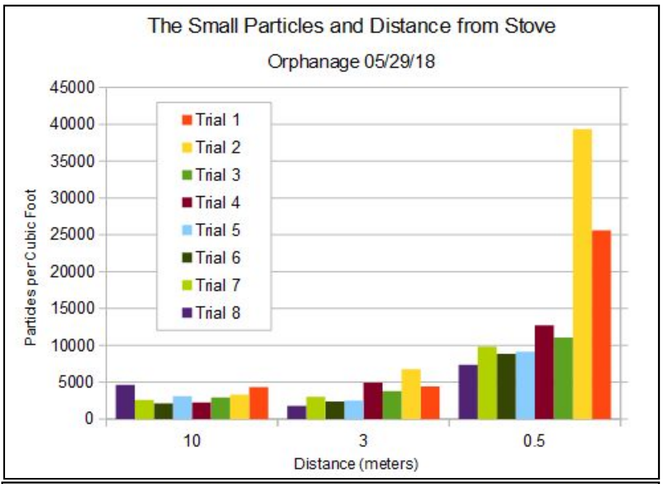


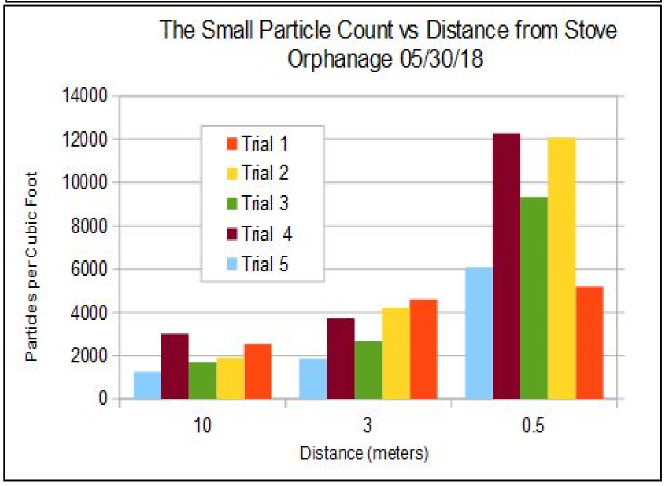


One possible explanation for the increased readings of large particles from the 0.5m distance in this kitchen location is that because the cooking-space is more closed-in, the larger particles tend to disburse less with the general flow of the air.

PM Small Particles -- 0.5 to 2.5 Microns (Two Days of Trials)

The charcoal-stove readings at the orphanage house consistently recorded critically high health-risking levels of PM small-particle as well as large-particle exposure. The health risks due to smoke exposure in this house are even greater than the other two houses because in this house the cooks are preparing meals in the poorly ventilated kitchen all three meals every day. The other two houses do much more cooking at noon than they do in the morning or evening. While the background impurity levels are very high for $PM_{2.5}$; the near-stove levels are magnitudes higher (Figs. 18 - 19).

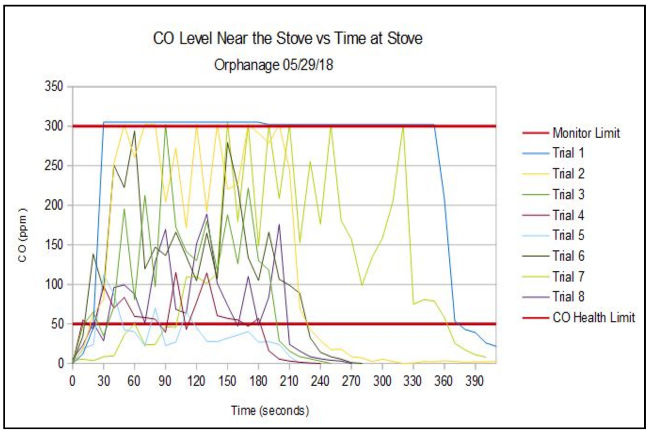




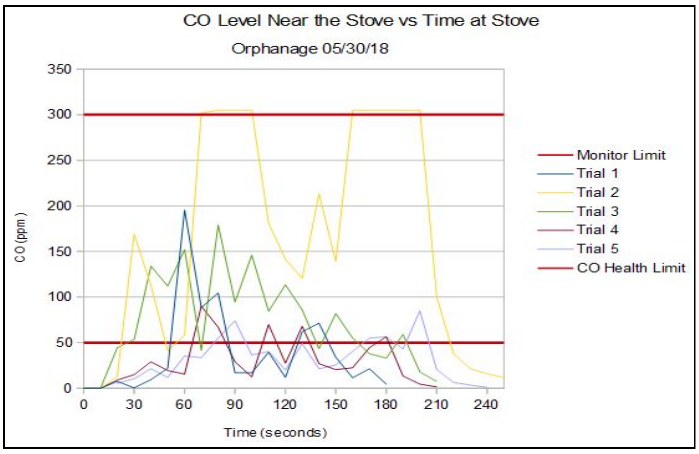
The data from the $PM_{2.5}$ readings from all of the houses will be compared in one chart following the House 3 CO results.

CO Data (All Readings <0.5m from Charcoal Stoves)

Possibly due to the walls surrounding this kitchen, the LASCAR monitors consistently registered zero (0) CO stove emissions at both the 10m location and the 2.5m location. Thus the data displayed in the multiple test-trials on the following two composite charts were each recorded <0.5m from the stoves (Fig. 20 below and Fig. 21 on following page).



The LASCAR CO monitors only register up to 300 ppm; the CO emissions graphs for House 3 from both Fig. 20 and Fig. 21 (on the following page) contain some readings that are flat-topped because CO levels exceeded 300 ppm, which is 6-times an "Evacuate" level for carbon monoxide exposure.



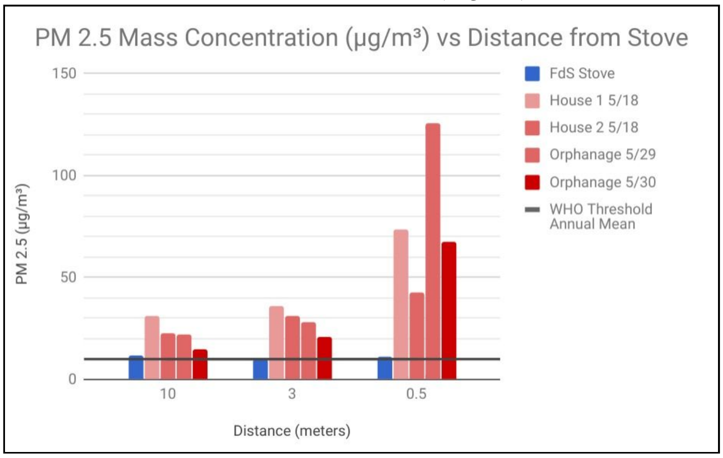
The FdS testing team recorded readings at specific intervals over the course of two days at the orphanage. The test model for this study did not monitor a single cooking cycle from ignition through the completion of cooking for that meal. It is possible that the widely differing readings from one test to the next on the same day may be explained by how recently the charcoal had been lit or how recently new non-burning charcoal was added. Recording emissions for the full cooking process of the stoves is a recommended follow-up study.

The LASCAR factory-installed audible alarm is intended to warn researchers of the need to evacuate when CO levels reach or exceed 50 ppm. The LASCAR owners manual indicates that 50 ppm corresponds to the concentration that would require mandatory evacuation by EPA standards. It is crucial to note that in 100% of the charcoal-stove emission tests, over three locations, four days of testing, and 15+ trials, CO levels *always* significantly exceeded the 50 ppm level. Cooks in Haiti are constantly exposed to levels as high as 6X or more the point where everyone should evacuate for their own safety. For comparison, the FdS Gen-8 Gasifier Stove registered *zero* (0) detectible CO levels while cooking.

This study included the 2.5m and the 0.5m distance readings to explore the differences between personnel exposure levels and stove emissions. For future testing, FdS recommends utilizing two CO test-monitors simultaneously, to record data directly at stove level as well as at mouth level. Then, when possible, a third CO monitor could potentially be worn throughout the cooking-period by the head-cook to test personal direct-exposure throughout the course of the day.

Comparison of Results to WHO Threshold and International Studies

$PM_{2.5}$ measurements are recorded in either particle concentration: µm/cubic-foot or in mass concentration: µg/cubic-meter. The conversion equation from particle concentration data of the DM 1700 to mass concentration for $PM_{2.5}$ (provided by DYLOS Customer Service) is small-particle-value minus large-particle-value with the result then divided by 100. The World Health Organization (WHO), EPA, and most professional publications address $PM_{2.5}$ (and offer exposure guidelines) in units of µg/m3. The WHO issued an annual mean threshold for $PM_{2.5}$ of 10 µg/m3 (WHO 2005). The following chart has the compilation of both the FdS Gen-8 Gasifier stove emission result *and* all of the charcoal stove test trial results from all three charcoal-cooking house locations. This data are only regarding $PM_{2.5}$, with all of the readings converted into mass concentration units, and with the WHO annual mean threshold indicated (Fig. 22).



Haiti's background $PM_{2.5}$ levels are at-or-above the WHO Annual Mean Threshold for PM exposure, so it is crucial that Haitian cooks are not exposed to additional large concentrations of $PM_{2.5}$ in their kitchens everyday. Cooking with charcoal stoves raises the $PM_{2.5}$ exposure levels to 4 to 12.5 times the WHO Threshold. The FdS stoves add zero CO and $PM_{2.5}$ to the kitchen environment during cooking.

Now, with this study's data converted into µg/m3, that data can be compared with published studies to discuss results in context. One prominent study of improved cookstoves, reported by the BBC, was conducted in Nepal by Prof. Jim Tielsch of George Washington University (BBC 2016). Tielsch stated: "With the first stove intervention, we brought [exposure] down to about 900 from 1,400 micrograms. And the LPG stove brought that down by another 50%. That's substantial, but nowhere near what was needed to have an effect on respiratory health."

Consistent with Tielsch's statement, on its website, the GACC (2016) references Mortimer's Malawi study, which was also profiled in BBC (2016), "Based on the type of stove evaluated in the Malawi trial, the lack of impact on child pneumonia is not surprising. While this stove may offer a range of environmental, climate, and lifestyle benefits, the stove does not meet WHO indoor air quality guideline levels expected to reduce child pneumonia."

In contrast, the FdS Gen-8 Gasifier Stove *does* bring the $PM_{2.5}$ levels down within the WHO threshold where neither of the stoves profiled by the two BBC (2016) studies succeeded. While charcoal cooking in Haiti was measured as having up to 125 µg/m3, or 12+ times the WHO threshold of 10 µg/m3 annual mean, these numbers are not nearly as terrible as the 900 - 1400 µg/m3 data reported by the BBC. Two possible reasons for this are that Haitians burn charcoal, not dried dung, and that the most dangerous particulate matter in the wood-fuel is actually released while producing the charcoal. However this highlights the huge ecological damage that the 10:1 ratio of wood-destroyed to charcoal-produced has on the the environment. Additional research should measure health-risk exposure for Haitian charcoal producers, who have complained about health issues. Charcoal producers reported, "The most difficult aspects of the job were...the health and hygiene impacts from the charcoal dust." (UNEP 2016)

The focus of this study is the health-effects of $PM_{2.5}$ and CO exposure while the Haitian cooks are cooking; this is why the data points are based on testing brief periods while cooking. An additional focus of study would be the overall cooking-system emissions-footprint (also called a life cycle analysis). For charcoal, this would document the complete emissions, including the trees that are destroyed in making the charcoal. Also, since most charcoal is produced in rural areas and transported to urban areas for use (Ghilardi 2018), more fuel is used for transportation of charcoal than FdS briquettes, which are utilized near where they are produced. Thus, when full emissions-footprints are considered, the FdS health and ecological advantages over the charcoal status quo would likely be even more substantial than in the current study.

FdS integrates a chimney into the Gen-8 Gasifier Stove (Fig. 23), which leads the non-carbonized briquettes to burn much more efficiently than in a non-chimney stove. Were a study to focus on out-of-kitchen emissions, a small amount of $PM_{2.5}$ would be emitted from the FdS chimney. FdS Gen-8 Gasification Stoves are available now for independent peer-reviewed studies to compare FdS emissions to any cooking technology in the world. If the FdS stove were used in Nepal, for example, there is every reason to believe that the results would show improvements from the 1400 $\mu g/m^3$ cited in the BBC study to levels close to local ambient-air background impurity levels.

Carbon Monoxide and $PM_{2.5}$ Discussion

Whether compared against Nepalese stoves' 1400 $\mu g/m^3$ or Haitian stoves' 125 $\mu g/m^3$, FdS stoves should lower $PM_{2.5}$ emissions to near background levels. Currently, $PM_{2.5}$ levels are the primary focus of research in the cooking sector. Many researchers and the WHO consider $PM_{2.5}$ to be the key pollutant for which health risk is evaluated. It has been linked to many diseases, including, respiratory and cardiovascular effects and mortality (Sclar 2015) CO exposure is also associated with high health risks (WHO 2014). Considering also that CO monitors are less bulky for researchers to use and cooking personnel to wear, FdS highly recommends CO testing be included in all future stove emissions studies.

According to GACC 2017, "Solid fuels remain a critical part of the energy formula for almost all [Haitian] households. 93% of households (~2.2 million households) [primarily] use wood or charcoal [for cooking]. More than 80% of urban households use charcoal as their primary cooking fuel."

Health and developmental experts agree that Household Air Pollution (HAP) from wood and charcoal cooking is a major health factor in countries such as Haiti. WHO (2014): "Global burden of disease estimates have found that exposure to HAP from cooking results in around 4 million premature deaths, with the most recent estimates from WHO reporting 4.3 million deaths for 2012. HAP is responsible for nearly 5% of the global disease burden (expressed as disability-adjusted life-years (DALYs)), making it globally the single most important environmental risk factor." These findings reflect life-or-death conditions and thus deserve greater attention.

Haitian charcoal's negative health impacts have been the long-established consensus of the developmental community. USAID 2007: "Cooking with charcoal and firewood on crude stoves has a significant adverse impact on human health in Haiti. It has been estimated that the average lifespan in Haiti is shortened by 6.6 years because of the impacts of indoor air pollution caused by indoor burning of biomass. Acute Lower Respiratory Illness (ALRI), the global number one killer of children under five years of age is also the number one killer of under-fives in Haiti — with ALRI mortality estimated to be more than 40 percent. This mortality burden is undoubtedly related to the massive use of biomass as cooking fuel."

There are signs that sector-consensus regarding charcoal's negative effects on trees is also approaching. The latest research into the environmental effects of Haiti's charcoal industry, conducted by researchers who had previously discounted charcoal's tree destruction (Tarter 2016), now broadly supports the scientific consensus that the charcoal industry has a destructive effect on Haiti's remaining trees. Ghilardi, Tarter, and Bailis (2018): "Woodfuels constitute nearly 80% of Haiti's primary energy supply. Forests are severely degraded and the nation has long been considered an archetypal case of woodfuel-driven deforestation....Under a business-as-usual scenario, the simulated regenerative capacity of woody biomass is insufficient to meet Haiti's increasing demand for wood energy and, as a result, between 2017 and 2027 stocks of above-ground (woody) biomass could decline by 4%+/-1%." Now that scientists agree on the ecological destruction caused by Haiti's charcoal sector, it is time to turn to the specific health effects of charcoal cooking.

Similarly, while charcoal made from agricultural waste was once suggested as a solution for Haiti's charcoal crisis, when Amy Banzaert tested agricultural waste charcoal (AWC) vs. Wood Charcoal (WC) for her PhD Thesis, she reported, "On average, AWC produces 5 times the total suspended particles emissions of WC and 2.7 times the ultra-fine particles." Banzaert (2013). This research adds more data that support the concept that non-carbonized briquette cooking-systems, such as FdS, are superior to any type of charcoal.

Propane gas has been proposed to replace charcoal in Haiti. However, imported propane is economically detrimental to the country. USAID (2007): "Imported propane gas (LPG) remains the most expensive form of cooking fuel in Haiti." ..."Haiti imports all of its petroleum fuels. More than 50% of Haiti's export-generated foreign currency is spent each year to cover the costs of petroleum imports." FdS stoves and briquettes provide a verified solution to each of these issues, leading toward Haitian cooking-fuel energy independence. Imported Propane is not viable even if subsidized. USAID (2011):"Even with a heavily subsidized price for purchasing tanks, LPG will not be a viable option for many Haitians due to unstable incomes and perceived safety concerns."

Expanded Version of this Study is Expected by April 2019

While the first two charcoal-burning houses were chosen at random by just walking in off of the street, House 3, with the orphanage was chosen for this study because it is the location selected (by a supporter of the FdS project) to receive the donation of four FdS Gen-8 Gasifier Stoves and one FdS Retained-Heat Basket-Cooker in the coming weeks. The data featured in this initial study will be complemented with further data before and after the FdS stoves are donated and installed. Later in 2019, FdS is contracted to deliver 23 FdS stoves to a factory / industrial park where 9 cooks prepare food for 200 workers. Additional data will continue to be generated and published. Simultaneously, FdS is exploring CDM carbon credits to support widespread FdS stove distribution in Haiti.

The FdS Plan for Haiti

The Social-Eco Enterprise, FdS Haiti SA, has been working on the island of Hispaniola in the introduction, evaluation and promotion of eco-cooking solutions since 2006. In 2011, the UN World Food Program (WFP) invited FdS to move primary operations to Haiti to produce recycled fuel briquettes for the WFP school-feeding program. The FdS briquettes are non-carbonized - none of the source-materials are burned while producing the briquettes. The only binder for FdS briquettes is recycled paper fiber and water, which cures in the sun. The WFP / FdS stove-briquette program was very popular with Haitian schools and students. School kitchen committees were quoted in Socio-Digital (2017): “[The WFP] gave us a briquette [as cooking fuel]. The briquette helped a lot.” “The briquettes are good. They’re so good. They’re good, yes.” “We make food quick (with the briquettes).”

For the FdS generation-1 briquette program, the WFP supplied biomass stoves, imported from India, and FdS made the briquettes. USAID (2011) independently evaluated the stoves and briquettes in Haiti and reported (Fig. 24, fourth column) the briquette stoves replaced 100% of wood with fuel costing half as much as charcoal of propane. The WFP implemented 500 stoves with FdS briquettes in 70+ schools.

Institutional Stoves: Kg of Fuel Comsumed per Kg of Food Cooked							
Stove	Traditional Recho Fer	Prakti Orka Wood	Colgan	Prakti Orka Briquette	3 Stone Fire	Winner - LPG	Recho Kreyol - Gaz Blan
Fuel Type	Charcoal	Wood	Wood	Briquettes	Wood	LPG	Kerosene
Test #1	0.184	0.220	0.136	0.187	0.585	0.053	0.137
Test #2	0.184	0.191	0.205	0.221		0.076	0.061
Test #3	0.218	0.119	0.143				
Test #4							
Food Cooked (Kg)	28.8	33.1	25.4	27.0	23.8	18.6	17.0
AVERAGE (Kg fuel per Kg of food)	0.195	0.177	0.162	0.204	0.585	0.065	0.099
Standard Deviation	0.020	0.052	0.038	0.024		0.016	0.053
Coefficient of Variation	10%	30%	23%	12%		25%	54%
Wood Saving % (3 Stone Fire base line)		70%	72%	100%	0%		
Cost of Fuel Per 50Kg of Food cooked (aprox. 150 meals)	$5.08	$0.79	$0.72	$2.55	$2.61	$4.05	$4.46

Table 4: Institutional stoves (wood, charcoal, briquettes, LPG, kerosene)

Dr. Paul Anderson (2017) adds: “FdS stoves are optimized for use of the biomass briquette-fuel that FdS produces from recycled materials in PaP. The stoves...can also use [available wood] fuels in rural areas. A major factor is the substantial savings in fuel costs compared with [other] cookstoves.”

In addition to recycled paper and cardboard, FdS briquettes are produced from available sawdust and other similar dense-cellulose biomass material. One of the best sources of a cellulose briquette ingredient is a local indigenous plant. The tree known as Candlewood or *Amyris Balsamifera* (Fig. 25) has grown plentifully on the island of Hispaniola since before European arrival. Now, the remaining *Amyris* are being harvested and not replanted. The long-term FdS plan for Haiti is to plant *Amyris* forests throughout Haiti. *Amyris* can grow in many places where food crops cannot. The plant is durable and extremely drought resistant. With waste paper and cardboard supplies increasing in availability in Haiti as the country develops, the planting of *Amyris* fuel forests would allow non-carbonized briquettes to fuel stoves throughout Haiti’s urban locations. Haiti would then become further energy independent. All charcoal-sector jobs would be replaced 1:1 with safer cleaner briquette industry and agroforestry jobs. Unlike charcoal which destroys trees in a 10:1 ratio in compared to the fuel product produced. *Amyris* fuel forests provide a *double*-harvest. First the trees yield the valuable *Amyris* essential oil, which is sold internationally by the ounce, and second, the remaining tree-pulp can be mixed with paper and cardboard to make briquettes. Additionally, with the dramatically improved efficiency *Amyris* forests can be poly-cropped, unlike the mono-cropped charcoal forests being raised in Haiti today. As herein demonstrated, the FdS Eco-Cooking System would be better for Haitians’ health than the charcoal status quo.

International biomass fuel experts, including John Dale “Zach” Lea (2017), see that Haiti’s sustainable future lies in the transition to multi-cropped fuel-forests. “In collaboration with the ministries of Tourism, Agriculture, and Environment encourage friends and citizens of Haiti to plant trees. A “Fast Forest” program...would...cover the land quickly...on flat land or gently-sloping hillsides… If the fast-growing trees are nitrogen-fixing, use their leaves for fertilization. Intersperse fruit and lumber trees in gardens of fast-growing trees on flat or sloping land. A “Giant Trees” program would promote use of *E. grandis* for borders and windbreaks, topping the trees at 12-14 feet for wind-breaking strength and for production of planks, using the toppings for...fuelwood.”

Through fiscal sponsor, Omprakash, FdS has IRS 501 (c)(3) status, which facilitates the power of volunteers and donations for implementation of innovative technologies and business opportunities for Haiti. The FdS plan follows ideas promoted by Daniel Jean-Louis and Jacqueline Klamer in their 2016 book, *From Aid to Trade: How Aid Organizations, Businesses, and Governments Can Work Together: Lessons Learned from Haiti.* FdS engages the authors’ perspective that NGOs should move away from the gifting-economy for Haiti, which can encourage a culture of dependency. Instead: “Anyone who truly desires to help Haiti must realign their strategy to help create legal profitable business opportunities in the country.” (Jean-Louis and Klamer 2016)

The FdS plan recognizes that the charcoal-cooking status quo has been a key component of Haitian culture and economics for decades. ESMAP (2007): “Charcoal and wood provide 70%-75% of Haiti’s energy supply.” To address such an ingrained component of Haitian culture, the FdS plan incorporates key concepts of Behavioral Economics (B.E.) including what Nobel Prize Laureate, Richard H. Thaler identifies as, “useful lessons about how to change the way people think about things, especially when they have a lot invested in maintaining the status quo.” (Thaler 2017). Personal loyalties and cultural traditions must be respected in any effective behavior change process, so the FdS process is to engage local stakeholder investment in the plan's design and implementation. In Thaler 2017, the author also summarizes his previously published "Nudge" strategy, which develops methods to encourage large groups of people to move away from the status quo, in favor of choices that are better from them, while maintaining their access to free choice. This B.E. concept is the core behavior-change model of FdS. Further documentation of the parallels of the FdS plan and the

In order to compete with the entire charcoal sector, follow the B.E. "Nudge" model, and have the most chance to help Haiti move beyond the charcoal status quo, the FdS Eco-Cooking System is developed to be equal or superior to charcoal across all available metrics:

Less CO exposure in kitchens	More ecological: saving the trees
Less PM2.5 exposure in kitchens	Greatly lower carbon footprint
Less pollution to Haiti's air-quality	Upcycling underused resources
Boils water faster than charcoal	Efficient Agroforestry
Highly effective for Haitian cuisine	New forestry for unused land
Less expensive than charcoal fuel	Effective stove / Ease of use
Replaces Haiti's charcoal jobs 1:1	Design-Feedback-Loops
New jobs safer & more ergonomic	Multiple income streams for Haiti

Further documentation of the parallels of the FdS plan and the core features of B.E. will be explicated in upcoming FdS publications, which focus on the social psychology required for country-wide adoption of the FdS Eco-Cooking System.

The FdS plan will maintain and expand Haitian energy independence without the negative health risks of the country's current charcoal cooking status quo. The FdS team will continue the before-and-after testing for the orphanage home location's four stove implementation, with a similar process followed for the upcoming 24 stove implementation. The comparative data generated will be published in future studies. The advance release of this initial study was required by NIH Researcher Ethics. NIH (2008): "Researchers should remove subjects from the study if it becomes too risky or harmful." Since in Haiti, it is the status quo of charcoal-stove emissions in 80+% of urban households which is the risky element identified in this preliminary study, research-ethics require that this data be shared as quickly and as widely as possible for verification of data and for identified solutions to be implemented. Please share this study your colleagues.

Additional Study Recommendations

1. Further study is immediately recommended.
2. Since this study's author is one of the developers of the FdS Gen-8 Gasifier Stove, the author encourages independent replication / verification.
3. Always test CO emissions with every $PM_{2.5}$ emissions test administered.
4. The primary cook could wear a CO monitor to further test exposure level.
5. The $PM_{2.5}$ monitor manufacturer identifies high-wind as a contamination factor in emission tests: Refrain from testing in high-wind conditions. If wind speeds change dramatically during a testing trial, cancel the trial and test again in lower wind conditions.
6. The health risk compounded with the negative environmental impacts of charcoal cooking must be further discussed and solutions must be brought forward that align with the social context of Haiti.

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