Feasibility of Ethanol Fuel for Cooking in Upland Sierra Leone

A capstone project submitted in partial satisfaction of the requirements for
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Statement of Conflict of Interest and Consent

This study was initiated by Martin Kailie, resident of Sierra Leone and UC Davis Humphrey Fellow. Research protocol was designed by Dana Armstrong (me). Because I was working with Martin, a local individual, and not a large established agency, my access to support in country relied on him. Our research team therefore consisted of myself and another UC Davis student, Martin's friend Suley Koroma, and Martin's daughter Massa Kailie. Both Suley and Massa are university graduates and possessed significant experience in research, having been employed by NGOs such as Médecins sans Frontiers and Gallup World Poll. They are experienced researchers but also friends and family of Martin, which may have resulted in unmeasurable bias in data collection or interpretation.

Study participants were invited to the study's orientation session through word of mouth, and because this spread through a network of friends, at least 2/3 of the study participants were friends or acquaintances of Martin Kailie. For this reason, friendship with Martin may have had an unmeasurable effect on purchasing behavior.

This study was designated "Not Research" by the IRB, but consent signatures were collected regardless. A copy of the consent form can be found in Appendix C and signed copies can be produced upon request.

Funding for this project was provided by the Blum Center for Developing Economies and the Jastro-Shields grant.

Use of icons in infographics were through free online icon providers including FLATICON, Piktochart, and Free Icons Library. Photos are all the author's own or property of Peter Nasielski.

Original art by Peter Nasielski

This work is in loving memory of Elizabeth Senesie, house 3, for whose support to our team was but a drop in the ocean compared your support and love in people's lives. You are missed.

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I. Executive Summary

Ninety-seven percent of households in Sierra Leone prepare their food over wood-burning fires (Statistics Sierra Leone, 2017). This leads to pulmonary disease, increased risks for women who collect firewood, and severe deforestation. The rapid deforestation is additionally contributing to greater irregularities in regional climate including severe droughts and flash floods, which in turn further lowers the resilience of the rural population. Martin Kailie, UC Davis Humphrey Fellow and citizen of Sierra Leone, along with our team, proposed to implement a market for cassava-based ethanol for cooking. His long-term objective is to replace wood and charcoal consumption in urban areas with bioethanol fuel sourced by a high-yielding, high starch strain of cassava grown by women in regional cooperatives. Sunbird Bioenergy is a large, internationally owned ethanol and biogas producer near Mikeni that is interested in building a local market for its product, currently sourced from sugar cane. We performed an initial pilot study to assess the acceptance and affordability of alcohol fuel and stoves in the urban environment.

Our primary objectives during our visit to Sierra Leone were to:

- Perform an energy market analysis to understand current fuel type and demand in Bo city
- Gather qualitative input on people's experience with ethanol-based fuel and stoves
- Determine the consumption rate of ethanol fuel when used for all household cooking tasks
- Determine a feasible pricepoint for Sunbird's ethanol in the Bo region.

During this study, we introduced twenty-four ethanol stoves and fuel to households in Bo, the second-largest city in Sierra Leone. We offered 2.5 weeks of free fuel, and determined through three metrics that families used an average of 0.9 liters per day when using the stove for all household purposes, with a calculated individual use rate of 0.2 liters per day. After introducing a pricing scheme of Le 8000 ($0.94 or $3.29 PPP) and later Le 6000 ($0.70 or $2.45 PPP) per liter, we saw families reduced their stove use drastically, with primary food preparation reverting to biomass fuel. Stoves were used only for simple tasks such as boiling water or frying eggs, confirming the fact that a price of even Le 6000 is not currently competitive with the average daily cost of biomass fuel at Le 2000 ($0.23 or $0.84 PPP). However, when compared to the cost of butane gas stoves used by some higher-income households, the ethanol stoves proved very competitive.

Additionally, we performed an energy market analysis by conducting over two hundred interviews with charcoal and wood sellers, as well as consumers of biomass fuel and butane gas. Recommendations and business models for ethanol distributors are also included in the text. Lastly, we developed an early prototype of an ethanol-fueled stove that could be produced locally rather than imported, along with additional initiatives, which are shared in Appendices A and B.

II. Literature Review and Background

a. Biomass Fuel

Throughout the developing world, reliance on cookstoves that run on natural biomass such as dung, straw, wood, and charcoal are ubiquitous. It is estimated that over 40% of the world's total population relies on these fuels for cooking and household activities (World Bank, 2018). The burning of these biomass fuels leads to formidable health and environmental concerns.

It is well established that the inhalation of black carbon increases the risk of pulmonary diseases (Smith, Mehta, & Maeusezahl-Feuz, 2004). In 2009, the World Health Organization estimated that indoor air pollution from burning "dirty" fuels is responsible for about 3.3% of the global disease burden or around 2 million deaths per year (World Health Organization, 2009); this has alternately been measured in over 38.5 million disability-adjusted life years (Smith et al., 2004). This is disproportionately the case in women and children, who spend more time in the kitchen than men (World Health Organization, 2009). Biomass fuels, when burned, release a complex of chemicals coarsely known as black carbon, including carbon monoxide, nitrous and sulfuric oxide, benzene, formaldehyde, polyaromatic compounds and other small respirable particles (Smith, 1987).

Hundreds of studies and meta-analyses have been done on the influence of smoke from cookstoves on human health (examples include Dherani et al., 2008; Kim, Jahan, & Kabir, 2011). Notably, only one study of this sort has been conducted in Sierra Leone, which compared acute respiratory infection rates between households with woodstoves against households with charcoal, outside the capital city of Freetown (Taylor & Nakai, 2012). Predictably, a study that compared ethanol and improved biomass (wood) stoves in Ghana and Ethiopia found cleaner air in the households that used ethanol stoves (Pennise et al., 2009).

Most families in Sierra Leone cook on traditional three-stone fires

It is not just the burden of pulmonary disease that is borne by women. Men can assist and sometimes dominate the job of fuel collection in a few African countries, but in most countries the burden of fuel collection falls to the women (Blackden, Wodon, & Shetty, 2006). Women must travel ever longer distances, and in precarious territories, to gather fuel for cooking, subjecting them to

dangers ranging from fatigue and spinal problems to snakebites and assault. Köhlin and colleagues, in preparing a background paper for the World Bank in 2011, confirmed these realities when they stated that the primary outcome of their review was the confirmation that energy interventions in the developing world "can have significant gender benefits" (Köhlin, Sills, Pattanayak, & Wilfong, 2011).

The burden of biomass cookstoves is not just a social or health issue but an environmental one as well. The burning of woodfuel is a major contributor to global climate warming through the release of carbon dioxide and black carbon compounds. Compounds emitted from burning biomass and from fossil fuel cookstoves is estimated at 29%, making them the second highest contributor to global warming after carbon dioxide (Ramanathan & Carmichael, 2008). Equally, if not more pressing is the rapid removal of trees and the process of deforestation associated with urbanization and increased wood collection, further decreasing terrestrial stored carbon and reducing biodiversity and natural habitat (J. E. Fargione, Plevin, & Hill, 2010).

b. Improved cookstoves

In response to the crisis explored above, many studies have been done not just on the effects of dirty fuel, but on the adoption of clean fuel and on more efficient stoves. The world of development and the academic papers associated with it can be divided into two general types, for the sake of this review. The first is improved biomass stoves, which still burn biomass but at a much more efficient rate than the traditional three-stone fire, resulting in slightly lower exposure to emissions and much less biomass fuel used overall, therefore assuming reduced rates of wood collection and subsequent deforestation. The second revolves around "clean fuels", or stoves that run on fuels such as LPG, kerosene, electric, solar, and in the case of this paper, biogas (or ethanol).

Varying types of improved charcoal pots in upland Sierra Leone, which still take biomass fuel but retain heat and therefore necessitate less charcoal usage overall

As far back as the 1980s, the idea of an "energy ladder hypothesis" prevailed, suggesting that higher incomes generally lead along a spectrum toward adoption of cleaner fuels. Poorer families use biomass such as dung or sticks or wood, higher income families move to charcoal, and highest income families move to clean-burning fuels (Leach, 1992). While this mentality persists, even from the idea's inception it appears never to work as cleanly as presented.

Data from the UN Food and Agriculture Organization have indeed confirmed that "per capita consumption of both fuelwood and charcoal generally decreases with an increase in income" (Arnold, Köhlin, & Persson, 2006). However, many additional factors besides income influence stove decisions. In most cases, "stove stacking" occurs where families may adopt a cleaner or more efficient technology, and use it to varying degrees alongside their open fires or other "old" technologies (Hosier & Dowd, 1987; Masera, Saatkamp, & Kammen, 2000). Masera and colleagues (Masera et al., 2000) argued that no clear evidence exists for the fuel ladder at all; a more appropriate mentality is that of "multiple fuel" model, where one recognizes that a move to clean fuel is more often an adoption of an additional fuel source rather than an outright substitution.

Regardless, meta-analyses that have been performed on stove adoption studies do report a high prevalence of studies that show a significant relationship between income level and improved stove adoption (Lewis & Pattanayak, 2012; Shen et al., 2015). Interestingly, Lewis and Pattanayak (Lewis & Pattanayak, 2012) also found a prevalent positive correlation between women's education level and adoption of improved stoves, though much fewer studies have taken this metric into account.

The studies around the psychology and economics of alternative stove adoption are many and varied. Willingness-to-pay studies measure sales types, auction methods, covariates such as gender and income, and more. Beltramo et al. discovered in Uganda that marketing messages such as "this stove will save you time and money" or "this stove can improve health" played little role in willingness to pay (Beltramo, Levine, & Blalock, 2014). Additionally, they determined that: 1) auctions are poor indicators of actual purchase behavior; 2) allowing more time to pay will increase willingness to pay; and 3) being female is associated with a decreased willingness to pay (Beltramo, Blalock, Levine, & Simons, 2015). They also confirmed that free trial periods had positive effects on willingness to pay (Levine, Beltramo, Blalock, Cotterman, & Simons, 2016). Yonas Alem further determined that access to credit and the prevailing price of the alternative fuel are also indicators toward increased adoption, which he studied over time rather than using cross-sectional data (Alem, Hassen, & Köhlin, 2014).

c. Ethanol

Ethanol is a biofuel, sourced from sugar and starch-heavy plants rather than petroleum. It is an uncompressed liquid alcohol that is clear and burns odorless. Biofuels are generally considered a clean alternative fuel because the burning of the fuel gives off only CO_2 and H_2O upon combustion, and no particulate matter or black carbon compounds that would be unsafe to inhale. It can also be considered safer than compressed gas such as butane, as it is flammable but not explosive (except under certain circumstances).

In addition to being a "clean" fuel, ethanol is often described across academic, political and social spheres as a "carbon neutral" energy source, and therefore an effective fuel alternative to combat global climate change (e.g. (Farrell et al., 2006)). The logic in this rhetoric is that unlike fossil fuels, a plant takes in carbon dioxide as it grows. Upon the combustion of the fuel made from the feedstock, CO_2 is re-released back into the atmosphere. Therefore, the only CO_2 being added to the system is that which the plant took in originally as it grew, meaning there's a net carbon balance as no additional carbon is

being added to the atmosphere (Zhang & Dincer, 2017). However, this perspective has been strongly critiqued for being dangerously limited in scope (J. Fargione, Hill, Tilman, Polasky, & Hawthorne, 2008).

Ethanol is a clear liquid that can be mistaken for water if not for its strong smell and quick evaporability; it is highly flammable but not explosive unless pressurized and heated.

Describing these fuels as carbon-neutral or climate-friendly has come under strong fire in the last ten years from ecosystem ecologists, who argue that indirect effects of ethanol production actually create strong carbon fluxes into the atmosphere, exacerbating overall climate warming by factors of 10 (J. E. Fargione et al., 2010). They argue that by far, the largest source of this net carbon increase comes from land use change, as the increased demand for biofuels will cause the conversion of previously unconverted natural land into agriculture to grow the feedstock crops. As this previously intact land is now converted, large pools of carbon previously stored in these ecosystems are released into the atmosphere through the tilling of soil and burning of wood (J. Fargione et al., 2008; Searchinger et al., 2008).

Despite the controversial findings regarding ethanol's contribution to increasing global atmospheric carbon, the fuel continues to receive attention in the energy arena due to its comparatively renewable feedstock source (crops such as sugarcane, corn and cassava), convenience and comparative safety in use, and clean-burning composition, making it safe to inhale.

d. Sierra Leone

Sierra Leone is no exception to many challenges facing underdeveloped countries. The West African colonial state had initially evolved as an outpost for freed British, Canadian and Jamaican slaves after the abolition of slavery--hence the capital of "Freetown" and its predominant language of Krio, an adaptation of "Creole" spoken by the newest Caribbean settlers. The Western education possessed by many of the "repatriated" individuals resulted in Sierra Leone becoming a leading state in the West African peninsula during the midcentury.

However, entrenched corruption associated with the government and diamond mining industry gave way to the country's brutal 12-year conflict from 1990-2002. This plunged the country into economic ruin. Development and growth after the end of the civil war have been steady, though the Ebola outbreak of 2014 again wreaked social and economic havoc on the recovering country, landing it 6th from the bottom on the UN human Development Index today (UNDP, 2018). It is currently the lowest non-landlocked country in the index.

Sierra Leone's comparatively low population of 7.5 million, impacted by increased migration to urban areas, leaves fewer hands to conduct agricultural work compared to other parts of Africa. In comparison, Nigeria's capital of Lagos alone has a population of over 21 million (The World Bank, 2019). The strains of cassava currently grown in Sierra Leone are low yielding, both due to lack of inputs and to the natural varietal. According to the World Bank, the average cassava yield for the country is less than 5 tons per hectare, though the FAO shows their output comparable to the world average at around 12 tons per hectare (FAO, 2019; The World Bank, 2016). World leaders include India and Thailand at 21 and 23 tons per hectare respectively (FAO, 2019). Cassava is observed here as the agricultural example as the crop could pose a more reasonable future feedstock for ethanol than sugar cane. It's a culturally familiar staple food, and the plant's resilience in the face of climate change can lead to higher resilience overall for smallholder farmers without sacrificing feedstock starch quality.

Overall, the prevalence of improved energy throughout the country remains very low. Different reports reveal varying numbers, and as the 2012 UNDP National Energy Profile of Sierra Leone shared, "Energy statistics are difficult to obtain in Sierra Leone… no consolidated set of statistics exists for the total Energy situation of Sierra Leone" (UNDP, 2012). With this in mind, the report determined that about 6% of the country's overall energy was powered by grid-generated electricity, with a maximum of 9% of the population provided possible access; 13% powered by imported petroleum products and 80% by biomass fuel, mostly in the form of wood and charcoal (UNDP, 2012). The outdated, overburdened electrical grid is inefficient and produces low voltage quality, with substantial losses in the transmission and distribution network, frequent breakdowns that lead to load shedding, and is further compounded by high numbers of illicit users (Government of Sierra Leone, 2002; UNDP, 2012).

Bo city, where we selected to run our pilot study, is the capital of the Bo region which is supported primarily by Bo-Kenema Power Services (BKPS). BKPS is a mixed hydro and thermal system that supports around 15.5 thousand households out of the 103 thousand households in the region. Like the National Power Supply (NPS) that supports the western area, transmission networks are over 50 years old and are sorely in need of overhaul, investment, and organization. The stations provide a combined 11 MW of power, with the hydro station operating in the wet season and the thermal system in the dry season (Government of Sierra Leone, 2002; UNDP, 2012). Most businesses in the city of Bo rely on private diesel generators for their energy supply. The majority of households in the Bo region (83,000 out of 103,000) light their house with battery powered flashlights, with alternative options including solar, generators, candles and wood (fewer than 2,500 households combined). Statistics for cooking material in the Bo region are explored below (Statistics Sierra Leone, 2017; UNDP, 2012).

The government of Sierra Leone confirmed in their renewable energy policy in 2015 that from 1990 to 2010, the country lost 12.6% of its forest cover, or 2.72 million hectares of forest (Government

of Sierra Leone, 2015). The 2002 National Energy Policy publication stated that "the rate of depletion [of firewood] exceeds the replenishment rate," and is most critical in areas surrounding urban settlements and alongside motorable roads (Government of Sierra Leone, 2002). This statement was readily observed during our visit.

A student prepares to start school by candlelight; power outages are frequent in the city of Bo. Candles are uncommon as a lighting source; most urban families use battery-powered flashlights.

Much of the fuel for cooking in Sierra Leone comes from land that is cleared as part of the fallow system in the agricultural rotation, but increasing population has made the demand for food greater, shortening the length of fallow (Government of Sierra Leone, 2002). This information was supported by the personal interviews we conducted in fuel-supplying villages. This shortened fallow season can therefore lead not just to reduced fuelwood harvesting but to soil degradation and therefore lower crop yields.

i. 2015 Census report

The 2015 consensus reports the following breakdown in primary cooking fuel usage, titled "Households by principal source of fuel for cooking by region, district and area of residence." For Bo district (which includes Bo city but also the surrounding countryside), the following was reported:

Total Households in Bo District	102,723
Households using electricity	380
Households using gas	309
Households using kerosene	500
Households using solar	152
Households using charcoal	21,620
Households using wood	78,632
Households using other (e.g. animal waste, sawdust, crop residue, etc.)	1,130

Figure 1: Households by cookfuel source (Statistics Sierra Leone, 2017)

It is important to note the large reported number of households using electricity and kerosene, compared to the number using gas. Our energy market analysis was unable to identify houses using electricity or kerosene, thus diverging significantly from the results above. Reports that kerosene has continued to decline since well before 2015 may play a role in the inability to find those that use it. The low number of gas in comparison is also likely that while many households have a gas burner, very few use it for all or most purposes—simply to boil water or other quick tasks--and the census looks only at the "principal source of fuel for cooking". It is likely that the high number of households using wood is due to the fact most villagers and those outside the urban center use wood almost exclusively, saving the charcoal for sale and export to the urban centers.

The 2015 Census reports the household fuel breakdown in the Freetown area as follows:

Total Households in Western Area, Urban only	229,951
Households using electricity	4,497
Households using gas	7,160
Households using kerosene	3,363
Households using charcoal	201,083
Households using wood	8,067
Households using solar	152
Households using other (e.g. animal waste, sawdust, crop residue, etc.)	6,029

Figure 2: Freetown households by cookfuel source(Statistics Sierra Leone, 2017)

Cooking with wood is very uncommon in the capital city. Because of the high level of urbanization, most people have no land outside their living space to cook so must cook indoors or on their porch. Additionally, transportation into the city makes transporting heavy logs economically unviable. Bakeries were reported as the main business in the city that still use wood. Charcoal is overwhelmingly the primary cookfuel in the capital city.

e. Renewable Energy and Sunbird Bioenergy

A 2015 Renewable Energy Policy for Sierra Leone report acknowledges the potential of the country for biogas and biofuel production. It acknowledges the country's rich agricultural potential as well as the 656,400 tons of crop residue currently produced per annum, that hold 500 MW of potential energy (Government of Sierra Leone, 2015). Both the Renewable Energy Policy and the UNDP 2012 report discuss the high likelihood of foreign direct investment into ethanol production projects.

The most consequential project in energy development has been the 2014 completion of the Addax Energy Bioethanol and Power Production plant in Mikeni, now acquired and run by Sunbird Bioenergy. This plant has capacity to produce 85 million liters of ethanol per year, mostly for export to Europe, along with a biogas generator from agricultural residue, and is designed to provide 20% of the country's national grid capacity (Sunbird, 2018; UNDP, 2012).

The completion of the Addax bioenergy plant brought 500 million dollars of investment into northern Sierra Leone, but not without controversy. The acquisition of the land and building of the plant was fraught with human rights concerns—for the most comprehensive of critiques, see ActionAid's Report "Broken Promises" (ActionAid, 2013). Many individuals on the ground informed us local paramount chiefs were believed to have conspired with the government to sell a large swath of land to Addax, without the knowledge of those who currently lived on the land. It was reported by word of mouth that because the company worked with the prior governmental administration, well known for its widespread corruption, the company was required to build on land near to the current president's home city of Mikeni. We were informed that the initial survey that was conducted exposed alternate optimal locations for sugar cane production, as the existing location produces low yields due to its shallow and saline soils.

The above information was acquired mostly through conversations with locals, but it indeed seems it was poor yields that drove Addax under in two years, and was purchased by Sunbird Bioenergy. At the time of this study, Sunbird had expressed interest in moving away from sugarcane as its primary ethanol feedstock, and instead was considering using cassava for ethanol production and elephant grass for biogas production (Gee, 2018). Both these crops grow readily throughout the country, and Sunbird was considering moving to a model that would support local farmers in cassava production through distribution of inputs and higher yielding varieties. Sunbird would then buy dried, chipped cassava at-the-gate from local farmers rather than monocropped by the company itself as the sugarcane had been done.

Sunbird Bioenergy Production facility

It is for this reason we stepped in to assist Sunbird in determining the feasibility of a local market for cookstoves that run on ethanol produced from cassava. Because Sunbird's updated vision aligned with Martin Kailie's in many ways, it made sense to pursue the question further of whether cassava-based ethanol could be a viable clean cooking solution for the country.

f. Project Initiation

Martin Kailie is a social entrepreneur from Bo, Sierra Leone. He is founder of Green Africa NGO and his (currently) one-man organization, Desert Water Social Enterprise. Both of these organizations focus on value-added cassava products and economic opportunities for female cassava growers in the Bo region, who are currently organized in cooperatives. He served a year as a Humphrey fellow from 2017-2018 at UC Davis, where he became involved with UC Davis' Program for International Energy Technologies (D-Lab). He acted an international client for the D-Lab course "Feasibility Studies in Development", during which time three students including me were tasked with assessing the feasibility of his proposed idea, "Cassava-based Ethanol for Clean Cooking in Sierra Leone."

As stated in the Executive Summary, our primary objectives during our visit to Sierra Leone were to:

- Perform an energy market analysis to understand current demand in Bo city
- Gather qualitative input on people's experience with ethanol-based fuel and stoves
- Determine the consumption rate of ethanol fuel when used for all household cooking tasks, and
- Determine a feasible pricepoint for Sunbird's ethanol in the Bo region.

Martin selected the city of Bo because it is his hometown, and a leading cassava-producing region of the country. It is known as the "second city", due to its reputation as the second-largest city in the country after the capital of Freetown (though the 2015 Census reveals Bo as the third largest city after Kenema). Regardless, the vast majority of this urban population purchases their biomass fuel, rather than collects it themselves as is done in rural areas.

Our research team consisted of five individuals:

1. Martin Kailie, who laid out the initial idea and vision and served as the primary bridge between our team and his community
2. Suley Koroma, longtime friend of Martin and student of Sociology at Njala University. Suley's research experience includes employment through Gallup World Poll, Bread for the World and Sierra Leone National Clubfoot Association
3. Massa Kailie, Martin's daughter and graduate of Political Science at Fourah Bay College. Massa's research experience includes Gallup World Poll, Médecins Sans Frontiers, International Growth Center, and Innovations for Poverty Actions
4. Peter Nasielski, UC Davis recent graduate with a BS in Sustainable Industrial Design
5. Myself, Dana Armstrong, UC Davis graduate student in International Agricultural Development.

Our research team, L to R: Martin Kailie, me, Suley Koroma, Peter Nasielski, Massa Kailie

Interviews and home visits consisted of two teams: Suley and I, and Peter and Massa. Massa and Suley are both fluent in Mende and Krio, and served as cultural and linguistic translators in addition to providing research expertise. Martin conducted home visits once research began but was not present during energy market analysis interviews (below).

III. Energy Market Analysis: The Existing Fuel Market in Bo

Before beginning research into alternative fuels, we needed to gain a clear picture of the existing fuel market. To do this, we spent two weeks conducting a series of interviews with wood and charcoal producers, wholesalers, retailers and consumers, and gas consumers.

While in Bo, we conducted interviews with 30 charcoal retailers and 30 wood retailers. We then interviewed 55 wholesalers and producers of wood and charcoal, and 79 consumers of wood, charcoal and gas. These interviews were collected across thirteen neighborhoods in the city of Bo, and four villages outside the city for suppliers. Participants were approached in no particular order as we spotted them in the markets. Participants received a bar of soap in compensation for their time. We also interviewed 34 individuals involved in the market in the capital city of Freetown, in order to gain an initial understanding of variations in market dynamics and fuel price between the capital city and Bo.

As shared above, 97% of the country cooks their food over wood or charcoal (Statistics Sierra Leone, 2017). These biomass fuel sources originate in villages that are located outside of, but adjacent to urban areas, as well as along the few major highways.

Copies of all interview outlines can be found in Appendix B. A brief breakdown of the biomass supply market can be found below.

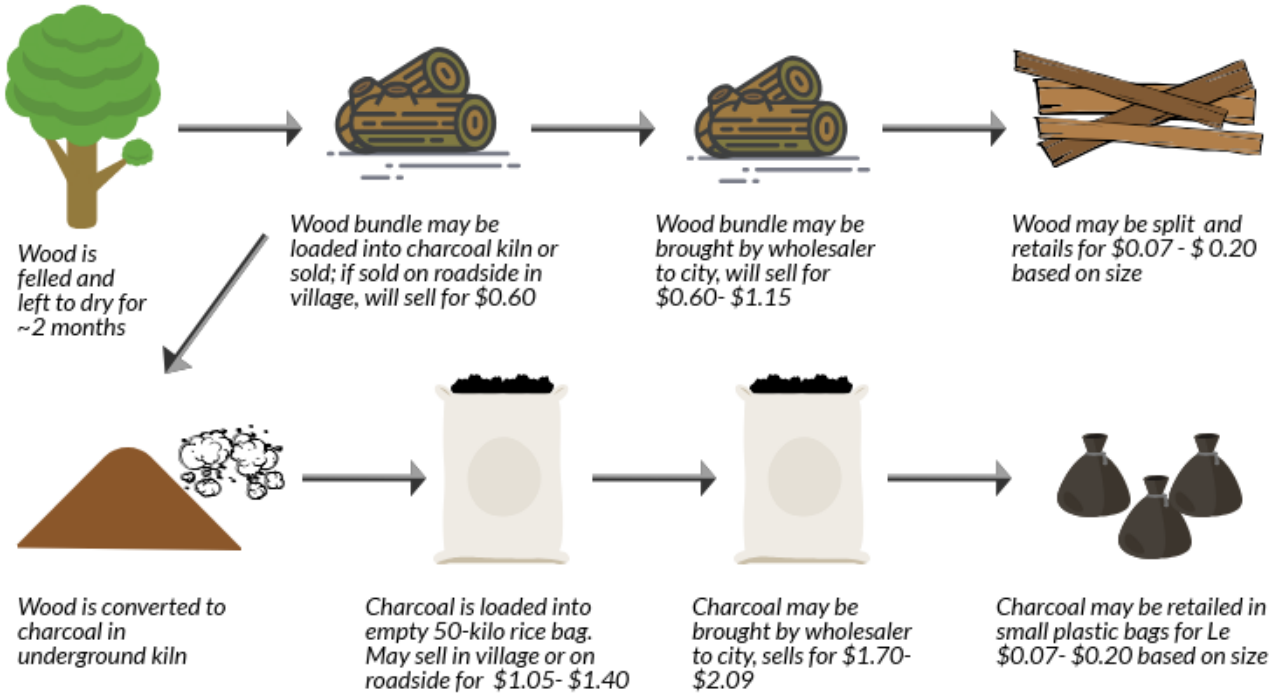


Figure 3: The biomass fuel supply process (real prices, not PPP)

g. Producers and Wholesalers

We interviewed 32 men and 23 women who identified themselves as wood or charcoal producers or wholesalers, in Bo city and four major biomass supplying villages. These villages were Banda Juma (east of the city), Cocofili and Benduma (South of the city), and Pundegumahun (north of the city). Both men and women collected and processed wood for sale, though those that managed charcoal kilns were exclusively men.

i. Wood production and wholesale

Woodfuel is collected in these villages by some people year-round, by others only seasonally. The most common time for individuals to collect wood is during the dry season, between January and April, after clearing land for planting crops. This happens both before and after the land is burned; many will fell trees early in the dry season and return to process them into smaller logs when they have dried, later in the year. Some individuals collect wood from their cleared land all year round, and others would move into forest or public land when the cleared land was exhausted. Forty-four percent of interviewees collected wood only on their own land, 30% harvested only on other's land, and the remainder collected from both their own and other's land. When this happened, there generally was not an overt exchange of money or goods for permission to cut on someone else's land, though in several cases people reported paying a small sum to the landowner.

In all cases, producers shared that wood was easier to collect in the dry season because the ground wasn't muddy, and the wood wasn't "soak", making it much heavier. In general, most individuals (17 out of 26 or 65%) reported that suitable biomass had become harder to come by over the years, as

exhibited by the phrase “I have exhausted my own bush”, stated many times by interviewees. In Banda Juma specifically, most individuals reported that they had to venture further to collect fuel not just because there were fewer trees, but also because more and more land was being privatized and developed. Nearby properties that used to be forests, or shared, now consisted of houses or buildings bought up by city dwellers, or business sprawling outward. Unlike the other villages, no individuals in Pundegumahun reported that they might be “exhausting their bush”, expressing little concern for the future of biomass availability.

Unsplit wood bundles can be found for sale of around $0.60/$2.10 PPP on highway and in villages; a wood retailer and daughter in Bo city show their supply, which would likely sell unsplit for $1/$3.50 PPP each

Because Pundegumahun was on a less traveled road, there was a higher rate of women reporting they would make the two-hour journey to Bo on foot to sell their wood bundles. Women would carry one to three bundles each day they made a trip. Bundles in the village would sell for Le 5000 (about $0.60 or $2.10 PPP), and in Bo they would sell for about Le 6000 or $0.72/$2.52 PPP each. Therefore, women were regularly making a four-hour round-trip journey to secure a profit of Le 1000 or $0.12/$0.42 PPP for the day (up to $0.36/$1.26 PPP for those able to bring three bundles). Bundles sold wholesale in villages or town are not standardized in the same way charcoal selling is. Bundles consist of

varying sizes and amounts of logs, though most logs are between two and four inches in diameter and two to three feet in length, with higher diameter (and therefore denser) logs rarely exceeding two feet. In the dry season, bundles are reported to sometimes be larger than in the rainy season.

Chopping and carrying wood is hard work, and individuals, especially women, readily expressed the pain and wearing they felt this job brought to their bodies. Reported costs for all required tools, usually a cutlass and a hoe (and sometimes an ax or shovel) run about $9 ($31 PPP). Because the blacksmithing quality can't be assessed visually, most reported their tools will last for a full season, while others reported that sometimes they last for only a few weeks, or even may break on the first swing.

Very few villagers in this profession had attended school, and those who had made it the furthest had left school to become either a pastor or imam (three cases). Regardless of their education level, all those interviewed reported that their children were in school.

ii. Charcoal production and wholesale

Charcoal production, as mentioned above, was undertaken exclusively by men. Some men had more than one kiln, and a few reported an income as high as Le 300-400,000 per kiln load ($35-47/$123-165 PPP). Others had smaller kilns that they managed in addition to their farm, petty trading, or other sources of income. We interviewed twelve men in total between the four villages.

The charcoal production process consists of an individual digging a big hole about four feet deep and ten feet long, and filling it with wood logs placed parallel to each other with a slit at the bottom to allow air flow. They bury this pile with leaves and then dirt, and light a fire at one end with smoke escaping out the other end. This pile would smolder for over two weeks, depending on the size of the kiln. Those with multiple kilns explained they would prepare wood and stock kilns while another kiln was burning. Three kiln owners shared that they took the time to separate wood by size and type, since different wood varieties will burn at different speeds, presumably depending on size, density and moisture content. One individual shared with us that "the mango tree is known as "iron coal" because it takes so long to burn. The small pieces cannot be put in with it or they will turn to ash."

A boy shows off one of his village's charcoal kilns

Charcoal, once dug up, is packed into empty 50 kg rice bags and sold on the side of the road or brought by motorcycle to Bo city. No producer we interviewed confessed to putting small pieces and dust (referred to as "chaff chaff" by the public) in their bags, though this was a primary report of dissatisfaction when we interviewed both retailers and consumers.

When bought in villages or along the highway, the price for a 50kg rice bag ranges from Le 9000-12000 ($4.10-$5.40 PPP), as opposed to Le 15,000+ ($6.20 PPP) in the city. Many urban families will venture out to purchase charcoal or wood outside of town to find the better price—despite the fact that funds spent on fuel for transportation will sometimes negate any money that otherwise might have been saved. This fact was never recognized by consumers but gleaned from us after estimating costs when asking individuals to quantify travel time.


Charcoal is packed into 50-kilo rice bags; wholesalers bring charcoal to Bo City by motorbike

Wholesalers, however, have been able to make a secure living by having a keener sense for prices and transport costs. They buy charcoal bags in bulk from villages, transporting them usually in loads of 5 to 10 bags by motorcycle, and selling in Bo. Charcoal bags in Bo sell usually for about Le 15,000 or $1.77/$6.20 PPP to retailers, and in some parts of the cities, especially in the rainy season, they can be sold for Le 18,000 or $2.12/$7.42 PPP when sold directly to consumers.

h. Retailers

Sierra Leone has been described as a "world of middlemen" by Sunbird's transition director. We saw this to be true; creative individuals have determined all kinds of ways to connect markets to buyers. For many individuals, buying unsplit wood or a bag of charcoal too crippling. For this market, a market of retailers emerges to meet daily fuel needs.

i. Charcoal Retailers

First we interviewed 31 charcoal retailers. Charcoal retailers are almost exclusively women with little or no education or alternative opportunities to make ends meet, or these women's children. These women buy large bags of charcoal and package them into small, thin black plastic bags (referred to as

"plastics" or "tie ties" because of the fact they would tie the handles to secure the plastic bags). These would then sell for Le 500, 1000 or 2000, appropriate sizes for one day's worth of cooking. Charcoal retail provides an opportunity for households that can't afford to purchase the full bag to be able to buy small plastics day to day. Retail "plastics" can be spotted for sale in the market, piled up on people's front porches, and on the heads of women and children roaming the markets and neighborhoods.


Charcoal retailers show us their "tie ties" for sale for Le 1000 ($0.12/$0.43 PPP)

Plastics cost Le 3000 for a roll and one roll lasts through 2-3 large bags of charcoal. It was hard to get accurate estimates for how many small plastics can be packed from one large bag, despite that many women spent their whole day doing it. They simply "don't take account", as my research partner regularly translated for me. It appears, however, that one can pack between 20 to 30 Le 1000 size plastics from one large bag—resulting in revenues of Le 20,000 to 30,000, or a profit of anywhere between Le 2,000 to 15,000 ($0.84-$6.65 PPP), depending on how much the bag was bought for from the wholesaler, and how many bags they could pack out of one. When asked how they know how much charcoal to put in each bag, one woman reported, "I weigh them with my eyes". Only one woman interviewed used a formal measurement, a small metal bowl that she would fill before pouring into the plastics. Only eight of the 31 individuals were also actively selling wood at the time, with six reporting they no longer sold it due to the effort and pain of chopping it.

Many women reported using the chaff in the big bags for their own cooking needs, as it was hard to sell it in plastics because astute customers would pick up the plastics and could feel if there was chaff in them.

Reported daily income for charcoal retailers varied widely, from Le 2,000 to Le 90,000 ($0.84-$40 PPP), which appeared to come from whether the individual was accurately considering revenue vs. profit as well as how active of a seller the individual was. Fifty-eight percent (18 out of 31) of individuals reported an income of between Le 10,000 and Le 20,000 ($4.20-8.40 PPP) per day.

ii. Wood Retailers

Wood, additionally, lends itself to retail. We interviewed 32 wood retailers. Families will buy bundles of wood for Le 5000 to 10,000, but these logs, though still only about three to four inches in diameter, are often still whole and unsplit. After buying these bundles, women will either split them themselves or entreat their brothers or children to split them, then selling the split wood in small, single-day-use increments of Le 500, 1000 or 2000. Most families reported putting five split sticks in each Le 1000 bundle, or a similar number based on size. Like charcoal, others reported they would not count but simply "weigh them with their eyes".

Wood retailers show us their split wood bundles for sale

Two-thirds of wood sellers (21 out of 32) also sold charcoal, in contrast to eight of 31 charcoal sellers who also sold wood. In general, women reported the strain of wood chopping and selling was demanding, and that they simply didn't sell wood if the primary wood chopper was unable to prepare bundles for sale. Interestingly, few said they would switch to charcoal if the strain of wood retail became too much, and instead cited retail options of onions, peppers, and other food items.

We also asked the question, "Why would someone prefer to cook with charcoal over wood, or wood over charcoal?". In general, most responses centered around the observation that wood is preferred because it's faster, whereas charcoal might be preferred because it produces less smoke. If someone doesn't have very much space to cook, it was observed they're more likely to invest in a coal pot because many people can cook on their veranda or inside next to a window, whereas if they have a separate, stand-apart kitchen structure they are more likely to use wood. Some individuals reported they believed that younger people preferred charcoal and older preferred wood, and another indirectly referred to the energy ladder hypothesis, suggesting that poorer or less educated people were more likely to use wood while comparatively better-off people would use charcoal.

Twenty-seven of 31 charcoal sellers reported that people buy more charcoal in the rainy season, because wood is often too wet to cook with and harder to come by, or more people wish to cook indoors. Most consumers observed that charcoal plastics were smaller in the rainy season for the same

price, but few retailers admitted to packing their plastics differently. Nineteen of 31 charcoal retailers reported they enjoyed selling charcoal because it brings them income or gives them something to do, but only 13 of 32 wood retailers reported favorably when asked the same question.

i. Consumers- Wood and Charcoal

After completing our supply-related interviews, we turned to assessing demand and began interviewing wood and charcoal consumers, defined as those who used this fuel every day for their household cooking and chores. We conducted 52 in-depth interviews in five neighborhoods around Bo, and an additional 35 brief surveys in two neighborhoods to further hone in on our estimate of average daily fuel expenses and fuel choice.

The majority of Sierra Leoneans prepare one major meal per day, usually in the middle of the day. This meal is usually rice with a leaf-or-bean based sauce, sometimes with fish or chicken added if it can be afforded. Leftovers are often saved and eaten cold later in the evening, or re-heated the next morning for breakfast. In addition to lighting coal for cooking, families will also use heat to boil water, fry eggs or fish, to put into an iron, or other small tasks. Often water is boiled immediately following meal preparation when coals are still hot, and poured into a flask which keeps it hot for bathing that night or tea the next morning.

Only 15% of those surveyed (13 of 87) reported using wood only. Additionally, only 15% (also 13 of 87) reported using both charcoal and wood either simultaneously or switching by season. The remaining 70% reported using charcoal most or all of the time.

Of the thirteen individuals using wood daily, there was an average spending on wood of Le 2,600 per day. Those using charcoal averaged to a much lower average daily cost of Le 1,800 per day. Importantly, the pool size for this average was notably bigger at 61 households. However, the price difference is worth observing. A large part of this lower cost for charcoal appears to come from the ability to buy the large bags of charcoal. Most of the families interviewed reported purchasing the large "50 kilo" rice bags of charcoal for Le 15-17,000 (~$6-8 PPP), and estimated they lasted "about two weeks", leading to an average daily use of Le 1071- 1214 (~$0.13-0.15/$0.45-$0.52 PPP). Only a small portion of those that bought plastics day-to-day bought Le 1000 or fewer; most bought Le 2000, and some more. Therefore, we can determine that "buying in bulk" results in greater cost savings for the family, but the family must have Le 14,000+ on hand to spend at once to take advantage of this offer. Incidentally, poorer families that cannot afford this investment appear to be paying more for charcoal fuel over time.

For general estimates and the sake of simple comparisons, I move forward in this paper with the assumption families in general spend an average of Le 2000 per day on biomass fuel for cooking. This is $0.24 or $0.84 PPP per day. Twenty-seven families that were surveyed reported spending an average of Le 27,000 on food every day. Roughly, a fuel cost of Le 2000 represents about 7% of the daily cooking budget.

Most families would light the wood and charcoal with a lighter or a match, or borrow hot coals from a neighbor. However, an important public health observation is that almost everyone who

purchased charcoal in plastics would light the plastic bag itself to start the fire. The daily burning of this plastic releases dioxins, PCBs, carbon monoxide and other greenhouse gases and chemicals dangerous for inhaling (Verma, Vinoda, Papireddy, & Gowda, 2016). We observed many women leaning in close during this time, prepared to blow on the charcoal to assist it in catching, directly breathing in these dangerous plastic fumes.

Preparing to cook on two coal pots; women often light the charcoal by lighting the plastic bag they buy it in, standing directly over it

An important observation is that it appears there is no correlation between family size and the daily amount of money spent on fuel—the trendline is weak at best. We had anticipated that larger family sizes would naturally spend more, but it appears this isn't the case. After observation, it appears that because a fire needs to be lit regardless, preparing sauce and rice for fourteen doesn't take too much larger of a fire than sauce and rice for four—just a much larger pot.

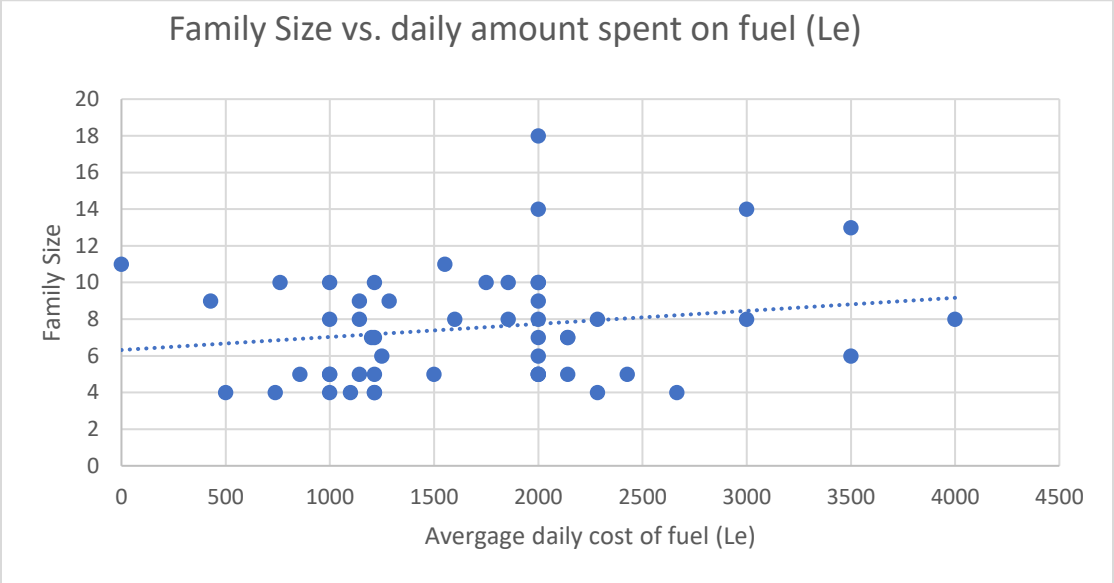


Figure 4: The correlation between people consuming food and amount of money spent on fuel was weak at best. The cluster around Le 1200 are those that purchase large 50-kilo rice bags of charcoal and report they last "about two weeks".

Another critical observation is that only 14 of 52 households cooked with one fire. The remaining households cooked with either two fires or two coal pots side by side. The reported average amount of time spent cooking was 1.5 hours. However, we neglected to consider that with two fires, that was actually three burner-hours. This oversight was one reason we were more optimistic about estimated ethanol usage than we should have been.

Two standard coal pots are used at once, usually one for rice and another for sauce

It is important to disclose that when taking account of time or money—or anything that requires quantifying—there was little understanding of how to make sense of our questions. If I asked, "how often do you…", we were met with blank stares, but if we offered a suggestion to clarify—for example, "one time a week, or three times a month", we were immediately met with a repeat answer of our suggestion. Many times my fellow researcher and cultural translator would turn to me and shrug, and just say, "she doesn't know. She doesn't take account."

j. Consumers-Gas

Five of the fifty-two households surveyed had expressed experience using a butane gas burner, and one of those families possessed one. One household expressed familiarity with kerosene. Butane gas burners were perceived to be the leading option in Bo, and in the whole of the country, for families that can afford an improved cookstove.

We therefore sought to interview twenty-seven households in Bo that used butane gas burners to learn about their behavior, income, and benefits and drawbacks of gas. However, these individuals were hard to find, so only eight of those interviewed were standard family households. The remaining nineteen were students at Njala university, the nearby college campus. It was well known in the area that university students used gas burners because they were fast and far more convenient, and many of their parents could afford to assist their children with this investment.

Gas storage and setups come in several sizes, but the most popular in Bo was the 6kg container (weighing 13kg when full). The initial setup for a full canister, burner and pot stand runs about Le 200,000 ($24/$84 PPP). After that, exchanging the empty canister for a full one costs Le 90,000 ($11/$38 PPP). This task can be done at most petrol stations and some stores in the city center.

After the new government came into power in 2018, they removed fuel subsidies as part of their anti-corruption campaign, to prevent smuggling over the borders to Guinea and Liberia. This led to the immediately unpopular result of increased fuel prices, the disapproval of which our interviewees did not hesitate to make known to us. It appears butane gas refills jumped from around Le 75,000 ($28 PPP) to refill to Le 90,000 ($38 PPP) in the last six months.

Butane gas is the most popular improved-cooking method

Most university students would share a burner between themselves and their housemates, using it to cook food for their roommates or one at a time to heat food. Outside of this, no household we interviewed or interacted with used gas for their meals, but only for re-heating food, frying eggs, boiling water, and other small tasks. To leave the burner on, even on low, to cook rice or sauce was considered wasteful when biomass was so much cheaper and more readily available. Because of this, gathering accurate data on how long one container of butane actually lasts proved impossible from interviews. Respondents reported anywhere from two weeks to six months, which only barely correlated with reports of how often they used it.

To get a clearer understanding of this, we set up two households with a full gas burner and asked them to use it for all cooking, completely replacing any wood and charcoal they might otherwise have used. One household consisted of two adults and a nursing baby; the other house consisted of five adults and two children. For the larger family, the butane gas lasted about sixteen days; for the small family, it lasted only three days longer at nineteen days. This gave us the general understanding that the Le 90,000 investment will last a family **between two and three weeks when used for all household tasks**.

The Le 200,000 investment was a barrier for many, but the Le 90,000 refills were more regularly mentioned as the exorbitant barrier. When spread over sixteen days, this comes out to around Le **5,600 per day**. This is about three times the daily cost of biomass fuel (Le 2000) for most. One interviewee observed, "I can use a bag of charcoal for three weeks and it'll cost me Le 18,000. I like gas but using up one canister takes me the same time as one bag of charcoal and that costs Le 90,000. I can't do it."

Perceptions about gas are mixed. Many individuals love the gas because it burns (comparatively) clean, doesn't leave soot residue on the pot, is easy to use indoors or on a veranda, and is very fast. However, there is also a deep fear around pressurized gas and its safety. Several accidents in West Africa have led to substantial safety campaigns, instilling fear in a lot of individuals about the dangers of explosion and flame. Others reported they didn't like the smell of the gas, but other than safety, cost was the largest factor in the fact few people used gas.

For all intents and purposes, butane gas is the only improved cookfuel available outside of the capital. The only alternative we came across during our time was kerosene, essentially available only in the capital. As shared above, the 2015 Census report reported an even greater number of kerosene users than gas (Statistics Sierra Leone, 2017). However, our team identified only one source for kerosene, government-run gas station that offered kerosene at Le 8000 per liter for purchase. Through informal but repeated reports, it was believed that the only people that use kerosene in Bo are painters, who use it for their trade, not for cooking. Reportedly, kerosene used to be a relatively common fuel available. People often had kerosene stoves and would cook with it, but they would also light kerosene lamps in their house with it. Once "Chinese lamps" became available—battery-powered flashlights, many of which then gave way to solar-powered flashlights—the demand for kerosene dissolved. The lack of market demand combined with poor infrastructure and corrupt government continued to impact the availability of kerosene until it has now all but disappeared.

Individuals that recalled using kerosene in the past mostly reported that they very much disliked the smell, which would remain around the house and on their hands long after the fuel was used up. They reported a large "orange, blazing flame" which gave off dark smoke, making their pot much blacker than the butane gas would.

k. Freetown

In addition to all of these interviews in Bo, we also conducted 33 interviews in the capital city, Freetown, to gather a picture of how the market might be different in a much larger urban area with greater access to international trade, and higher paying jobs. Our time in the capital was only one day but we managed to interview two wood retailers, six charcoal retailers, 16 wood and charcoal consumers, and nine gas consumers.

Most comparatively well-off individuals in the capital city use butane gas, and those less well-off use charcoal. Gas is cheaper in the capital city, with the price to refill currently reported at Le 80,000 (as opposed to 90,000 in Bo)—likely because transport costs to take canisters upland to Bo are sizeable. This phenomenon is reversed when it comes to charcoal, since charcoal is supplied by the villagers in the countryside. One 50 kilo rice bag in Bo costs around Le 15,000, but in the capital city of Freetown was generally reported at Le 25,000.

Charcoal retailers reported paying Le 25-30,000 for a large bag of charcoal, with the margin between rainy season and dry season being much wider—about a Le 7,000 difference by season, compared to about Le 3000 difference in Bo. Charcoal retailers did not offer a Le 500 size bag, but only sold charcoal in 1000 and 2000 increments—2000 was an increment never observed in Bo. Also, charcoal in the capital is not packaged in "plastics" as often, but instead in baskets—when the woman selling walks past your house and you purchase a basket, she'll pour the charcoal from the basket into your own bag.

Figure 5: Comparative costs of charcoal and gas in Bo and Freetown for 2.5 weeks

The average daily cost of fuel of the 16 individuals surveyed in Freetown was Le 3,000—50% more expensive than the daily estimate of 2000 in Bo (Figure 2).

IV. Stove and Ethanol Feasibility Study

My primary objectives during my visit to Sierra Leone, after conducting the energy market analysis, were threefold:

- Gather qualitative input on people's experience with the Cleancook ethanol stove
- Determine the rate of use of ethanol when used for all household cooking tasks
- Determine a feasible price point for Sunbird's ethanol in the Bo region.

The study did **not** undertake research into purchasing behavior of the Cleancook stove itself, but provided them to participating families for a deposit. Discussion around stove pricing and accessibility is discussed in sections below as well as Appendix B.

A brief outline of the study consisted of the following.

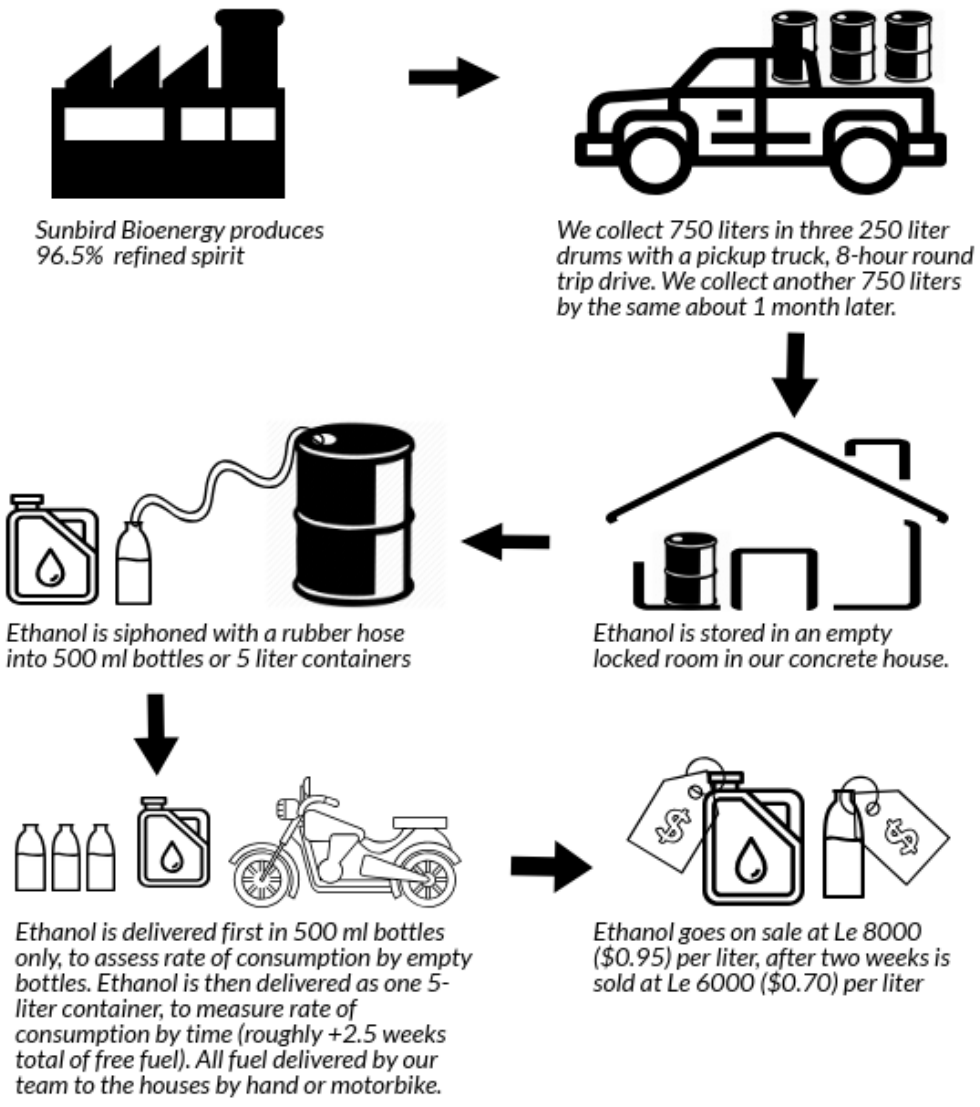


Figure 6: Our study outline (prices are real, not PPP)

After an orientation session that covered background, safety, stove use, and participation requirements, families took the stove home. They received unlimited free fuel for two and a half weeks. During this time, we conducted interviews and surveys to understand their experience with the stoves, and gathered estimates of daily household fuel consumption when using the stove for all household tasks.

After two and a half weeks, we implemented a price of Le 8000 per liter ($0.95/$3.33 PPP). Households no longer had to use the stoves for all tasks, and could purchase fuel as they wanted. During this time, we tracked changes in stove use, and reasons why families didn't purchase the fuel. After that, we advertised a one-week-only discount of Le 6000 ($0.70/$2.45 PPP) per liter, to gauge sensitivity of response. During this week, we determined to keep the selling price at Le 6000 per liter for the final two weeks of the study, and informed users accordingly.

At the completion of our study, we allowed households that had been purchasing fuel to keep the stove on indefinite loan and continue to purchase the fuel for as long as supply could be assured. We were clear from the beginning of the study that the nature of research was temporal and exploratory, and it was highly likely they would be required to return the stoves in the end. Four households were required to return the stoves due to no purchase behavior during the study period, and the remainder are still purchasing fuel, though at a reduced rate, at the time of this writing.

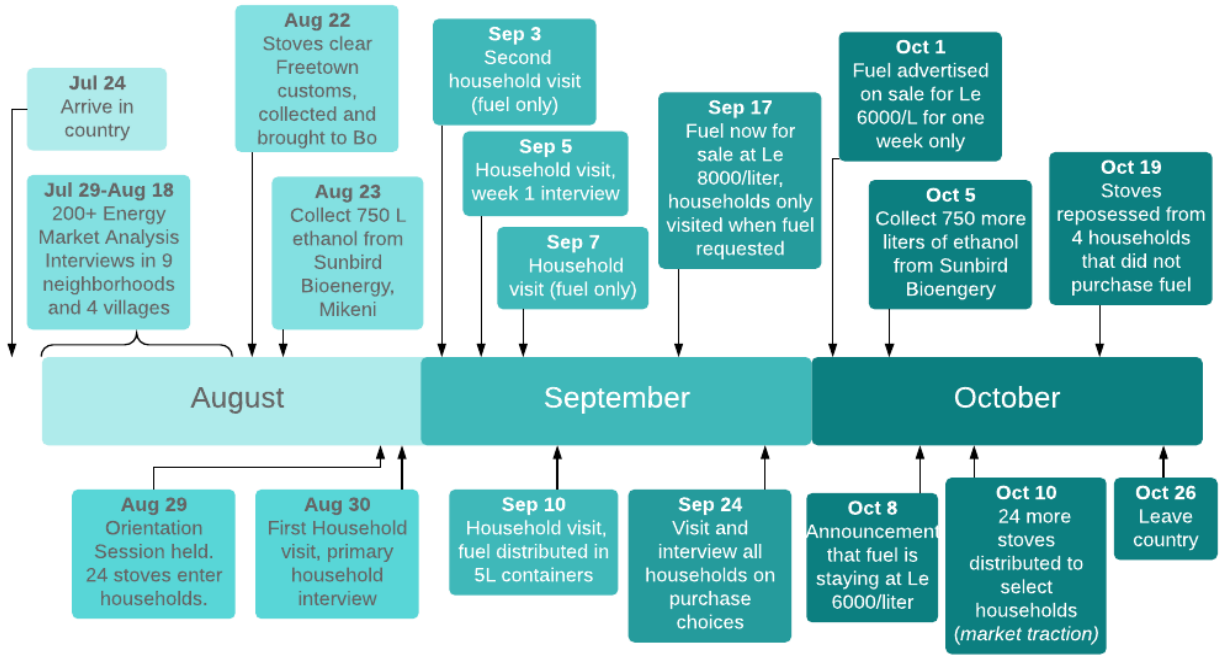


Figure 7: our study timeline

a. The Stoves and Fuel

i. Stoves- Cleancook NOVA 2

For this study, we selected the Dometic manufactured Cleancook NOVA-2 double-burner stove. This was determined to be the most appropriate design, due to its simplicity and efficiency, and its designation as a daily use cookstove (rather than camping, boating or other irregular use). It also had a proven track record of implementation in contexts similar to our project (eg. Benka-Coker, Tadele, Milano, Getaneh, & Stokes, 2018). Each stove weighs 4.2 kg, and contains two burners to facilitate side-by-side rice and sauce cooking. The stove contains two canisters with absorbent ceramic and mesh that take up liquid fuel poured onto them, are drip and spill resistant, and are loaded into the stove from beneath. Single burner varieties exist, including the Cleancook COMET 1 which can be shipped flat and assembled onsite. However, we initially selected the two-burner stove because we had been informed of the regional preference to prepare both rice-and-sauce dishes at once.

CLEANCOOK NOVA 2

Material	Aluminum stainless steel, galvanized steel
Number of burners	2
Weight	4.1 kg
Canister capacity	1.2 L each
Canister Weight	1.60kg full 0.59 kg empty each
Fuel type	Ethanol and/or methanol
Power on high	1.8kW each
Power on low	.3 kW each
Cooking time	4.5 hr each
Average cooking capacity	1 L of fuel per day enables cooking for a family of 5
Efficiency	>60%
Emissions	Negligible soot or carbon. Meets WHO standards for carbon monoxide emissions
Dimensions (WxDxH	608 x 288 x 168
Cost	$55 plus import fees (~$80), includes two canisters

Dometic Canister

Material	Stainless steel and absorbing material
Canister capacity	1.2 L each
Canister Weight	1.60kg full 0.59 kg empty each
Fuel type	Ethanol and/or methanol

Figure 8: Cleancook stove specs

Fifty Cleancook NOVA-2 ethanol stoves were purchased at a discounted price of $40 per stove (retail price $55). They were purchased not from the original manufacturer in South Africa but from Project Gaia NGO, a global leader for ethanol cookstove research in the developing world, who preferred this design above others in similar contexts. Stoves were shipped by air from Project Gaia's office in Lagos, Nigeria to Freetown, Sierra Leone, and transported by SUV to Bo.

We found that the Cleancook stove, when consuming ethanol priced at Le 6000 per liter, is economically equivalent to using butane gas. Details of our gas and kerosene comparison studies can be found in Appendix A.

ii. Ethanol—96.5% Refined Spirit

Sunbird Bioenergy had guaranteed the donation of 2000 liters of ethanol to use in our research, of which we collected 1500 liters in two trips. We acquired four 250-liter drums and took them in a pickup truck to the ethanol plant, an eight-hour roundtrip journey despite the fact it's only 300 total kilometers of road.




Retrieving ethanol from Sunbird; meeting with Andy Gee, Sunbird's transition director

During this time, Sunbird's transition director Andy Gee shared with our team the company's operations and vision. We became more familiar with Sunbird's early initiatives to shift away from sugar cane as an ethanol feedstock source, and move to higher-yielding cassava varieties. Currently, as sugar cane is processed, the plant matter becomes biogas to fuel the neighboring city, and the juice extract goes to ethanol production. Forty-three brix syrup goes to the fermenter for refined spirit at 96.5%, what we used. Their existing estate covers 53,000 square km but they are currently only using about 100 square km and considering outsourcing more of their feedstock operations rather than monocropping themselves (Gee, 2018).

In Bo, we stored the full drums in a concrete room and removed ethanol from the drums using a rubber tube as a siphon system. We siphoned the fuel into 500 ml bottles and 5 liter containers, purchased in the town and clearly labeled with the following labels, either printed in red on white paper or black on red paper:

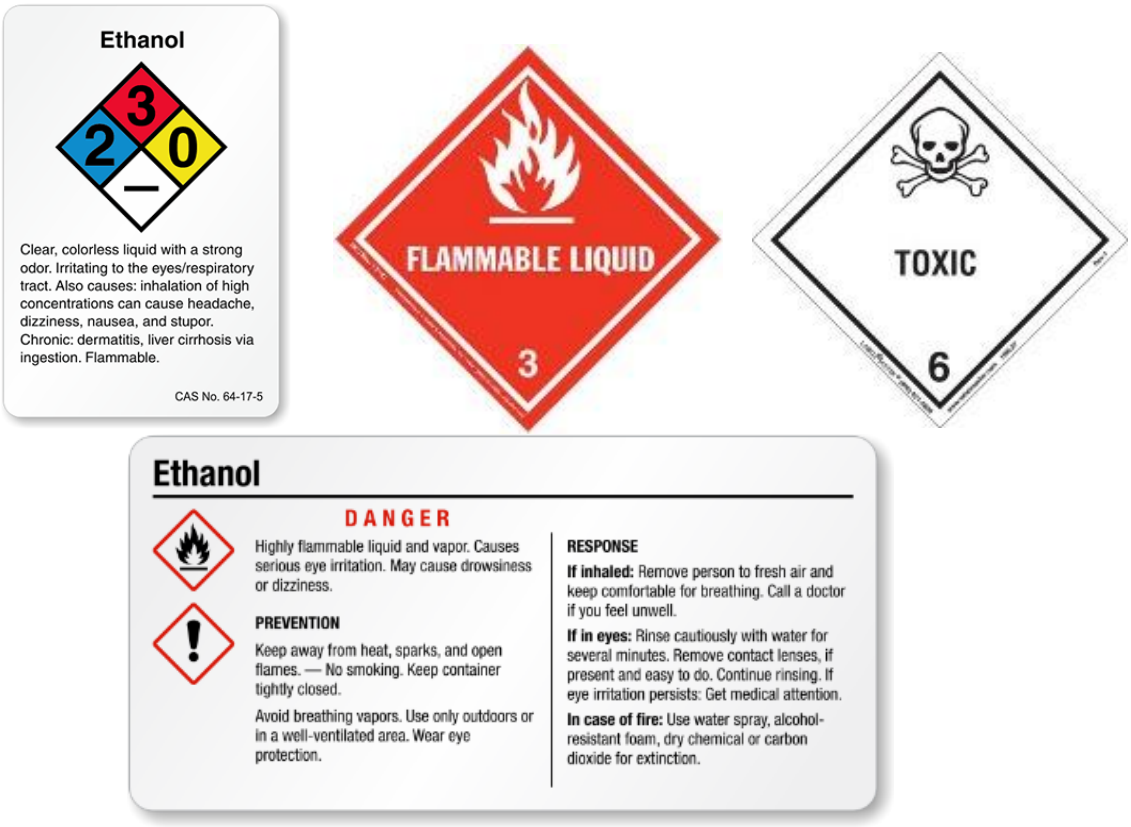


Figure 9: Containers displayed the above labels; testing our siphon system

We were not able to acquire Bitrex, methanol or an alternative chemical to denature the ethanol and render it undrinkable. While this presented a matter of concern, we determined the limited nature of the study and personal exposure with participating households allowed us to provide extensive education on storage, handling, and urgency not to consume it. We experienced no issues

during the course of our study around the handling or consumption of the fuel, but these concerns must be more adequately addressed if the market is to scale up.

Families were given or sold the ethanol in the labeled containers and asked to keep the empty containers to return to us, so we could refill and re-use them. This is common practice in the country and we experienced no issues with this system, other than the anticipated attrition that required the regular purchasing of more containers as the study went on.

Ethanol stored in 500 ml and 5-liter containers

b. Orientation and Phase 1

Due to our limited personnel, we decided to run the study with twenty-four stoves in twenty-four households. To identify participating households, our team hosted an event to draw attention to the study, allowing us to get all twenty-four stoves out into households on the same day. We held this event at an empty restaurant facility adjacent to a popular gathering area for many men in the town. We spread word about the event both through the men at the gathering space, and visiting individual households from our consumer interviews that posed themselves as potentially good participants.

In order to take home a stove and participate in the study, households had to meet the following eligibility criteria:

1. The primary cook for the household had to attend the orientation session
2. Must have a visitable house and working mobile phone number or Whatsapp number
3. Be a household that cooks every day, or almost every day
4. Semi-literate, and good at gauging time in order to adequately fill out the log sheet
5. Able to pay Le 30,000 as a deposit for the stove, which would be returned upon completion of the study, or at any time if they wished to opt out and return the stove
6. Must be in town for the duration of the study, or inform us if they leave town for more than three days.

The outline for our orientation session went as follows:

As Martin was the initiator of the project, he gave the introduction, vision and context for the project. Suley, his friend and our research partner, explained the current problems with biomass fuel and the potential benefits of clean cooking and ethanol fuel. Peter then explained ethanol fuel, what it was and how it worked. We performed a burn test against petrol to show participants how cleanly it burns and how long it lasts, and also to raise and address the safety concern that the flame is almost clear and therefore very hard to see compared to wood fire. After this portion, Ivina, Martin's wife and Massa, Martin's daughter and our research partner, introduced the stove and its features, showed the attendants how to use it and safely load the fuel, and prepared some snacks on the stove to pass around. Lastly, I got up and reiterated again that this was a study—not a free gift, the stoves (at this point) would need to be returned at the end, and that we couldn't guarantee delivery of fuel after the duration of the study. I also explained the log sheet, which we asked participants to complete every time they used the stove. We clarified what would be asked of them during the study, what to expect, and procedures if they wished to take home a stove.

The orientation was very exciting for participants

After the session, if individuals met the exclusion criteria and wanted to participate, they were required to prove to our team that they could safely fill a fuel canister, load the canister into the stove, light it, and adjust the flame size. If they did, they received a stove and provided their contact information, and completed consent and agreement forms. They then received a folder with stove care and safety instructions, a copy of the consent form, a log sheet, a pen and our team's contact information. The contents of this folder can be found in Appendix E.

This orientation proved a success when it came to getting all stoves into households at the same time, greatly simplifying our timeline. It was also important for drumming up excitement and interest around the study. However, in retrospect it was not the most effective way to identify suitable subjects. Because it was held at a local gathering spot, most of the participants were families of men who regularly attended that spot, therefore many of them friends and acquaintances, and in most cases undertaken because the men were excited about the new technology. Only about two thirds of the people who left with stoves were the primary cooks of the family, despite its requirement as inclusion criteria. The remaining one-third of men insisted they would show their wives how to use it, or insisted to us that they cooked for themselves. Because these men were friends of Martin, I was not in a position to deny them. In most cases this turned out fine, but in two cases turned out to be problematic.

Additionally, the excitement rendered the latter part of the orientation rather chaotic. This made it hard to clearly communicate the tasks that were actually required of each household, that this was indeed a research study and they were participating of their own volition, and would likely need to return the stove at the end and receive back their deposit. Despite our repeated insistence, we were left with the feeling most households walked away perceiving that they had secured a free gift.

We followed up the following day with personal interviews at each of the participating households. We asked to see where they stored the fuel and stove to ensure safety, provided more fuel to them, made sure they understood how to use the log sheet and what to expect as part of the study, and conducted the initial household interviews. Standard Operating Procedures for this first visit can be found in Appendix F, and copies of interviews for the households can be found in Appendix G.

One week later, we returned to the house to perform a second, short user interview to identify their fuel use over the week and collect additional thoughts and input. The following sections below—Household Characteristics and Qualitative input—are excerpts from these two interviews.

c. Household Characteristics

i. Education

Of the participating households, all women and men possessed a significant level of education. All men and women interviewed had at least the equivalent of secondary level 2, roughly the equivalent of 7th grade. Most had completed their primary and secondary schooling. Two women reported going into vocational programs, others university, others certificate programs. These levels are significantly higher than the average education for most consumer interviews with biomass and charcoal, suggesting higher level of comprehension, ability to engage with new technologies, use the log sheet and possibly afford the deposit.

ii. Income and Assets

Because some households were friends with our research team, they were not always comfortable sharing their income levels when asked. We were unable to gather any information for three of the 25 households, and in two cases the woman interviewed didn't know how much her husband made, but could share with us that he would give her Le 20-30,000 ($2.30-3.50/ $8-12 PPP) per day for "keeping the house" which primarily meant cooking. Assessing income proved to be tricky because of the irregularity of income (for example, a diamond miner reported he received nothing for months, then three million for one find), and whether or not they reported remittances from loved ones. Mostly however, as was mentioned in prior sections, people simply don't take account. We gathered roughly that four of the households reported making over Le 100,000 ($11.80/$41 PPP) per day; six reported making between 50,000 and 100,000 ($5.90-11.80/$21-41 PPP); and nine reported making between Le 10-50,000 per day ($1.18-5.90/ $4.15-21 PPP).

Another metric to measure income was asking about valued assets; the most popular reported asset was a television (12 households), followed by freezer or refrigerator (11; though none of these houses have consistent power supply), possession of a house or land or currently constructing a house or commercial kitchen (6). Four houses owned their own vehicles. One woman insisted on reporting her most valuable asset as "I am very proud of my own self… to be a vibrant, strong, hardworking woman!" We observed she owned a television and her husband was in the process of buying a used motorbike. According to the 2015 census, only 19.8 percent of households owned a television, and 10.3% a refrigerator or freezer. It may therefore be reasonable to say the majority of our households were in the upper 20% of the population (Statistics Sierra Leone, 2017).

Typical jobs possessed by the men (and sometimes also the women) in these households included: NGO workers, teachers, small businesses, contractors, construction, miner, engineer. Some of the women worked as teachers or operated small businesses.

iii. Family size

Household sizes ranged from two adults to 14 individuals—five kids and nine adults. The median family size was 5.5 individuals, and the most common family size was five individuals (six households). In two households, children outnumbered adults; in two, the adult to child ratio was equal; in two we could not acquire data. In the remainder of households, adults outnumbered children by one or more.

iv. Cooking habits

Every household reported either cooking their food in their stand-apart kitchen or on their veranda. Only three of these households shared that they cooked with wood; the remainder cooked with charcoal. Twenty of the twenty five households reported some experience with either a gas or kerosene stove, and six households owned a gas stove at the time of this study—though only three were actively using it due to either high reported cost, or being afraid of it. This was in contrast to the fact only five of our 52 regular charcoal and wood consumers had experience with gas, and further evidence of the higher socioeconomic group we were working with.

d. Qualitative Input

Overwhelmingly, user feedback regarding stove use over the course of the first two weeks was impressively positive. By far, the greatest observation was how fast it was. Nine of the twenty-four households overtly referenced the fact it was "*fast fast*" to light, boil water, and cook food. Other primary positive observations included:

- how clean it was
- that it gave off no smoke or fumes when burning
- that they didn't have to dirty their hands with charcoal
- its portability and ease of handling
- the feeling of safety knowing that it wouldn't explode like a gas canister might

One woman would use it atop a table, and she reported that she appreciated standing up when she cooked and not having to crouch or kneel down consistently. While not overtly reported besides that, this was observed in many households—women would use the stove standing upright or sitting in a chair rather than crouched on the floor or short stool when using a coal pot.

Households reported favorably when using the stove and fuel

The primary negative feedback revolved around the smell of the fuel and the need to keep the fuel stored safely. One astute observer insisted the stove used fuel too quickly and would not be economical or financially feasible. This was in contrast to most households who were too excited about the new acquisition to give it proper time to critique it. Two individuals reported the burners were too close together to put two large pots on at one time, so they needed to be further apart. One woman determined that boiling a large amount of water or preparing a large amount of food takes longer on the stove than it would on a wood fire.

There were concerns about the appearance of the fuel as well, that despite labeling and smell, it clearly looks like water and could be misused by children or mistaken adults. One woman insisted that the pot would not boil evenly, and that the right burner burned faster than the left. There were also two reports of dissatisfaction that the stove still blackens the bottom of their pot, though only slightly, and the reporters did not seem overly disappointed or upset by it—just keen to let us know.

Fears and questions that were raised after the first week of stove use included:

- *can I use my cell phone when I'm using the stove?* (Gas stations throughout the country still have posted signs insisting no cell phone use in the vicinity)
- *It's made of metal—can I use it in a lightning storm?*
- *Can I use it in the hot, direct sun?*

The primary feedback when asked "do you have any additional questions about the stove or fuel at this time?" consistently was, *"where will I get this fuel from when you go?"* and despite our daily explanations that it was a six-week study with no guarantee of continuing, the same question would arise every visit. Additional observations and feedback in the first two weeks included:

- The fuel canisters should be bigger, so they don't have to be refueled as often.
- A one-burner stove would be more economical.
- Concerns around the chemicals and content in the canisters
- Belief that selling the stove, even at a high price, would be very easy as long as the fuel was readily available
- How can I clean it?
- All my neighbors are asking where I got it! Please don't take it away at the end.
- "If a stranger visits, you can prepare food fast!"
- Thick pots aren't as economical because they take longer to warm up- tell people to use thin pots
- The regulator is crucial because food will burn
- "very, very unique"

Everyone said the food tastes the same as when they cook it on wood or charcoal, except for two families that said it "tastes even better on the stove!"

Most families cooked with the stove either on their verandas or inside their house on a table or coffee table. Many of them stored it in their bedrooms or behind a locked door when not using it.

Families would use palm frond strands from brooms to light the stove by lighting them with a lighter and placing the lit end into the metal chimney where the ethanol was.

e. Fuel Consumption Rates

After qualitative feedback, our second primary goal was to determine how quickly families used the ethanol. Harry Stokes, CEO of Project Gaia NGO, shared with us anecdotally in an interview that based on their studies in Nigeria and Ethiopia, "richer families tend to use more than one liter per day, poorer families less than one liter per day". We had assumed that because Sierra Leonians ate only one meal per day, their use would be comparatively low. This may have been the case if we'd shared a single-burner stove, but the double burner stove facilitated use and therefore also facilitated fuel consumption.

We gathered estimates of fuel use in four different ways:

1. **When visiting the households, we would drop off 500 ml bottles and collect any empty bottles they had, and record these with each visit.** This proved to be somewhat effective, though as part of the household visits research teams would also top off their canisters with fuel as well, to make sure everyone had enough fuel before the next visit. Different researchers visiting different households would do this differently, with some measuring how much was left in the canisters before filling, some not, and some not topping them off if the stove was currently in use during the visit. Because of this inconsistency, this method of collection—which should have been the clearest—was somewhat foiled. However, we came away with a mostly reliable understanding for each.
2. **We asked the households how much fuel they added and how often.** This proved to be a relatively reliable method with all houses answering somewhat clearly, and someone consistently with the amount of fuel they used that we gathered. Because two bottles equaled one liter, and there were two canisters in the stove, this led to some confusion with reporting—for example, some said "I add two bottles every day". We would have to clarify, is that two bottles in *each canister*, one in each canister, therefore two into the stove in general? Most instances this was sorted out pretty clearly but did lead us to tighten up our rhetoric and measurement metrics (bottles vs. liters, canisters vs. stoves, etc.)
3. **We gave them a large 5-L container of fuel** and filled their canisters—leaving each household starting with 7 liters total—and tracked how long it took each family to run out. This proved to be very reliable for all families that ran out before we began to charge for fuel, at which time if a family had remaining fuel we would make a note of how much was left at the time, knowing they would begin treating it differently now that we were charging.
4. **We checked their log sheet—**but this fourth method of determination was quickly neglected, and therefore not shown in the table below, as it soon became clear that their log sheets were unreliable in all but a few cases.

i. Table 1: Fuel use by household

The table below lays out the findings from the metrics reported above. The final column is the assumed average use per day. In instances where two of the three metrics appear consistent, we used that metric as the final assumption. In instances where they all three varied, we averaged the metrics to gain our final measurement. X's represent information we were not able to reliably gather.

Stove No.	Household size (age adjusted; 1 child = 0.5 adult)	Avg. L/day based on empty bottles collected	Avg. L/day based on self-report in interview	Avg L/day based on 7L across x amount of days	**Avg. L/day based on previous three metrics**
2	6	0.6	0.6	0.5	**0.6**
3	3.5	0.62	1	1	**1**
4	2	1.25	0.8	1.4	**1.2**
5	11.5	1	2	>1	**1.5**
6	4.5	1	0.5	0.5	**0.5**
7	2	x	0.5	0.42	**0.5**
8	2	x	0.4	x	**0.5**
9	2	0.62	1.3	>1	**1.1**
10	4	0.4	0.4	x	**0.4**
11	8	1	0.5	0.42	**0.5**
12	x	x	1	x	**1**
13	x	x	x	0.8	**0.8**
14	7	1	1	1.75	**1**
15	10	1.25	1	1.4	**1.2**
16	4	1	1	1.16	**1**
17	9	1.25	0.75	0.67	**0.9**
18	6	1.25	2	1.4	**1.6**
19	5.5	0.5	0.5	0.64	**0.5**
20	5	x	1?	x	**1**
21	4	1.5	1?	0.57	**1**
22	5	1?	1	x	**1**
23	6.5	2	1.6	1.16	**1.6**
24*	4.5	0.5	0.5	0.4	**0.5**
25	x	x	x	x	**x**
26*	7	0.25	0.25	0.42	**0.25**
				Avg. all:	***0.9 L/day***

*Figure 10; *stoves were observed or reported not being used for all tasks*
***stove 25 was not participating in the study*

Using these rough metrics, we find that about 10 households use less than a liter per day (0.4-0.8 Liters); eight households use almost exactly a liter a day (0.9-1.1 liters); and five households would use more than a liter a day (1.2 – 1.6 liters). These metrics are roughly consistent with Mr. Stokes' comments of use in other countries, and served as a metric for us to understand the feasibility of this fuel to displace charcoal and wood.

In trying to determine per-individual fuel consumption, we reached similar inconsistencies as with biomass fuel—that family size has little effect on fuel consumption. The graph below is age-adjusted household size against fuel consumption rates. Children are counted as 0.5 of adult.

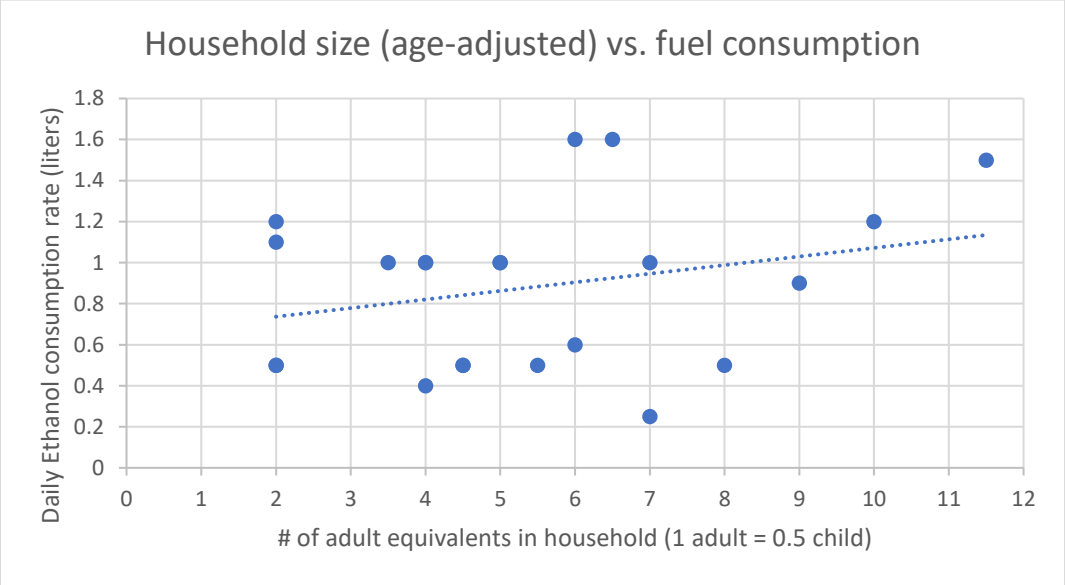


Figure 11: Like biomass fuel consumption, the rate of ethanol use to household size was weak

If we were to average rates, this would result in **the per-person daily use of 0.2 liters of fuel per adult and therefore 0.1 liters per child**. However, because of the physics of the stove, as well as the fact fuel is often used for boiling water to make rice, sauce, etc., it's unlikely an individual person could use that little for their household needs—0.4 liters per day would likely be about the reasonable minimum.

ii. Table 2: Costs per day for 100% biomass replacement

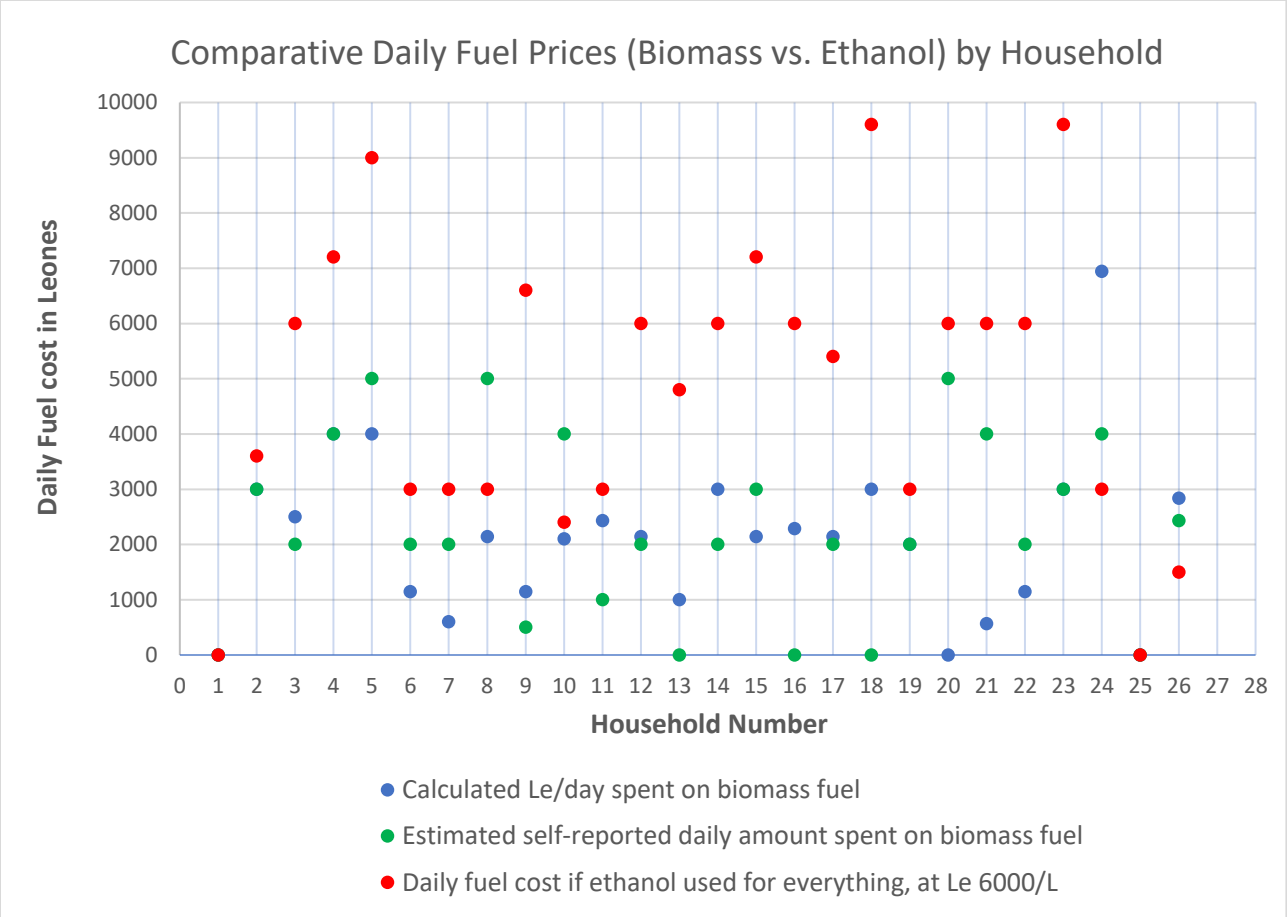
Below are a comparison of household's biomass fuel use and costs against ethanol fuel use and costs (Figure 12; pricing discussed more in next section).

The blue points, calculated biomass expenses, were derived from the initial interview. For example, information such as "I buy one large bag of charcoal and it lasts me two weeks" allowed us to do the math for the actual daily average amount. The green points were their self-reported daily biomass fuel costs, and were meant to gauge what they *thought* or *felt* they spent on biomass fuel per day, compared to what we calculated. It was their response to our question of "how much money do

you spend on charcoal (or wood) per day?"—most of the time, they weren't sure and simply took a guess. The red points are each household's average ethanol fuel consumption from the table above; it is important to note the fuel at this point is free, but it's shown here as if it had a cost of Le 6,000 ($0.70/$2.45PPP) per liter. In this way, it does not reflect real use rates but rather the cost of use if it *were* to be used to replace biofuel for everything.

In four cases, it's possible that ethanol fuel is roughly the same price, or even cheaper, than the fuel they're currently using. For all other cases, fuel is at least 50% more expensive, and in other cases more than 200% more. This can be readily observed by the elevation of the red points, the daily consumption of ethanol fuel, above the blue and green points—calculated and reported daily household costs of biomass fuel.

Figure 12: Comparative daily fuel prices for ethanol vs. biomass fuel



The above graph was generated from the table on the following page. Green boxes are the instances where ethanol would cost the household roughly the same, or less, than biomass fuel.

Stove Number	Fuel Choice	Calculated Le/day spent on biomass fuel	Estimated self-reported daily amount spent on biomass fuel	Daily fuel cost if ethanol used for everything, at Le 6000/L ($0.70)
2	coal bag or plastics	3000	3000	3600
3	plastics and gas	2500	2000	6000
4	wood and coal bag	4000	4000	7200
5	coal bag	4000	5000	9000
6	coal bag	1142	2000	3000
7	coal bag	600	2000	3000
8	coal bag	2142	5000	3000
9	coal bag	1142	500	6600
10	coal bag or plastics	2100	4000	2400
11	coal bag and wood	2428	1000	3000
12	coal bag and gas	2142	2000	6000
13	coal bag	1000	x	4800
14	coal bag or plastics	3000	2000	6000
15	coal bag	2142	3000	7200
16	coal bag	2285	x	6000
17	coal bag	2142	2000	5400
18	coal and wood	3000	3000-5000	9600
19	plastics and gas	2000	2000	3000
20	coal bag	x	5000	6000
21	coal bag	566	4000	6000
22	coal bag	1142	2000	6000
23	wood and coal bag	3000	3000	9600
24*	coal bag and gas	6944	4000	3000
26*	coal bag	2833	2428	1500

*Figure 13; *these households observed or reported not using the stove for all tasks*

f. Phase 2: Instilling cost

After 2.5 weeks of free fuel, families were informed they no longer had to use the stoves for all household tasks, but could use it as much or as little as they pleased. Ethanol was now for sale at the set

price of Le 8000/L ($0.95/$3.32 PPP), and families would need to call or Whatsapp a member of our research team to request fuel. Just as before, our research team would deliver fuel to participating households.

When Martin had first proposed the project, he had cited $1 per liter as an estimated feasible amount to charge for the fuel; at that time (March 2018) $1 was equal to Le 8,000. Since then, and during the time we were there, the Leone had weakened to a rate of $1= Le 8,450 (currently it has further weakened to Le 8,800). At the time we hadn't determined all moving costs of an ethanol business, and because petrol and kerosene were Le 8000 (a fixed price set by the government), it made sense to us to introduce the fuel at this rate as well.

i. Behavior and responses under Le 8000 ($0.95) pricing

After announcing the new phase of the study, we noted that 9 of the 24 households still had small amounts of remaining fuel left in their 5L containers, so we recognized they might not purchase fuel within the first few days. The first week, we had eight households purchase fuel. Six of the 8 households purchased the large 5L container for Le 40,000 ($4.72/$16.50 PPP), even though we offered the option to purchase fuel in any amount. We had heard nothing from the remaining sixteen houses, despite overwhelmingly positive compliments on the stove the prior two weeks.

Knowing that any non-zero price could feel expensive, after one week of sales we interviewed all households again. Surveys primarily explored why households did or did not buy fuel. *Note: At this time we also enquired further about the stove's use as compared to using butane gas, as it had become apparent that the .9 L average use rate meant that the fuel could not displace wood and charcoal in the Bo region and would therefore be treated more like gas. Most households preferred the ethanol to the gas because it felt safer. Responses on which "felt more expensive" were mixed—half said gas would cost more and about 1/5 said ethanol more, and many couldn't tell. In brief, ethanol at Le 8000/L ($0.95) would not be competitive with gas; ethanol at Le 6,000 ($0.70) would be. Our gas/ethanol comparison study can be found in Appendix A.*

Of the families that hadn't purchased fuel by the end of the first week, five reported they still had fuel left over from their 5L container, which suggested their stove use at this point was negligible and they were trying to make their remaining fuel last as long as possible. Two reported that they were saving money to purchase the 5L container, despite the fact we made it clear they could purchase any amount or size, and it was not a "better deal" to "buy in bulk". Two reported being out of town for the week, despite the fact they had signed an agreement not to be. One reported that the text and home visits explaining pricing and next phase-of-study information had not reached the head of household, and that they would relay the message. Three reported that the fuel was simply too expensive, or the stove used it up too quickly to make it worth it. One family had needed to put spare funds toward car payments. This implementation coincided with back-to-school week, and one family reported that their spare money had to go toward school supplies for the kids (note these responses add up to more than sixteen; some households gave several reasons).

During this interview, we also asked what price people thought was a fair price-per-liter of ethanol. We recognized such a straightforward question couldn't accurately determine behavior, but

with such a small-scale study we knew we weren't getting pure market behavior anyway. Eight respondents said Le 4000 would be a good price for the ethanol. Three respondents said Le 5000 for a liter, and five said they would manage with the price at Le 6000 per liter. Nobody voiced Le 8000 as a reasonable or sustainable price.

The second week, seven households purchased fuel, in amounts ranging from 1.5 liters to 5 liters. Of these seven, only one buyer was a repeat from the prior week. This means that by the end of the two week period of price implementation, a total of 14 out of 24 households, or 58% of households had purchased some amount of ethanol for their stoves for Le 8000 per liter, for a total of 59.5 liters sold.

Overall, once pricing was instilled, behavior immediately emulated that of using a gas stove. The suddenly valuable fuel was saved for specific tasks such as boiling water, frying an egg, or preparing the baby's food, and other small tasks for which lighting a fire was considered excessive trouble. Like gas, it was considered wasteful to use the stove to prepare rice and sauce for the main meal each day, even by the participating households that had comparably high incomes.

ii. Behavior and Responses under Le 6000 ($0.70) pricing

After two weeks of pricing at Le 8000, we announced via text message and Whatsapp that for one week there would be a 25% discount, and liters would be sold at Le 6000 ($0.70/$2.45 PPP). We were interested in determining sensitivity to price adjustment and response. That first day we announced the discount, we had five households request fuel; four asked for the 5L container that was now priced at Le 30,000 ($12.50 PPP) and one asked for 2 liters. Within two days, almost half the households had expressed interest through a text or phone call, which was almost as many as the total households that had purchased over the course of the first two weeks. We had four orders later in the week, bringing to total amount of purchases to 9, or 38% of households. Two of these nine households were individuals that hadn't purchased any fuel during the two weeks of Le 8000 pricing.

Predictably, many individuals were thankful for the price decrease and in general it seemed to be perceived as a "reasonable" cost as opposed to an "exorbitant" one. This certainly may have simply been because of the higher price quoted initially. **When we added up liters sold across weeks, we had sold only slightly more per week—32 liters per week when at $0.70 and 29 per week when at $0.95.** Had we set Le 6000 from the beginning, it would have been interesting to know if the response would have been different. Our participant size was too small to implement different prices for different households and compare.

After some discussion, we decided to stabilize the price at Le 6000 for the remaining two weeks of the study, during which time we made ten further sales. It had been reported to us by Sunbird that a possible out-the-gate price for ethanol could be Le 4000 or 5000 per liter, so we did not consider offering any price below Le 6000 because distribution operating costs would likely be considerable and necessitated a margin of at least Le 1000/liter.

Figure 14: Total sales by price and day

2- week timespan	Liters sold at Le $0.95	3- week timespan	Liters sold at $0.70
18-Sep	16	1-Oct	22
19-Sep	10	3-Oct	15
22-Sep	7.5	6-Oct	15
23-Sep	2.5	10-Oct	7
25-Sep	2	11-Oct	7.5
26-Sep	4	12-Oct	5
27-Sep	5	16-Oct	15
29-Sep	12.5	17-Oct	7
		18-Oct	5
sold total	**59.5**	sold total	**98.5**
per week sales	**29.75**	per week sales	**32.83**

In the end, five of the 24 households had not bought anything, and five households had only bought once. The remaining houses bought at least twice. Of the houses that bought, households purchased an average of 8.6 liters over the course of five weeks, hardly enough to do more than boil water as this amounts to about a quarter of a liter a day. However, participation was highly varied (one house buying 20 liters, one buying 1.5), so averaging across households may not be an appropriate mechanism. The most often purchased amount among participants over the five weeks was ten liters, which would be two liters per week. The median cumulative purchase was 7.5 liters, 1.5 liters per week.

Figure 15: Cumulative sales responses

Of 19 households that purchased fuel:	Cumulative purchases (L) over 5 weeks	avg. per week
mean fuel purchased	8.6	1.72
most common fuel purchase*	10	2
median fuel purchase	7.5	1.5

***these households purchased the 5-liter container two times over the 5 weeks.**

g. Market Traction & Wrapping Up

Our team had varying opinions on how best to conclude the study and move forward. One team member felt re-collecting the stoves would be a reasonable course of action as the stoves could then be used in similar or alternative studies in other parts of the country. Other team members wished to continue delivering fuel to participating households, as we still had over 600 liters in supply. Ultimately, however, it was Martin's initiative. Having discovered where the fuel sat in the local economy, he

wished to move away from research and into building a more targeted market for the remaining stoves and fuel.

Martin was keen to continue to build on what we'd started rather than end it and re-assess. In his mind, not collecting the stoves back allowed for momentum to continue, and most of the participants were equally keen to see it continue and desired to keep the stoves. Therefore, households that had been purchasing fuel were allowed to keep the stove on indefinite loan. Not selling the stoves absolved Martin of responsibility to provide fuel should challenges arise when or if he went to resupply with more fuel. Sunbird had agreed to donate fuel for research, and agreement to sell ethanol to Martin out-the-gate and set up a market had yet to be confirmed at the time. It also allowed him the freedom to request back the stoves at any time if he wished to use them in research or market traction elsewhere.1

Martin decided that households that kept the stoves were required to continue purchasing fuel at the initial and very low threshold of 1 liter per week, to which all households were happy to agree. Four participants had purchased no fuel during the course of the study, so these stoves were repossessed and the deposit returned. All households where stoves were repossessed had reported the fuel costs were "unmanageable".

Martin was keen to move into what he called a *Market Traction* phase. He hand-picked an additional twenty individuals who were officials in the town, NGO workers, and other friends of his with high-income jobs and high willingness to pay. All of these selected were men, and it is not clear to what degree they planned to share the stoves with their wives or families. Martin began this phase about two weeks before the study ended, and the additional twenty people selected purchased fuel at a noticeably faster rate and in larger amounts than the twenty-four in the study. By the time we left the country, forty-three stoves were in households: twenty from the study, and twenty three through market traction.

Martin and team have since decided to move to a provide-your-own container system, where customers can bring their own bottles, jerry cans, and other containers for filling with ethanol. This move raises substantial concern from a safety perspective, though it is a very common practice within the country. Gas stations fill water bottles and jerry cans with petrol; it is commonplace in the country to put palm wine in motor oil containers, and motor oil in liquor containers. The market for single-use plastic bottles is thriving, and it's almost guaranteed that whatever is inside a container is not what's on its label. This leads to inherent attentiveness amongst the community when opening bottles, and is a process that is culturally relevant. However, despite the fact it's a culturally familiar practice, unlabeled chemicals are inherently matter of legitimate safety concern.

h. Observations from the study

i. Product packaging and sizes

One key observation from our initial energy market analysis was a common preference for buying all consumable products in very small quantities for single use. This is because of financial necessity, perishability of fresh food, and simply a cultural practice. In many ways this appears the opposite of the American cultural preference for buying in bulk at reduced cost, and so we initially

adapted our ethanol sales technique, primarily packaging fuel in 500ml bottles only rather than the 5L containers as we planned. However, once fuel sales began, and especially toward the conclusion of the study when we introduced the market traction phase with selected buyers, this relationship inverted. The customer base shifted to higher income men who worked longer hours and thus had less time to spend making purchases, but relatively more purchasing power. This customer base was comfortable buying large quantities of ethanol to save time.

In addition, the double burner design of the Cleancook NOVA-2 proved to be inappropriate for this market. Although families use two fires to cook, very few of our research participants used ethanol for proper cooking and instead only used one burner for quick tasks like boiling water. This suggests a need for a different stove model for this market, a smaller, cheaper single-burner option. The COMET-1 or a locally assembled stove could prove more affordable options. The Cleancook NOVA-2 could be a good option for the capital city, where a greater number of individuals prepare all their food over gas (and would therefore be likely to prepare all their food over ethanol).

ii. Gender

This project was a token example of the challenges of introducing technology into the developing world market. In general, technology is considered a man's enterprise. Many of the families that received stoves did so because the male head of household was very interested in the technology and wanted either to use it himself or simply have it in his house. It's clear that in most cases this stove is a technology that the women loved, and they reported it made their lives easier and better. However, the gateway to the technology, even in our study and despite my efforts, was through the men. Because ethanol was a pricier purchase than biomass fuel, women often had to consult with their husbands and entreat them to buy more fuel for the stoves. Until women are afforded more power with the purse strings, it may be hard to build a flourishing market for the fuel.

Women are the cooks in the families; it is rare to see men cook

Women across the board reported loving it, except for two cases. One particular woman said being anywhere near the fuel made her feel queasy, drunk, and developed a headache. Another woman avoided using the stove as much as possible because she hated her husband, and he had introduced it to her—so she didn't use it because she was asked to use it at his directive. In both these cases, the

husbands insisted in keeping the stoves in the house, and used them for themselves to boil water and perform small tasks.

An interesting dynamic arose within our research team as well. One researcher was friends with many of the men who had attended the session with or without their wives and obtained a stove, and remained a staunch advocate for the male participants. He argued that it's fine for the men to express interest and use the stoves in whatever ways are most useful to them, as that's likely what would happen in the market. Another researcher was not friends with these men and generally considered them untrustworthy and not good candidates for study. She regularly would report frustration with their behavior, that they were being dismissive in interviews or selective in when and who could use the stove. When Martin started his market traction initiative, most individuals I observed coming to pick up a stove were men.

iii. Where to sell?

In our week five interview, we asked participants that if a market were to emerge, where they think would be a natural place to buy the fuel from, as we would only deliver it to their houses during the study. Overwhelmingly, the response was "gas station", with many also reporting "supermarket". These are the two places gas users can exchange their canisters, so it made sense individuals considered this fuel in the same way. Two houses requested to have it in the regular marketplaces, but one household astutely observed that "I don't think petty traders could keep it safe". One individual suggested that certified dealers go to the fuel stations to pick it up, and could then deliver it to specific households or sell it in neighborhoods. Overall, it was clear most people perceived its high cost and flammability as therefore very similar to gas, and should be sold according to the same systems the gas industry has set up.

iv. Alcoholism

Thankfully, we experienced no abuse of the ethanol during the duration of our study. A large part of this was our overt urging of individuals not to drink it, and us telling them it would make them very sick. At no point did we explain to households that the fuel is highly concentrated refined spirit, and that it could very easily be watered down and consumed. However, it is only a matter of time before someone understands this and makes the information readily available. For this reason it's critical to introduce some kind of denaturing agent as soon as is feasible. Suggestions for appropriate denaturing agents can be found in the 'recommendations' section below.

Martin had hoped to see local villages produce the ethanol with a "traditional" distillation system, but the rough and unscientific nature of the practice could not efficiently yield anything much higher than probably 55%. A study in Nigeria yielded similar results (Ohimain, 2015), and there is a further gender-based concern. Distillers in villages currently can refine palm liquor to ~40% and drink it, and they can sell 5 liters for Le 30,000—exactly what we sold Sunbird's ethanol for. If this is the case, where will be the motivation to distill it several more times—far more work and resources—in order to sell it for the same price or give it to their wives to cook with? It's unlikely that refined spirit over 90%-the quality needed for the cookstoves—can and will be produced at the village level.

Receiving a tour of a "traditional" village distillation system

V. Recommendations for Moving forward

From this study, we have determined that further probing into a domestic market for Sunbird's ethanol is a viable option and certainly encouraged. Throughout much of the country, however, the fuel would not be able to displace biomass fuel and would be more competitive with the gas market. We estimate the most viable markets for the fuel would be in Freetown, due to the high concentration of a population that possesses significant ability to pay, followed by Mikeni, due to the short distance and therefore low transportation costs from Sunbird to the market.

Recommendations are intended for Sunbird Bioenergy, the only viable supplier of ethanol for cooking at this time, though are also relevant for Martin Kailie, Project Gaia NGO, or any other organization that might partner with Sunbird Bioenergy for ethanol distribution and delivery.

a. Safety

- Despite the fact this isn't common practice in the culture, ethanol should only be stored in labeled containers. These can and should be reusable, with participants able to return and refill designated containers. However, we recommend distributors not take on the practice of filling unmarked containers as is common practice at gas stations. At the very least, do not fill clear containers as the substance appears identical to water.
- The addition of denatonium benzoate (Bitrex) or another alternative to deter drinking is critical. Methanol is highly discouraged as excessive consumption can lead to blindness. Bitrex would be preferred as the highly unpalatable taste has proven successful in precluding abuse.
- Bitrex can be removed through further distillation, so third-party distributor partnerships should be well-vetted and monitored to ensure they are not subjecting the denatured ethanol to further distillation.
- Stoves should be sold at designated stores, and anyone wishing to purchase a stove should sit for a safety orientation on how to load and manage the stove and fuel.

b. Market for Ethanol

- The majority of individuals surveyed suggested ethanol be available at petrol stations or supermarkets. Separate stores for both stoves and fuel appear to be a viable option, and also selling butane gas setups could be a useful for tapping into the same market.
- Ethanol containers could be sold sealed, and empty containers returned and re-sealed
- As mentioned above, individual canisters could be filled, but should be appropriately labeled
- Due to rate of consumption, it would not be worth selling ethanol in containers smaller than one liter. The 5L container proved to be a familiar and preferred size, and is the largest recommended size for ease of pouring. Larger, jerry-can (20+ L) sized amounts were requested, but an intermediary container would need to exist as one could not load the stove canisters safely from a container that large.
- Transportation is by far the largest cost, as petrol costs Le 8000/liter. For this reason it would make sense to transport ethanol in large drums or tanks, and transfer into intermediary containers on-site, in order to reduce transport of small containers and other weight. Also for this reason, it's likely that fuel will be more expensive the further it travels from Sunbird.

c. Market for Stoves

- Carbon financing initiatives for developing markets exist, which could cover the cost of Cleancook or other ethanol-burning stoves and make them available to Sierra Leonians for a reasonable cost. Anyone initiating the stove market for this would be remiss not to look into this option, as it's likely the only possible way an imported stove could be made available.
- As mentioned above, Cleancook's canisters can be bought for $8. With shipping and import costs this would likely be just over $10 for a canister, which, combined with a $2.35 stove made locally, could be a reasonable cost for middle and upper income Sierra Leoneans.
    - The capacity within the local stove market for building stove bodies is definitely present, and a well-defined prototype could serve as an excellent design for local stove makers to copy.
    - Stove canisters could also qualify for carbon financing, further lowering the cost of this locally made option.
    - This direction could provide jobs for many local stove makers and continue to keep the market somewhat domestic.

VI. Business outlines for local distribution

Based on the positive qualitative reception, and the ethanol's clear competitiveness with butane gas when sold at a pricepoint of Le 6000 ($0.70/$2.45 PPP) per liter, we believe a feasible market for the fuel can exist at this pricepoint in the capital city of Freetown and in select urban areas outside of the Western Area. Because the product is currently being sold at over $1 per liter to the European market,

the local market will not present as large a profit margin as the developed world market. However, expenses could be saved in transportation costs, as well as contributing to environmental and health benefits in the immediate environment. Startup funding from external sources such as UKAID, Global Alliance for Clean Cookstoves or carbon financing initiatives may be required for the success of this endeavor.

While the below numbers are very rough, we propose the following as a feasible growth projection over the course of time. Sierra Leone has a population of 7.1 million, with an average of 8.8 individuals in each house and 1.6 households in each house (Census 2015). Therefore, a target of 80,000 households would represent about 1/10 of the country's households, and could be a reasonable market size for the stoves and fuel as this was roughly the number of households that used some version of improved cookfuels in the 2015 Census. If these households purchased fuel at a rate of 2 liters per week, the amount required for quick jobs like boiling water and frying eggs, this would be a supply requirement rate of about 160,000 liters per week. If they purchased at about 7 liters per week, an estimated amount for most all cooking and proper displacement of biomass fuel, this would represent a necessitated supply of about 560,000 liters per week.

We propose the following distribution process (Figure 16):

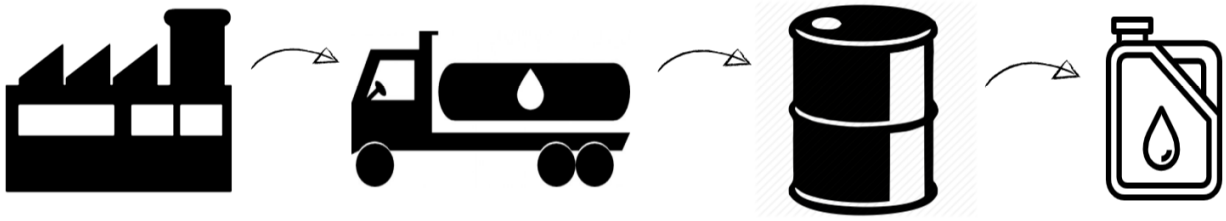


Figure 16: Proposed business distribution system

We propose the sale of Sunbird Bioenergy's ethanol out-the-gate to distributors at a price of $0.52 (Le 4500) per liter. As based on conversation, if Sunbird could streamline operations, it's possible production costs could run around $0.40/L. If achievable, would allow for a manageable profit of $0.12 per liter.

In order to sell in the market at a $0.70 pricepoint, this would leave the distribution company with operating margin of $0.18 (Le 1500) per liter to work with, or $180 per 1000 liters. It appears this margin can be sustainable, barring volatility in the petrol market as the cost of transport is substantial.

Infrastructure within the country and the lack of adequate roads makes transportation challenging, and petrol for ethanol transportation the largest input expense. The most effective way to manage this would be to establish regional hubs from which further specialized distribution could operate. Our suggested locations for regional hubs would be Freetown, Waterloo, Mikeni, Bo and Kenema, with additional possible expansion to Port Loko or Kabala if appropriate. We suggest Freetown

and Waterloo because of the disproportionate amount of improved fuel users in this region, presumably due to significantly higher incomes as well as the convenience offered by improved fuel alternatives in the dense urban environment. We suggest Mikeni because of its proximity next to Sunbird therefore saving greatly on transportation costs, and Bo and Kenema for their large population sizes and roles as the education and commercial centers of the upland country, respectively. Currently, these five places all exist along well-paved highways, though Bo and Kenema will need to be served via Masaika as the direct road is not paved and therefore unsuitable for transportation of this nature and at this scale. Paved and adequate roads are a must for transporting fuel to regional hubs, so many possible locations off the Freetown-Kenema and Freetown-Mikeni highways must be shelved at the current time.

Figure 17: Suggested distribution hubs for ethanol. Sunbird Bioenergy Production Plant in green; potential recommended distribution hubs in red; traveling to Bo and Kenema currently would require indirect travel via Masaika junction (Blue) due to road conditions.

Rough estimates from Sunbird's transition director suggest that tankers with a 45,000 liter capacity can be hired from Freetown with a necessary escort due to the nature of the material for a fee, with inland transport costs of about $0.043 per liter ($43 per 1000 liters) per 100 miles. This price is effective for Freetown and Waterloo (about 150 km from Sunbird), and would mean only about $10 per 1000 liters for Mikeni due to its close proximity. However, Bo and Kenema would necessitate roughly

twice this amount due to location, therefore a rate of about $85 per 1000 liters. An overall average of fuel transport to these five locations would be $53 per 1000 liters.

Therefore, an operating remainder of $180-53 = 127 per 1000 liters would be necessary for truck hire, personnel, business rentals and operations, and holding tanks.

Distribution hubs in these locations can receive refined spirit from the tankers, where fuel can be transferred from tankers to IBC containers (1000 liters) or drums (more easily transportable at 250 L) at each major hub for further dissemination. Individuals at points of sale can dispense ethanol from drums into smaller containers for sale through spigots installed in the drums, which would be much more reasonable than the siphon system our team deployed. Ethanol can then be easily transferred to 5 liter containers (or other preferred size) for retail sale. As per African tradition, individuals could bring their own containers and charged by liter or weight, but our team again recommends the use of labeled containers whenever possible.

An initial rough budget can be found here:

Per week at Max demand:	540,000 x $0.70 =	**$ 378,000 initial revenue**
Payment to Sunbird	540,000 x $0.52=	-$280,000
Fuel costs for transport	$53 per 1000L x 540	-$28,620
Personnel	5 hubs x 4 staff/hub x $15/day x 20 days	-$6000
Remaining Funds:		**$63,380, of which remove:**
Tanker truck rental/mileage fee	x 12 (necessary trips to reach delivery of 540,000 at capacity)	-TBD
Shop space rentals and business fees		-TBD
IBC containers and drums (one-time startup costs)		-TBD
Other costs		-TBD

Figure 18: Rough budget for ethanol distribution

VII. Reflections and Conclusions

a. Reflections on Development Theory

This project sits at a nexus of several different systems of thought and practice with regard to development theory. First, we must acknowledge this initiative was an idea of Martin's, a Sierra Leonean, who deeply loves his country and desires to devote his efforts to improving the lives of its residents, especially farmers. Martin's education has led him to incorporate many principles in his ideas and projects. Some of these include:

- cooperatives as a system of organization, empowerment and gender equity for women farmers

- investment of cassava for value-added products as climate-smart, and
- interest in cassava-based ethanol as both a health benefit and technological and economic boon for the rural countryside.

He is familiar with these trending topics in development discourse (which helps him win the ear of donors and academics alike). He also believes in them wholeheartedly. It is because of Martin's vision I was able to justify my presence in-country as someone who is supporting a local man with a vision, therefore something I could label a "grassroots initiative". I was not waltzing in to perform my own "exploitative western-centric research" and then retreating. To some degree, however, it still was that way; it was my insistence on an empirical research-centered approach, because that fit with my academic structure and needs, when Martin would have rather began selling and building his market traction initiative from the beginning. Additionally, stoves were purchased with funds I was granted, which forces one to wonder how this project might have gone forward had Martin not had access to the resources I brought with me.

I found Martin's initial vision represents a mismatch between traditional practice and industrial capacity. Martin's hope was for local communities to create ethanol through the traditional distillation system (shown in picture in prior section *Alcoholism*), and therefore strengthen traditional practices and activities. This grounded it initially in somewhat of a post-development theory and vision, as it centers on the desires, interests and capacities of locals. However, creation of ethanol as a fuel requires investment and infrastructure beyond what traditional villages are capable of. It was only with the help of a $500 million foreign direct investment project, built to assist the European Union with meeting its clean energy goals, that we were able to practically test the demand market for Martin's ideas. By nature, our project morphed from a post-development-theory centered project utilizing the visions and technologies of local people, to one that furthers the interest and agenda of a large foreign company. The neoliberal economics on which this type of investment project was based in many ways runs counter to the initial vision, especially when one scrutinizes the level of displacement and alleged corruption attached to the establishment of Addax (now Sunbird; see ActionAid's "Broken Promises"). Additionally, Addax's commissioning fits very neatly into dependency theory, as it was built exclusively to utilize the natural resources of the "periphery" of Sierra Leone for export to the "core", the European Union. Sunbird's vision of building a local market for their product alongside their exports opens the conversation of possible bridging of these theories, or at least a necessary acknowledgement of the social conscience becoming increasingly expected for large companies.

As humans, we seek to label projects as 'good' or 'bad', 'successful' or 'unsuccessful'. This project and its potential expansion, like in all things, necessitates tradeoffs. Successful improved cookstove initiatives the world over have shown to decrease pulmonary disease and improve ergonomic comfort for women. They increase available time or other chores or activities, and in some cases therefore agency. Qualitative comments we collected that are shared above aligned with these findings. There is no question that Sierra Leone needs a better cookfuel solution. However, what might be the cost of seeking this out? Switching to a cleaner-burning fuel removes jobs from local economies as it shifts the center of production from micro-economies of wood and charcoal in self-sustaining villages to capital-intense centers and specialized industry. If worked as hoped, the purchase of ethanol fuel may slow the

persistent deforestation caused by the demand for fuelwood. But if the demand for feedstock to make this fuel causes virgin ecosystems to be cleared, or even fallows to be shortened, the ecological destruction this 'clean' fuel might bring through increased carbon fluxes and biodiversity loss may do greater damage than had there been no intervention at all.

This project is not alone in the development landscape. Improved stoves of all kinds are being developed and tested across Africa, and our project aligns most closely with projects run by Project Gaia. Project Gaia tests ethanol stoves in eight countries, five in Africa (Ethiopia, Mozambique, Nigeria, Madagascar and Kenya) and the remaining Haiti, Brazil and India (Gaia, 2019). They all rely on industrial-scale ethanol plants to provide the fuel, with sugarcane and molasses as inputs. They are piloting a microdistillery system in Ethiopia, as ethanol can be produced at any scale. The challenge comes with the economics, as controlled heating and cooling even at the small scale might make refined spirit economically unviable. It would be a major boon to the movement if this can work successfully. Nigeria, as mentioned above, has initiated a cassava-based microdistillery system; however, it is hard to get the product to be higher than 55% proof (Ohimain, 2015). Martin is currently in discussion with Project Gaia to apply for a UNIDO grant to expand the market in Sierra Leone and bring this initiative under Project Gaia's wing. They are assisting with the application process and their successful track record and expert guidance would ensure future success.

b. Outcome Recap & Conclusions

Sierra Leone is rapidly deforesting itself in the need for biomass fuels for its growing population. In addition, burning these fuels leads to health risks especially for women and children. For this reason, an improved cooking method is necessary. Sunbird Bioenergy is conveniently poised to improve the lives of nationals in the country as well as improve economic growth for the struggling economy. While it is unlikely ethanol would be a competitive fuel to fully replace biomass for most of the population, it certainly gained significant traction in our study. In summary, during our time in Bo, our team acquired the following information.

i. Existing state of affairs

After conducting over 230 interviews in Bo and Freetown, we determined the following.

- Most households spend about Le 27,000 ($3.23/$11.30 PPP) on food for their household.
- Most households spend about Le 2,000 ($0.24/ $0.84 PPP) on biomass fuel for cooking.
- Families that use wood generally appear to spend a little bit more on wood than families that use charcoal, despite the fact some consider it "lower" than charcoal on the energy ladder
- Households that purchase the large bag of charcoal spend and less per day (~$0.18 per day/ $0.63 PPP) on fuel than households that purchase small plastic bags of charcoal for use that day. These families spend about $0.24 ($0.84 PPP) per day on fuel.
- Biomass fuel in the capital city of Freetown is about 50% more expensive than Bo, with a bag of charcoal costing around $3-3.60 ($10.50-12.60 PPP) and daily fuel costs around $0.30-0.40 ($1.05- $1.40 PPP).
- At a glance, it appears there is no significant positive correlation between household size and increased expenses on fuel.

- Many better-off households have a gas burner that they keep at their houses. The gas burner is almost never used for proper cooking and instead used for boiling water, frying eggs or plantains, re-heating food, and other quick tasks. This is because the fuel is considered very expensive.
- A gas cooker in upland Sierra Leone costs about $24/ $84 PPP to get, and refilling the empty tank costs $11/ $39 PPP, up from $8 / $28 PPP six months ago.
- A tank of gas, when used for all household tasks, would last between 2 to 3 weeks, or an average of Le 5,400 ($0.65/ $2.28 PPP) per day.

ii. Ethanol Stove Study Results

Twenty-four households received an ethanol burning clean-cook stove to take home for the duration of the study. Core lessons include:

- Consumption rate: the average user rate when fuel was free and unlimited, and used for all household tasks, was 0.9 L/day.
- This can also be calculated out to roughly 0.2 L per adult, however it is infeasible that any individual could use this little due to the physics of the stove and cooking styles.
- The feedback on the stove use was overwhelmingly positive. Primary feedback was appreciation at the speed to light and cook, its cleanliness and lack of smoke, and a higher level of comfort associated with its flexibility of use (indoor/outdoor, on a table vs. the ground, etc.)
- Critical feedback included some dislike over the smell of the alcohol fuel, the fact it makes the bottom of the pot black, and the inability to put two large pots on it at the same time (burners too close together).
- Implementation of pricing: The initial listed price of Le 8000 was not successful as a feasible market price, as it would be even more expensive than butane gas.
- Le 6000 ($0.70/$2.45 PPP) was perceived as a reasonable price by most users, and renders the ethanol possibly able to outcompete gas in upland settings.
- Ethanol sold at Le 6000 cannot displace daily charcoal and wood use in almost all cases.
- Stoves will be primarily used for small household tasks like boiling water, frying plantains etc.

iii. Final Words

Sunbird Bioenergy has an unparalleled access to a market that is in great need of alternative cooking solutions. Carbon financing could make stoves affordable and possibly create local jobs if the stove body was made locally, and only the canisters imported. The business plans provided above show that a market selling at $0.70 ($2.45 PPP) per liter could likely be a viable option. Roughly 80,000 households can purchase ethanol fuel that has been circulated through 5 key distribution points. We hope our research has proven useful, and it may be that Sunbird's presence in the country can contribute to greater quality of life for the residents of Sierra Leone through the diligent, responsible establishment of a self-sustaining market for ethanol fuel for household cooking.

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IX. Appendix A: Additional Stove Comparison Studies

In addition to our core objectives of identifying qualitative feedback, user rates and reasonable price, we conducted some additional studies with the Cleancook NOVA-2 stove and fuel to gain a better understanding of the product and how it might interact with the existing market.

a. Gas comparison test

After the first two weeks of the study when we determined families used an average of .9 liters a day, it was determined even a price of Le 6000 per liter would not be enough to displace biomass fuel, so we turned our sights more closely to compare it to butane gas.

Our 5th-week household visit interview asked households their opinions on ethanol compared to gas. Most households preferred the ethanol to the gas because it felt safer. Responses on which "felt more expensive" were mixed—12 said gas would cost more and 5 said ethanol more, and many didn't know.

To compare costs, we set up two families with butane gas burners and asked them to use it for all cooking and household tasks. We found in both cases the fuel lasted 16 and 19 days. Therefore, in Bo where a gas canister is Le 90,000 to refill, most families would be spending between Le 4,700 and 5,600 per day on gas for their household duties.

A typical butane gas canister currently costs Le 90,000 to refill in Bo

We then gave these same families 15 L of ethanol, determining that if priced at Le 6000/liter, this would be Le 90,000 in ethanol costs, and therefore comparable to one canister of gas. Since the average family uses .9 liters a day, this would suggest 17 days, almost exactly on par with the butane gas market. Both families that participated in the study used closer to .6 liters a day, and were still not out of ethanol fuel by the time I had to return to the US twenty-two days later. This suggests that if priced at Le 6000/L, it's possible in some cases ethanol is

actually financially advantageous to butane gas, in addition to its environmental health and safety benefits.

It's worth noting that in the capital city, refilling a butane gas tank costs Le 75,000, so this market would be much tighter. However, ability to pay in the capital city also suggests a much larger pool of potential customers.

Additionally, the gas stove has one burner and the ethanol stove provided has two. This undoubtedly influenced user behavior, as I was not present to ensure households never lit charcoal or exercised other behavior that may have distorted outcome.

b. Kerosene comparison attempt

Our team found one woman in the city that still used kerosene for her small tasks. We asked her to put 1 liter of kerosene in her stove and record all things she did with it. We then asked her to do the same tasks with 1 liter of ethanol. While I anticipated this was a relatively simple task, the results were inconclusive. When adding up her recorded hours, it appeared 1 liter of kerosene lasted about four hours and 20 minutes of burn time for her tasks. Her recording for ethanol only added up to 2 hours and 40 minutes, and appeared she had done fewer tasks before it ran out. When asked about this, she said she "feels" that the ethanol lasts much longer, regardless of what she'd written, and that there was already a little kerosene in her stove when she added the liter of kerosene to it. It's likely she was keen to tell me what I wanted to hear, and also likely the log sheet was not reliable. For this reason I had to dismiss the kerosene test, and was not able to find another kerosene stove anywhere in the city in order to ask another individual to try (or to try it ourselves).

c. Boil comparison test

Many individuals in the country use pots that are recycled from aluminum cans, made locally. Cans are melted in a small fire surrounded with clay to produce a kiln-like heat, and poured into a clay mold to cool. These pots are significantly thicker than the imported aluminum or steel pots, and two households had mentioned the increased boiling time on the stove.

We performed a water boil test on the Cleancook NOVA-2 stove three times, with two pots side-by-side: one local recycled aluminum pot, and one an imported pot. Both pots contained three liters of water. Pots were switched on the left and right burners each time the test was tried. The imported pot was cylindrical in shape and very smooth, while the local pot was spherical and rough. For these reasons small bubbles would appear and rise first in the local pot, but the imported pot achieved a rolling boil about two minutes before the local pot—an average of twenty-two minutes as opposed to twenty-four. Lack of access to a thermometer

rendered this test very unscientific but it was clear the imported pot boiled first by a margin of about two minutes.

Local aluminum pot (left) and imported pot (right) perform a boil test on the Cleancook stove

X. Appendix B: Manufacturing Local Stoves

Another sizeable initiative our team undertook was to determine to what extent the NOVA-2 stove could be replicated or re-designed locally. This was headed up by Peter, who had studied sustainable design and possessed substantial experience with metal fabrication and welding.

The Cleancook stove retails for $55, and with existing shipping and customs would cost over $80, a price that is completely unaffordable and unreasonable when a gas setup can cost only $18. The single-burner, assemble-yourself COMET-1 stove would retail for about $25 less after all shipping costs, still a price out of range for most.

The stove itself is a simple design, stainless galvanized steel and easily folded, and so we set out to see to what degree it could be replicated or modified among local stove makers. Fabricating stoves locally would provide an accessible alternative, avoiding import fees, providing opportunities for local fabricators, and creating the most appropriate design through a community co-design process.

The fuel canisters themselves are too specialized to come from a local producer, as their absorbent ceramic and mesh interior requires meticulous assembly and access to supply markets for their components. However, the canister can be purchased for about $8, and a stove body inside which it could fit could be built locally.

In order to explore the local fabrication option, our team partnered with three local metalsmiths. After observation of stove design and user feedback, we determined the most important elements and developed the following design criteria:

- Incorporates induction chimney to increase heat
- Incorporates a device for flame regulation
- Uses locally available materials
- Must be safe and easy to use
- Uses simple, available fabrication tools and techniques

Each fabricator shop was given a Cleancook NOVA-2 stove to examine and asked to design a cheaper, simpler single-burner stove that fits the existing fuel canister and incorporates the criteria above. This approach assumed fabricators possessed significant comprehension of stove operation, design principles and creative ability to undertake a unique design process. This assumption was incorrect.

Upon visiting the fabrication shops after a week of work, the first two shops built exact replicas of the NOVA-2, down to the ornamental metalsmithing, imitating every minute detail. This imitation fully dismissed the cost of the work, with one metalsmith suggesting the stove should retail for 1 million leones ($120). It became clear that despite the great talent required to replicate the NOVA-2, the charge to re-design a cheaper, simpler model had not been understood.

Initial stove designs replicated the NOVA-2 almost exactly

To ensure the design objective was understood, Peter stepped in further to join the third fabricator shop, a shop that specialized in recycled materials and improved-efficiency coal

pots. The round shape of existing coal pots fit well with the canister shape, and resulted in the first prototype seen below.

Existing coal pots made from recycled materials

Early ethanol stove prototypes made from similar materials

A second prototype turned more to the COMET-1 for inspiration and incorporated a folded piece of galvanized steel and a separate pot stand. This stove was unanimously determined to be simpler than the first, and of comparable affordability to a coal pot—Le 20,000, or $2.35. It is designed to be used with the imported canister, producing a final cost of just over $10. Peter and his fabrication team named the prototype GONDAEGOTI after the local Mende word for "cookstove".

Early prototypes of the "GONDAEGOTI" stove

Our research participants frequently expressed great appreciation for the NOVA-2 stove despite the fact that some did not use them often. One of our research team members suggested people valued the stove as furniture and simply liked having one in their homes even if it was rarely used. This realization informed the effort that to prototype a local ethanol stove, stoves must be pretty. This was further confirmed when the initial prototypes, when shared with participants who had worked with the NOVA-2, were met with the primary comment, "That stove is so ugly! No one can see me use it. I would be so embarrassed. The clean stove is more beautiful."

XI. Appendix C: Agreement and Consent Forms

AGREEMENT FORM

_____I will do my best to use only this stove almost every day, and will only use charcoal or wood when absolutely necessary.

_____I will not leave town for more than three days at a time for the next six weeks, and if I need to do so I will notify Dana Armstrong (information included in packet).

_____I will do my best to log all my stove use on the required sheet every time I use the stove.

_____I understand I need to turn over Le 30,000 as a deposit effective immediately to receive the stove and fuel. I will receive the Le 30,000 back at the end of the study, when the stove will be returned.

_____I will never, ever pour fuel into the stove canister from the top. I will always turn the stove off, turn it upside down, remove the canister, fill the fuel as taught, clean any spilled fuel, and return the canister to the stove.

_____I will never, ever use the fuel for anything other than putting into the stove. I will not try and pour it on a fire. I will not put it in my car. I will not try to drink it.

_____I will store the fuel safely. I will do my best to store the fuel away from children or open flames (including cigarettes and charcoal fires).

_____I understand if I have any questions or concerns I can contact Dana Armstrong at the number provided.

Note: This Consent form was compiled by the guidance of the HRP-502 Consent form Template. Some sentences are copied from the template itself: https://research.ucdavis.edu/policiescompliance/irb-admin/researchers/irb-forms/#Templates

Title of Study: Feasibility of Cassava-based Ethanol fuel and Cookstoves in Bo, Sierra Leone

Investigator: Dana Armstrong

Why am I being invited to take part in this research study?

We are inviting urban households that use wood or charcoal as their primary fuel source for cooking into an eight-week study testing a new stove and fuel type. As a household that purchases and cooks with biomass fuel, we invite you to replace that practice during the course of the study with the use of our CleanCook stove and accompanying fuel. We believe that using ethanol fuel is better for your lung health, for the air, is safer, and better for the forest.

What do I need to know?

If you are interested in the study, someone will explain to you:

- How this study will work, and what you should do
- How to use your stove safely, and how not to use your stove
- How to use your fuel safely, and how not to use your fuel
- The dangers that might occur if you do not use your stove the way it is supposed to
- Resources if these dangers were to occur

Know that you do not have to take part in this study. No one is making you and there is no problem if you do not want to participate. You may stop participating at any time if you change your mind. Know that the stove will be taken back at the end of the study, it is not a gift. However, you can keep the stove if you choose to purchase it for the appropriate price, which will be shared at the end of the study. You may ask as many questions as you need to both now and throughout the study.

If you agree to these things, you will sign this document and will be given a copy.

Who can I talk to?

If you have questions, concerns or complaints, talk to the research team at dkarmstrong@ucdavis.edu or 831-521-0703.

Why is this research being done?

Most women in Africa cook over woodburning fires, and the smoke from this practice is bad for your health. Also, women spend many hours collecting firewood to use or sell, and this time could be spent in other ways like taking care of their family or going to school. Also they would not be exposed to dangerous things like snakebites or assault by men because they would be able to stay in the village. Lastly, the deforestation contributes to greater droughts and floods, which further increases the insecurity in the region.

If women like these stoves and fuel, it might help provide jobs for women who farm cassava, keep wood collectors safe, and keep the air and people's lungs cleaner. However, it is important that you tell us the truth about this stove—if you do not like it, that is perfectly fine. We just want to know what people think of it.

How long will the research last?

The research should last no more than eight weeks. At the end of eight weeks, you will have the option to purchase the stove if you wish.

How many people will be studied?
At this point we have 40 households that will receive a stove that they will use daily.

What happens if I say yes, I want to be in this research?
As stated above, you will receive a stove and fuel at no cost, but for a deposit of Le 30,000. You will be shown how to use the stove and fuel safely and asked to do all of your regular cooking on it instead of on your stone fires. A student from Njala University or the University of California will come into your home once a week to talk to you and your family. We will first interview your family about how much wood you normally use and how often you buy it, and how much time you spend cooking. After a week or two, we will ask you what you think of the stove and fuel and if you have any questions about it, and how much time you spend cooking. After three weeks, you will be asked to buy the necessary fuel. We will return regularly to sell you fuel at market price, which will be Le 8000-9000 per liter. If at any point you do not want to pay for the fuel, you are welcome to switch back to your regular wood fires. However, we ask that you be honest- we want to know how much fuel you used in addition to your wood fires. At the end of the research you may have the opportunity to buy the stove if you like it and are able to pay the appropriate amount for it.

What are my responsibilities if I take part in this research?
Your responsibilities are to use the stove as much as you like instead of your wood fires, or in addition to your wood fires. We only ask that you be honest with us—we want to know if you are cooking more food in this case, if you are unhappy with the stove for any reason, etc.

What happens if I do not want to be in this research?
You do not need to be in this research. You will not receive a complimentary stove or fuel and we will not visit you at your house.

What happens if I say yes and change my mind later?
You may leave the study at any time. In fact, part of the study is to determine when you do not want to use the stove anymore because the fuel is expensive (or for another reason). We only ask that you tell us why you are no longer participating, as long as your reason for withdrawal has to do with the study. You will not be in trouble for stopping the study and nobody will be upset at you.

Can being in this study be bad for me?
The only way this study could be bad for you is if you make poor choices with the fuel that is given to you. You will be shown how to use it safely. The stove has an open flame, the same as a wood fire, so you must be careful around it in the same way you would be careful around your wood fire. If you store the fuel with the lid on tight, away from children or sources of fire (e.g. cigarettes) you will be safe. Do not try and pour the fuel onto a wood fire. It does not act like kerosene and will be very dangerous if you do that—all of this will be explained and demonstrated it to you. If the fuel is spilled, make sure it is cleaned up properly and thoroughly. This will also be shown and explained to you.

Will this research help me in any way?
We anticipate that the reduced smoke will improve the air you breathe, and therefore be better for your lungs. However, this will not be measured in the study so cannot be scientifically proven for you. You will also benefit by receiving free fuel for three weeks.

What happens to the information collected for the research?
The information will be compiled alongside information from the other 39 households and used to determine whether it is economically feasible to make these stoves and this fuel available in Bo. All efforts will be made to limit the use or sharing of any personal information. We cannot promise complete confidentiality. Organizations that may inspect and copy your information include the Institutional Research Board and other University of California representatives responsible for the management or oversight of this study.

Can I be removed from the study without my OK?
Yes, researchers reserve the right to remove your participation from the study. This would only happen under circumstances where we feel you did not make safe choices with the fuel. Researchers also reserve the right not to offer to sell you the stove at the end of the program.

What else should I know?

This research is being funded by the Blum Center for Developing Economies and Jastro-Shields grant. Ethanol has been donated to the researchers at manufacture price from Sunbird Bioenergy in Mikeni. Stoves have been provided at below-market price to researchers from Project Gaia NGO, who in turn purchased them from CleanCook AB. CleanCook has no interest in the study, though Sunbird Bioenergy is interested in the market outcomes of the study. Sponsors may change or be added.

It is important that you promptly tell the person in charge of the research if you believe that you have been injured because of taking part in this study.

You will not be compensated for taking part in this study.

SIGNATURE BLOCK FOR CAPABLE ADULT

Your signature documents your permission to take part in this research.

_____

Signature of Subject Date

_____

Printed Name of Subject Date

_____

Signature of Person Obtaining Consent Date

_____

Printed name of Person Obtaining Consent Date

_____

Signature of Witness to Consent Process Date

_____

Printed Name of Witness to Consent Process Date

XII. Appendix D: Energy Market Analysis Interviews

Form A. Charcoal Retailer Interview (1 of 1)

Interview #: _____ Interviewers: _____

Interviewee gender: M or F (circle one) Interviewee age: ____

Mobile or sedentary (m/s)? ____ Neighborhood: _____

1. How long have you been selling fuel for? _____

2. Do you sell anything besides charcoal? _____

---3. If yes, what do you sell besides charcoal? _____

---4. Why do you sell things other than charcoal? _____

5. Do you ever sell wood or other types of fuel? When?_____

6. How many days a week do you sell charcoal? _____

7. How many months a year do you sell charcoal? _____

8. How many hours a day do you sell for? _____

9. What sizes of charcoal do you sell, and how much do they cost?_____

---10. What is your most popular size to sell? _____

---11. Which bag size do you want to sell the most and why?_____

12. On average, how many of each size do you sell every day?_____

13. Are there days of the week when you sell more charcoal than other days (Mon-Sun)? _____

14. On average, how much money do you make every day? _____

15. If I have a family of 7, how much charcoal should I buy for one meal?_____

16. Does the amount of charcoal in each size bag that you sell change depending on the season?

17. Do you think people buy more charcoal overall in the rainy or the dry season? Why?

18. Are most of your customers male or female? _____

19. Can you tell me anything else about your customers that you have that you think I should know?

20. Do you always have the same customers that come to you, or do they change?

21. What is the average amount that a customer will buy from you each time?

22. Is it more common for customers to buy to provide for many days (for reserves)? Or they buy each day for one day at a time? _____

23. Do you make the charcoal yourself? _____

24. If no, where do you get your charcoal from? _____

25. *If from a middleman/wholesaler*: How do you get the charcoal from your wholesaler, and how often?

26. Do you know where your wholesaler gets their charcoal from? If so where?

27. How do you package your charcoal? _____

---28. Which of your bag sizes has the best quality charcoal?_____

29. Do you put small charcoal dust in your charcoal bags? Why or why not?

30. How long does it take you to sell one (large) bag of charcoal if you package it into smaller bags?

31. How many smaller bags (Le 500, Le 1000, etc.) of charcoal can you get out of one big bag?

30. If you buy from a wholesaler, how much do they charge you for one large bag this time of year, in the rainy season? _____

31. How much will they charge for the bag in the dry season? _____

32. How many big bags do you buy at a time? _____

33. Do you get a better deal if you buy many large bags at one time instead of one at a time? If yes, how much of a deal? _____

34. Do you buy more bags from them in the rainy or dry season? Or the same amount?

35. Do you always sell your charcoal in the same place or do you move around?_____

36. How do you decide on a good place to sell (or if in one place, how did you decide to sell here)?

37. Why do you sell charcoal? Do you enjoy being a charcoal seller?

Form B. Wood Retailer Interview (1 of 1)

Interview #: _____ Interviewers: _____

Where? House Market Other: _____ Neighborhood: _____

1. How long have you been selling wood for? _____

2. Do you sell anything besides wood? Which did you sell first, and why did you add the other?

3. Do you ever sell charcoal or other types of fuel? When?_____

4. How many days a week do you sell wood? _____

5. When are the times when you don't sell wood? _____

6. How many hours a day do you sell for? _____

7. What sizes of wood do you sell, and how much do they cost?_____

---8. What is your most popular size to sell? _____

---9. Which size do you want to sell the most and why?_____

10. Do you put the same number of sticks in each bundle? Do you weigh or measure them?

11. On average, how many of each size do you sell every day?_____

12. Are there days of the week when you sell more wood than other days (Mon-Sun)? _____

13. On average, how much money do you make every day? _____

14. If I have a family of 7, how much wood should I buy for one meal? _____

15. Does the amount of wood in each bundle that you sell change depending on the season? Or does the price change and the wood amount stay the same?

16. Do you think people buy more wood overall in the rainy or the dry season? Why?

17. Why would someone prefer wood over charcoal? Why would someone prefer charcoal over wood? What do you use?

18. If I used only wood or only charcoal for one year, which would be more expensive?

19. Are most of your customers male, female or children? _____

20. Can you tell me anything else about your customers that you think I should know (Mostly regulars or different? Locals or neighbors? do you give credit?)?

21. What is the average amount that a customer will buy from you each time?

22. Is it more common for customers to buy to provide for many days (for reserves)? Or they buy each day for one day at a time? _____

23. Do you harvest the wood yourself? If no, where do you get your wood from? How do you get the wood from your wholesaler, and how often?

24. How many bundles (big and small sticks) do you buy at a time? _____

25. Do you split it yourself? If you hire someone, how much do you pay?

26. How long does it take you to split your wood? _____

27. Are you tired after you split wood? Do you sell wood if you are sick or injured?

28. How long does it take you to sell one big bundle if you package it into smaller bundles?

29. How much money can you get from one big bundle? How many small bundles can you get from one big one?

30. How much do you pay for one large bundle this time of year, in the rainy season?
_____

31. How much do you pay in the dry season? _____

32. Do you get a better deal if you buy many large bundles at one time instead of one at a time? If yes, how much of a deal?
_____

33. Do you buy more bundles in the rainy or dry season? Or the same amount? _____

34. Do you always sell your wood in the same place or do you move around? _____

35. Why do you sell here? Do you live nearby?

36. Why do you sell wood?_____

37. Do you enjoy being a wood seller? _____

38. What would you do if you didn't sell wood? _____

39. Is there anything about buying and selling wood that you wish was different?

40. Would you be interested in selling liquid fuel in small canisters?

Interviewee gender: M or F Interviewee age: _____ # of kids: _____ Religion: _____ Amount of Schooling: _____ From Where?: _____

Form C. Fuel Consumer Questions

Interview #: _____ Interviewers: _____ Neighborhood: _____

1. Are you the primary person that cooks for your family? _____
2. How many people do you cook for in your household? How many are children vs. adults?
3. How many days a week do you cook? (If not every day- what do you do on the "off" days?)
4. Do you share this house with another family or another person that cooks for people?
5. Where is your kitchen? Is it a stand-apart kitchen? In the house? No kitchen?
6. Where is your preferred place to cook?
7. Does anyone help you cook? Who and when?
8. Do you normally cook with one or two pots? *Ask more about cooking process and implements*
9. What are the main sources of income for your household?

10. On average, how much money does your family make per [amount of time]?

11. What kind of fuel do you use most often? Why do you prefer it?

12. Do you ever use charcoal/wood instead? If so, when and why?

13. Do you ever harvest or make fuel yourself? If yes, how often and who does it?

14. Where do you usually buy your fuel from?

15. What size of fuel do you buy, and how much do you buy at a time? How often do you buy it?

16. How long does it take you to make a trip to buy fuel? (if a trip to the village- by car or motorbike? How much does transport cost?)

17. How much do you pay for the fuel (per day or per week?)

18. Do you usually buy other things or do other errands in the process?

19. How many hours per day do you spend cooking overall?

20. How many meals do you prepare each day? (If more than one meal: How long does it take you to prepare each meal?)

21. How long does it take you to prepare the coals/wood for cooking?

22. How do you light the fuel?

23. Do you ever use gas? (or have you ever)? If so, when?

24. Do you ever prepare wood, charcoal or gas for anything other than meals? (Heating water for tea, for example). If so how often, and do you use the same fuel as the meal or extra?

25. Do the sizes of fuel you buy change in the dry or wet season?

26. Do you spend more on fuel in the wet or dry season, or the same?

27. What do you like most about cooking? What do you like least about cooking?

28. What is the easiest dish to prepare? What is the hardest dish to prepare, and why?

29. Do you have a favorite or least favorite dish?

30. Is there anything about the process of buying and using the fuel you wish you could change?

31. If there was another way to cook, would you be interested in trying it?

Interviewee gender: M or F Interviewee age: _____ # of kids: _____ Religion: _____ Amount of Schooling: _____ From Where?: _____

Cost estimate of fuel per day: _____

Form D: Wood and Charcoal Producer Interview

Interview #: _____ Interviewers: _____ Village: _____

On road Off road Also a wholesaler? _____ Other notes:

WOOD PRODUCTION:

1. How long have you been harvesting wood for?_____

2. How many hours a day do you harvest and how many days a week?

_____

3. Do you harvest as much wood in the rainy season as the dry season? Is there anything that changes with the seasons? -

_____

4. Do you get some of your wood before or after clearing land for planting (related to farming at all)?

5. Please describe to me your process for producing wood for sale.

6. Do you own the bush or harvest on other people's land? Do you pay them to harvest on their land?

7. Has it gotten harder to collect wood as the years go on? Or can it regenerate?

8. Are there seasons related to this business? (Season for cutting and drying, for example?)

9. How long does it take you to cut one bundle of wood from the bush? *(Note how big of a bundle)*

10. What kind of wood is it? Can you get good wood from many kinds of plants?

11. Do you do anything else for income besides produce wood? If yes what?

_____

12. What type of tools or equipment do you need, and how much do they cost? How often do they need to be replaced?

13. How do you decide how much to charge for the wood? (Rainy and dry season also)

14. Do you sell to customers directly? Who are they, how often do they come, and how much do they buy?

15. If someone buys a large amount of charcoal, do you charge them less per bundle?

_____

16. Why do you produce wood? Do you enjoy it?

_____

CHARCOAL PRODUCTION:

17. Do you harvest the wood yourself to make charcoal? If no, where do you get the wood from? ***(if yes, ask the wood production questions also)***

18. Do different kinds of wood make better or worse quality charcoal? Tell us about it.

19. How long does a charcoal kiln last and how much does it cost? Where do you get them from?

20. How many loads a day do you put in the kiln? How long do they stay in there?

21. How many bags can you fill from one load from the kiln?

22. How do you decide how much to charge for the bags?

23. Do you do anything else for income? If yes what?

_____

24. Do you put chaff in your bags?

_____

25. If yes, why do you put the chaff in the bags? How do you pack the bags?

26. Do you sell to customers directly? Who are they, how often do they come, and how much do they buy?

27. If someone buys a large amount of charcoal, do you charge them less per bag?

_____

28. Why do you produce charcoal? Do you enjoy it?

Notes/ Other questions:

Form E: Wood and Charcoal Wholesaler Interview

Interview #: _____ Interviewers: _____ Village: _____

Also a Producer? _____ Other notes:

1. Do you sell wood, charcoal or both?

2. Is this your primary or only source of income? If no, what else? _____
3. How long have you been a wholesaler for? Do you do other things for income?

4. How often do you go from the village to town (or town to village) to get wood?

5. How much do you buy or bring at a time from the village to town?

6. How do you transport? Motorcycle, vehicle etc. How much does transport cost?

7. How many bundles/bags can you fit on your mode of transport? How many trips a day?

8. (If not a producer) What rates do you get for buying in bulk?

9. What do you sell your wood/charcoal for?

10. Do you charge less if people buy from you in bulk?

11. On average, how many bundles/bags do you sell each day?

12. If you only used wood or charcoal for one year which would be more expensive?

13. Who are the types of people that buy from you? How many buy to package and sell and how many buy just to use themselves?

14. What's the average amount the customer will buy from you each time?

15. How much do you make at the end of the day? (Profit Margin). Does this change in rainy or dry season?

Form F. Gas Consumer Questions

Interview #: _____ Interviewers: _____ Neighborhood: _____

1. Are you the primary person that cooks for your family? _____
2. How many people do you cook for in your household? How many are children vs. adults?

3. What are the main sources of income for your household?

4. On average, how much money does your family make per [amount of time]?

5. Where is your kitchen? Is it a stand-apart kitchen? In the house? No kitchen?

6. How many meals do you make for your family each day?

7. What kind of fuel do you use most often for cooking meals? Why do you prefer it?

8. When are times you use your gas, and what do you use it for?

    - (if They don't cook with it) Why do you not cook meals with gas?

9. How many hours per day do you spend cooking, boiling water, etc. overall? How much of that time is gas and how much wood/charcoal?

10. How many minutes per day do you have your gas on, and how many days of the week?

11. What size gas tank do you have? _____

_

12. How long does it take you before it runs out and you have to refill/exchange it?_____
13. How much does it cost you to refill/exchange your canister?_____
14. Where do you refill/exchange your canister?
15. How much did the stove and original tank cost you? _____
16. Why did you first start using gas? What 'inspired' you?
17. Which gas company do you use? (NP, Afrigas, etc.) Why?
18. What do you like about using gas?
19. Is there anything about using gas you don't like or wish you could change?
20. Does the amount of gas you use change in the rainy season or the dry season?
21. If there was another way to cook, would you be interested in trying it?

Interviewee gender: M or F Interviewee age: _____ # of kids: _____ Religion: _____ Amount of Schooling: _____ From Where?: _____

Cost estimate of fuel per day: _____

XIII. Appendix E: Participant Folder Contents

(excluding Consent form)

Safety Manual for the Double Burner Canister Distribution Model

1. Turn the stove upside down. Make sure the stove is cool before placing it on the table top.

2. Remove peel-off seal from the canister. Attach seal to bottom of canister for reuse.

3. Place canister in stove. Be sure it fits properly and is not loose. Always keep canister and stove clean from spilled fuel, grease, or oil.

4. Place stove on a flat, stable surface away from all flammable material such as curtains. Make sure stove is in a well-ventilated area away from drafts.

5. Light burner by holding a lit match, burning stick, or long lighter in the burner opening on the stove top. Burner lights easier by placing the flame down the burner tube at fuel canister opening.

6. Use only approved (name of local producer/distributor) fuel canister containing certified CleanCook fuel. Do not use any other fuel, as this may harm stove and create safety hazard.

7. The fuel canister burns for about 4 hours on highest heat setting. To conserve fuel, use regulator to adjust heat down during cooking. Store canister in stove with regulator in off position (closed) to prevent loss of fuel.

8. When canister is empty, replace with full canister and return empty canister to vendor.

9. Never pour any liquid fuel into the stove or the canister.

10. Never try to open the canister to get fuel out. If canister is damaged, return to the vendor for replacement.

ATTENTION! Be very careful when operating this stove. Follow instructions carefully in order to avoid burns or fire hazard. Water will extinguish this flame. When switching off stove, close and open the regulator three or four times rapidly to ensure that the flame is extinguished.

ENDORSED BY PROJECT GAIA

MANUFACTURED BY Dometic GROUP

Safety Manual for the Single Burner Bottle Supply Distribution Model

ENDORSED BY PROJECT GAIA

MANUFACTURED BY CLEANCOOK

1. Turn the stove upside down. Make sure the stove is cool before placing it on the table top.

2. Remove fuel canister from stove. Move fuel canister to an area away from sparks, flames, or other heat sources before filling with fuel.

3. Do not overfill the canister. Only one liter per filling.

4. Check the fuel level by tilting the canister vertically. If the canister is overfilled, the surplus will drain off in this position.

5. Wipe the canister to remove any spilled fuel before replacing in the stove. Be sure it fits properly in the stove. Always keep canister and stove clean from spilled fuel, grease, or oil. Use a soft brush to remove any food spillage on the canister top mesh before every re-fueling.

6. Light the burner by holding a lit match, burning stick, or long lighter at the burner opening on the stovetop.

7. Place stove on a flat, stable surface away from all flammable material such as curtains. Make sure stove is in a well-ventilated area away from drafts.

8. Never pour fuel through burner opening on top of stove. Never pour fuel into a fire!

9. The fuel burns with an almost invisible flame. Make sure that the flame is extinguished before filling the canister.

10. Store fuel in a safe place away from flames, sparks, ignition sources, and children. Do not smoke when working with fuel.

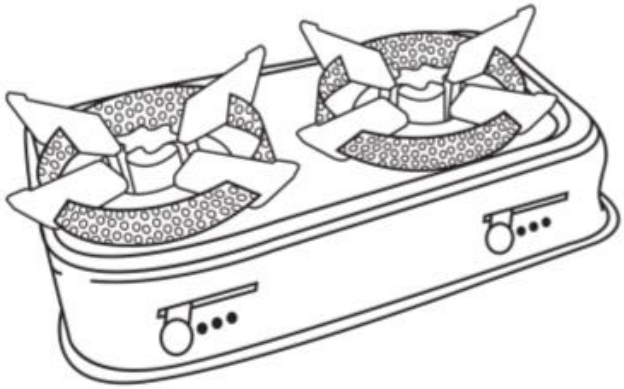
11. Do not drink the stove fuel!

ATTENTION!

Be very careful when operating this stove. Follow instructions carefully in order to avoid burns or fire hazard. Water will extinguish this flame. When switching off stove, close and open the regulator three or four times rapidly to ensure that the flame is extinguished.

How to Care for Your New CLEANCOOK Stove

Stove and Canister Precautions and Maintenance



- Ensure that both the stove and canister top are properly cleaned, and that all food spillage and dirt is wiped away before each use.
- Use a soft brush to clean off canister mouth. After brushing, wipe with a clean, damp cloth.
- **When the canister is empty, fill it with certified fuel only.**
- When inserting the canister into stove, make sure it's placed in the intended position.
- Before lighting, make sure the regulator arm can be moved back and forth freely and that the regulator plate covers the canister opening while in the closed position.
- Do not boil anything containing lye, as spillage can cause corrosive damage to certain stove parts.
- After use, make sure the flame is extinguished by moving regulator plate again from closed to open to closed again after the stove is shut off.

ENDORSED BY PROJECT GAIA

MANUFACTURED BY CLEANCOOK

LEFT BURNER

DAY	TIME ON	TIME OFF	LOW/MED/ HIGH	USE	NOTES
Aug 23	*10:23*	*11:07*	*Medium*	*Cook rice*	*Added more fuel*

RIGHT BURNER

DAY	TIME ON	TIME OFF	LOW/MED/ HIGH	USE	NOTES
Aug 23	*10:23*	*11:07*	*High*	*Boil water*	

XIV. Appendix F: Household Initial Visit Protocol

Household Checklist:

1. Make sure stove is in a safe place, but in a well-ventilated area (near a window for example)

2. Make sure fuel is stored in a place not accessible to children, or at least check that they have made it clear not to let children access the fuel.

3. Go over safety and logistics again:
    a. Never pour fuel from the top of the stove.
    b. Make them show you they know how to load canisters. Show them how to know it is full. Remind them it can only fit two bottles (one liter) at a time.
        i. They are welcome to add two bottles into each canister at a time, or they are welcome to do half a bottle in each every day (for example).
    c. Remind them to open it all the way when lighting it. Check the flame to make sure it is above the small flat metal part, to know if they need to light more fuel.
    d. Add fuel before cooking, not in the middle of cooking. Only load fuel into a canister that is cool, not hot.
    e. Do not drink the fuel, pour the fuel onto a fire, or smoke near the fuel. Keep away from children. TREAT IT LIKE PETROL AS FAR AS SAFETY GOES.
    f. If the fuel spills, pour water on it and wipe it up. If the fuel is on fire, pour water on it and the fire will go out.

4. Explain to them how the study works:
    a. They get free fuel for two weeks.
    b. They may use as much fuel as they like in those two weeks. However, please try to imitate how you normally cook—same cooking, boiling water, etc.
    c. Every time they cook, they must use the log sheet.

d. If you need to use charcoal or coal for any reason, please make a note on the log sheet so we know.
e. Show them how to use the log sheet. Make sure they understand how to read time and what to put for each category. Have them fill out each one in front of you to prove they understand.
f. After two weeks, they will purchase the fuel in sizes costing Le 2000, 4000, 12,000 or 40,000.
g. They may stop using the stove at any time if they do not wish to be part of the study. We will take back the stove and return the Le 30,000 to them.
h. We will be coming to their house regularly to conduct interviews and to give or sell them fuel. Tell them we will communicate through the number they wrote on the sheet.
i. The stove will be returned after 6-8 weeks at the end of the study. They will have the option to purchase at that time, but we only will encourage this option if continued fuel supply can be guaranteed.

5. Ask to see their packet. Make sure we have their consent signature page (e.g. it should be missing), and they understand all the points on the first page that they wrote "yes" to.

6. Administer the interview form (conduct the interview). The interview is an important base-point for us knowing how they normally cook. Make sure you get a clear estimate of how much they spend on fuel every day.

7. Collect empty fuel bottles and log them on the survey form. Give them more fuel.

8. See if they have any more questions. Show them Dana's number on the plastic folder and tell them to call, SMS or WhatsApp Dana if they are running low on fuel.

XV. Appendix G: Household Interviews

Form G. Household Initial Interview

Stove Number: _____ Interviewers: _____ Neighborhood: _____

Name of primary stove user and/or head of household: _____

Please interview the member of the household who will be the primary stove user.

1. Are you the primary person that cooks for your family? _____
2. How many people do you cook for in your household? What are their ages?
3. How many days a week do you cook? (If not every day- what do you do on the "off" days?)
4. Do you share this house with another family or another person that cooks for people?
5. What are all the sources of income for the household? Are there any income earners other than the head of household? Remittances?
6. On average, how much money does your family make per [amount of time]?
7. What assets do you own that you're most proud of?
8. What is the highest level of education you achieved? What is your husband's/head of household's education level?
9. Where is your kitchen? Is it a stand-apart kitchen? In the house? No kitchen?
10. Where is your preferred place to cook?
11. Does anyone help you cook? Who and when?
12. Do you normally cook with one or two fires?
13. What kind of fuel do you use most often? Why do you prefer it?

14. Do you ever use charcoal/wood instead? If so, when and why?

15. What size of fuel do you buy, and how much do you buy at a time? How often do you buy it? Do you ever harvest it or make it yourself?

16. Where do you usually buy your fuel from, and how long does it take you to make a trip to buy fuel? (if a trip to the village- by car or motorbike? How much does transport cost?)

17. How much do you pay for the fuel (per day or per week?)
    _____

18. Do the sizes, or prices, of fuel you buy change in the dry or wet season?

19. Do you spend more on fuel in the wet or dry season, or the same?

20. Do you usually buy other things or do other errands in the process?_____

21. Do you make a meal in the morning? Does it require heat? How long is the heat burning for?

22. Do you make a meal in the afternoon? Does it require heat? How long is the heat burning for?

23. How long does it take you to prepare the coals/wood for cooking? How do you light the fuel?

24. Do you ever prepare wood, charcoal or gas for anything other than meals? (Heating water for tea, for example). If so how often, and do you use the same fuel as the meal or extra?

25. Have you ever used gas, kerosene or another alternative or improved cooking stove? If yes, when?

26. What do you like most about cooking? What do you like least about cooking?

27. What is the easiest dish to prepare? What is the hardest dish to prepare, and why?

28. So far, what parts of this stove do you not like? What parts do you like?

29. So far, what parts of the fuel do you like? What parts do you not like?

30. Where do you plan to cook with this stove? (In the same place as before?)

31. How do you think cooking on this stove will be different than how you normally cook?

32. Do you have any other thoughts about the stove at this point?

Interviewee gender: M or F Interviewee age: _____ # of kids: _____ Religion: _____

Empty bottles collected: _____ Full bottles left with them: _____

Current Cost estimate of wood/charcoal fuel per day: _____ per person: _____

Form H. Household Follow-up Interview (Week 1)

Stove Number: _____ Interviewer names:_____

If you had to guess, how much money do you think you spend on charcoal/wood each day? _____

How much money do you spend on food each day? _____

How many meals could you cook on each canister before you had to fill it again? _____

How often have you had to put fuel into your stove? _____

When you add, do you add two bottles at a time or fewer? (How much?) _____

Are there times you are still lighting charcoal or wood? When are the times you are not using the stove?

How do you determine if it the stove running out of fuel? What indicators do you use to tell?

What are you using to light the stove?

_____

How would you feel about a one-burner stove? Would you use charcoal also? If so, what for?

Does the food taste the same as when you cook it on charcoal?

_____

Tell me more about your experience with the stove and fuel this past week. What do you think of it? What do you like about it? What do you not like about it? (*Write notes on the backside of this sheet)*

Total bottles they have:_____ Empty bottles: _____ Full bottles left with them: _____

Form I. Household Follow-up Interview (Week 5)- Purchase

Stove Number: _____ Interviewer names:_____

How many times per day, and how many days of the week do you use the stove?

_____

Do you cook your meals on the stove? What types of things do you use the stove for?

How did you used to prepare these things? (or did you used to do them at all?)

_____

Do you have a gas burner? If yes, do you still use it? What do you use it for and what do you use the ethanol for?

How do you feel ethanol compares to gas? Which one do you like cooking with more and why?

Which one do you feel is more expensive? Why?

_____

How much would you pay for this bottle in order to use the stove for all your cooking?

_____

Where do you think is the most suitable place to buy ethanol?

Form J- Household Interview Week 5 (No purchase)

Why have you chosen not to purchase fuel since we began selling it?

Do you have a gas burner? Are you using it? If so, what for?

How do you feel ethanol compares to gas? Which one do you like cooking with more and why?

Which one do you feel is more expensive? Why?

How much would you pay for this bottle in order to use the stove for just some things like boiling water?

How much would you pay for this bottle in order to use the stove for all your cooking, like you did the last two weeks?

Where do you think is the most suitable place to buy ethanol?

XVI. Appendix H: Final Report

FEASIBILITY OF ETHANOL FUEL IN BO, SIERRA LEONE

JANUARY 2019

DESERT WATER & UC DAVIS
Authored by: Dana Armstrong

UC DAVIS
UNIVERSITY OF CALIFORNIA

Report Brief

Research Design

From 1 August to 28 October, our team from UC Davis partnered with Sierra Leonean native Martin Kailie and his organization Desert Water to determine whether ethanol made from cassava could be a feasible source of cooking fuel in Bo, Sierra Leone. Fifty stoves were purchased from Project Gaia NGO and 1,500 liters of 96.5% refined spirit were donated from Sunbird Bioenergy.

Energy Market Analysis: We performed about 250 interviews to analyze the existing cooking fuel market, including the charcoal and wood supply chain, butane gas market and rates of biomass consumption.

Household Research: We then placed ethanol-burning stoves in 24 interested households and tracked their qualitative feedback and rate of consumption. After two weeks of free fuel, we instituted a price per liter of Le 8000, followed by a reduction to Le 6000, and purchase rates were tracked.

Market Traction Initiative: We distributed the remaining 24 stoves to interested customers with perceived higher willingness to pay as a way of gaining market traction. All 50 stoves are on indefinite loan to maintain a small, local market

Findings

Energy Market Analysis

- Households spend an average of **Le 2000 per day** for their daily fuel needs
- Household size has little to no effect on fuel consumption rates
- Charcoal is slightly favored over wood
- About 2/3 of villagers surveyed expressed concern over finding enough biomass supply in the future
- No households used butane gas as their primary fuel source, but only used it for heating water, frying eggs and other small tasks
- The price of butane gas if used for all household needs would be ~Le 6000 per day.

- 2015 Census reports substantial kerosene and electricity use for cooking (~1000 households), but we found no indication of this.
- Freetown households spend ~Le 3000 per day on charcoal, a 50% increase to Bo
- Few households cook with wood in Freetown, most all use charcoal
- About 16% of the population in the Western area uses electricity, gas or kerosene for all cooking tasks as opposed to 9% in Bo district (Census 2015)
- Butane gas in Freetown is about 15% cheaper than Bo

Household Research

Quantitative

- Households use an average of 0.9 liters of ethanol for household tasks per day
- Fuel use varied from 0.4 to 1.5 liters per day, and was only loosely correlated with household size
- When fuel was sold for Le 8000 and then Le 6000 per liter, households immediately began treating the fuel the same as butane gas, for small tasks only
- When sold at Le 6000 per liter, if households were to continue to use fuel for all tasks, this represents an average 200% increase on daily fuel expenses. For two of the 24 households, calculated costs were the same price or cheaper than biomass.
- When sold at Le 6000 per liter, ethanol can **very competitive** with butane gas.

"If a stranger visits, I can prepare food fast!" -Bernadette

"I like that I can put it on the table and stand while cooking. It is much more comfortable than sitting on the little stool" -Agnes

Qualitative

- Most households praised the stove for its *cleanliness* (no smoke) and *speed*
- Women praised the ability to put it on a table or other surface, thus helping their ergonomics
- There is a persistent fear of compressed gas like butane. Households expressed thankfulness at the lack of explosivity of the fuel (at the small scale)
- Many articulated the belief that selling the stove would not be hard as long as the fuel was available
- Most suggested selling fuel at petrol stations or supermarkets, much like gas

Market Traction Initiative

- Hand-picked high-income households purchased fuel at a higher rate than those in the study
- From the months November through January, all **households purchased fuel at the average rate of 2 liters per week.**

Recommendations & Takeaways

Recommendations

Safety

- Ethanol should only be stored in labeled containers. Ethanol distributors should not fill random, unlabeled containers as is common practice with other substances in the country.
- The addition of denatonium benzoate (Bittrex) or alternative denaturant to deter drinking is critical. The addition of methanol is highly discouraged as it can lead to blindness.
- Third party distributorships should be well monitored to ensure product is not distilled again to remove Bittrex, and/or watered down for sale for consumption

- Stoves should be sold at designated locations, and anyone wishing to purchase a stove must sit through a safety orientation on fuel handling and management.

Market for Ethanol

- Interview feedback revealed fuel should be sold in petrol stations, dedicated stores or supermarket locations.
- We recommend dedicated stores that sell stoves and fuel together
- Selling butane gas as well could allow tapping of the same market
- Ethanol containers should be sold sealed, and empty containers returned re-sealed
- Individuals' personal canisters could be filled, as is the case at petrol stations, but should be appropriately labeled
- We recommend ethanol bottle sizes of 1 liter, 5 liters and 10 liters. Containers larger than 5 liters would require an intermediary container for pouring and handling.
- Ethanol should be transported in large barrels or tanks and filled at the destination in order to minimize transportation costs
- Denatured ethanol should not be sold for a final market price higher than Le 6000. Such prices would make it less competitive than butane gas.

Market for Stoves

- Carbon financing initiatives could cover the cost of Cleancook or other ethanol stoves to make them available to Sierra Leoneans for a reasonable cost (Le 150,000 or less)
- Local fabrication of stove bodies can be made to provide local jobs and could be sold for Le 25,000 each, but ethanol fuel canisters from Cleancook would need to be purchased, shipped and imported for a rate of about 10 USD per item (though carbon finance may also apply)

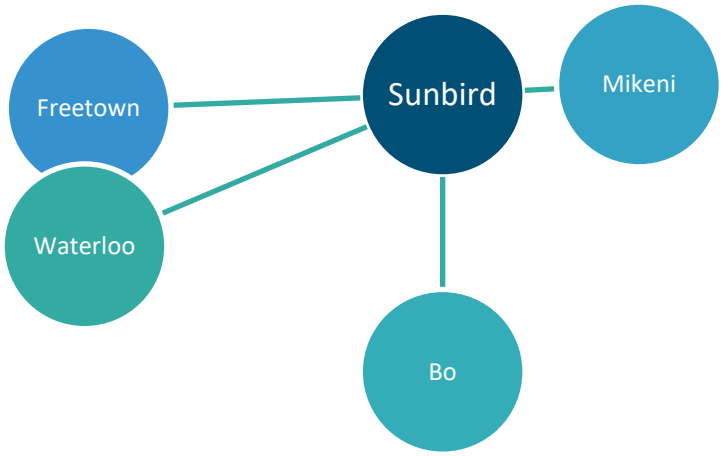
Business Viability

If sold out the gate at Sunbird for Le 4000/liter and for a market price of Le 6000/liter, a margin of Le 2000 per liter may be manageable for operating costs at scale. Funding from external sources such as UKAID, Global Alliance for Clean Cookstoves or carbon financing initiatives may be required for the success of this endeavor.

If financial support can be available for the stove bodies themselves, we anticipate a maximum market of up to 80,000 stoves (~10% of households) throughout the country, as roughly this many households use improved fuels in the 2015 census. If these households purchased 2 liters per week, this could be 1.4 million liters per week that Sunbird could provide.

If out-the-gate to distributor price was Le 4000 per liter, this would be a weekly revenue of about USD $321,000 for distribution. Roughly ¼ of these revenues would need to go to petrol costs in transportation, leaving about $240,000/week for vehicle hiring, personnel, and infrastructural and business costs. This manageable a margin likely won't be reached until scale is high.

Distribution hubs can receive refined spirit in large tankers for a per-liter transportation cost of ~Le 400 (Le 100 for Mikeni or Le 800 for Bo). Fuel can be transferred from tanker to barrels at each major hub for any further distribution. Individuals at points of sale can dispense ethanol through barrels into smaller containers for sale that can be returned and refilled.



Potential recommended regional distribution hubs

Overall Takeaways

If offered at the price of Le 6000/liter, most households will consume fuel at the rate of about 2 liters per week, and use fuel not for primary cooking but quick tasks like boiling water and frying eggs. For tasks like this a one-burner stove should be imported, not a two-burner (preferred for cooking meals).

An ethanol fuel market would make the most sense when established in Freetown, due to population density and ability to pay. It would also be feasible in Mikeni, due to minimal transportation costs from the plant. Savings from these markets may help to subsidize expansion in regions like Bo or Kabala.

Ethanol burns far more cleanly than biomass fuel. Because of its “carbon neutral” reputation, carbon financing should be pursued to support this initiative, as its success would be more greatly ensured if the stoves were subsidized. Organizations like the Global Alliance for Clean Cookstoves can be leveraged for support.

Further analysis of cassava as a feedstock would be beneficial. Prior experience on the allocated Addax land has resulted in low sugarcane yields. Despite the added investment costs in saccrification infrastructure, cassava can perform on par with other feedstock sources as seen in Thailand and China. Cassava grows well in degraded lands, which are (arguably) the only land use type that will keep overall lifecycle carbon output lower than had the land not been cultivated. Locals can grow cassava more readily and its hardiness can provide more resilience for outgrowers, should a contract growing arrangement be developed.

Partnering with existing organizations and infrastructure may be beneficial for market leverage and growth, rather than building distribution channels from scratch.

Critical Questions for Next Steps

Can Sunbird Bioenergy sell their ethanol out the gate domestically for less than Le 5000/liter?

What role is Sunbird interested in playing in the domestic distribution and sale of its product?

Can financing be secured for the further import of ethanol-burning stoves and to subsidize the project as a whole?

What viable transportation options exist for fuel at scale other than a 43,000 liter tanker?

Would distribution infrastructure best be developed independently or tap into existing networks (i.e. supermarkets, petrol stations etc.)?

Will Sunbird Bioenergy consider cassava over sugarcane, as a more sustainable feedstock?