Sustainable Biofuel for Sierra Leone

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Introduction

Burning of fuelwood in Sierra Leone is the root cause of deforestation, pollution-related disease, droughts, and flooding in the nation. Over 90% of the 1 million households in Sierra Leone are dependent on fuelwood, causing the loss of 95% of the forest cover, high rates of pulmonary disease for women and children who spend time in the kitchen and increased risks of injury, snake bites, and rape for rural women who collect fuelwood (Kailie, 2018). Rapid deforestation contributes to the risk of severe droughts, flash floods, ecosystem destruction, and fresh water scarcity all of which destabilize the resilience of rain fed agriculture which the rural subsistence farming population depends on. Every year, Sierra Leone experiences high levels of humanitarian disasters due to flooding and mudslides, and widespread hunger after farms fail or get destroyed by droughts and flooding. The Climate Vulnerability Index ranks Sierra Leone the second most vulnerable in the world, due to lack of adaptive capacity (UNDP, 2016). Throughout West Africa the situation is identical, 90% of the 43 million households use fuelwood.

Transitioning to an alternative fuel source will benefit both the urban households who depend on fuelwood and the rural women who cut down the forests to provide it. Ethanol stoves provide more heat than wood or charcoal fires and produce less soot and smoke, so cooking can happen faster and cleaner. The social impact will be greatest for women and children who avoid the dangerous occupation of fuelwood harvest and the unhealthy kitchen environments that result from burning biomass indoors. Local communities which currently depend on the unstable and over exploited fuelwood market will benefit by transitioning to sustainable agriculture business growing feedstock for bioethanol production.

Ethanol stoves represent a huge leap in technology compared to biomass stoves but are very similar in terms of usability to stoves currently used in Sierra Leone, especially the kerosene stoves which are common in urban areas. These similarities in function and user experience mean that ethanol stove technology should prove easy to learn and quick to adopt. Finally, this project has the potential to alleviate unstable environmental conditions by reducing the deforestation and carbon emissions associated with wood burning and providing alternatives for the community to adapt to climate change.

Project Scope

The long-term goal of this project is to redirect the developing energy market of Sierra Leone towards sustainable bioethanol. This transition will be achieved through 3 specific growth objectives:

1. Establish a market in the urban centers for cookstoves and bioethanol
2. Coordinate an effective transportation system for bioethanol feedstock and product (harvest-to-production and product-to-market)
3. To empower and further develop the farmer cooperatives that produce bioethanol feedstock

Naturally the transition of an entire country's energy market cannot be achieved in three months of fieldwork. Therefore, we adopted a more specific scope for this phase of the project targeting immediate adoption challenges and data acquisition. The scope for this ‘mini-pilot study’ includes:

1. Understand dynamics of the existing energy market
2. Introduce bioethanol technology to target households
3. Determine bioethanol consumption rates and marketable price per liter
4. Demonstrate market traction by selling fuel on a regular basis to consumers
5. Prototype ethanol stove for local production

Project Phases

The implementation of this project can be understood through 3 distinct phases:

1. **Existing Energy Market Analysis**
2. **Ethanol Pilot & Market Traction Phase**
3. **Local Ethanol Stove Prototyping**

The methodology and outcomes of each phase are discussed below.

Existing Energy Market Analysis

Methodology

Upon arrival to Sierra Leone, our first objective was to understand the dynamics of the existing energy market. Specifically, we wanted to learn what types of fuels were popular for cooking, the average cost of these fuels per day, and the fuel preferences of different socioeconomic groups. To gather this information, we conducted interviews with 200+ individuals of varying income levels/economic circumstances. These interviews were split between producers/retailers of fuel and consumers. We asked qualitative and quantitative questions about the biomass fuel production chain, and people's cooking habits and expenses.

Outcomes

The relevant data from our survey is summarized in Appendix A. Our key findings are:

- Most households spend about $3.60 per day (Le 30,000) on food for their household.
- Most households spend about $0.24 per day on charcoal or wood (Le 2000) for cooking.
- The price of fuel has a direct correlation to location. Fuel is least expensive at the point of production (often in the villages for charcoal and wood)
- Biomass fuel in the capital city of Freetown is more expensive, around 50% more, with a bag of charcoal costing around $3-3.60 and daily fuel costs around $0.30-0.40.

Figure 1. Okada riders bringing charcoal from village to Bo

In addition to these findings, the survey also highlights some ongoing transitions in the market. Charcoal is generally preferred over wood as it creates less soot and smoke while cooking and is more energy dense. Charcoal is generally sold wholesale in 50kg rice sacks for 18,000 leones ($1.80-2.16), these sacks are often bought by retailers who divide the charcoal into small plastic bags which they sell for 1000 or 2000 leones. Many families choose to purchase the large bag of charcoal for $1.80-2.16. This lasts about 2 weeks for most families. They therefore spend less per day (~$0.18 per day) on fuel than families that cannot afford to buy the large bag and instead spend about $0.24 on small plastic bags of charcoal for use that day. At a glance, it appears there is no positive correlation between household size and increased expenses on fuel. Some families report they cook for 15+ people on $0.12 worth of fuel while others cook for 3 or 4 and report spending $0.30-.40. Fuel expenses increase during the rainy season when dry fuel is harder to find.

Middle- and upper-income families often have a butane gas burner which they'll use for small tasks such as boiling water or frying an egg in the morning. This kind of stove is perceived as very expensive as it costs about $11 to refill the tank, so it is only used special small tasks. This refill cost has recently been climbing and only six months ago was closer to $8, as the new government has eliminated the subsidies on gas to prevent illegal smuggling across the borders to Guinea and Liberia. Gas in the capital city Freetown is cheaper to refill, around $9-10. This follows the natural access phenomenon where imported goods are more expensive in the countryside and cheaper in the capital, whereas domestically produced goods (like charcoal and wood) are cheaper in the countryside than the capital. Reported duration of fuel tanks varied widely from two weeks to several months, depending on the rate and amount of use. Our surveys and experiments suggest 1 butane tank will last around 2-3 months if used for small tasks and around 2.5 weeks if used for everything including cooking. If it's used for everything, this cost would be about $0.66-0.72 per day in Bo.

Ethanol Pilot and Market Traction Phase

Methodology

The soundest way to determine a given product's success in an unknown market is through a pilot study. To determine the acceptability of ethanol technology in Sierra Leone our team carried out a two-month pilot study using the NOVA 2 cookstove currently produced by CleanCook, AB in South Africa.

Outcomes

We loaned a set number of cookstoves to participating families in the Bo region and supplied each family with ethanol fuel while conducting regular interviews and surveys to understand the factors with the greatest influence on marketability. The first step was to identify families to participate in the research phase. We held an information session and distributed 24 stoves to eligible participants. We supplied each participant with unlimited free fuel for 2.5 weeks and encouraged each to use the stove for all household needs, completely replacing wood, charcoal, and gas. This free fuel period allowed participants to gain confidence to using the stove and provided data for fuel consumption. During this time, we learned that about a third of households use 0.5-0.9 L per day, a third use 1 L a day and a third use more than 1 L per day.

Following this free fuel period, we began to sell ethanol at a projected market price of 8000 Leones/liter ($0.95). The data from this period of the study suggests how the stoves would be used in the current market. In reaction to this price, every participating family began conserving their ethanol and resumed using charcoal and wood for many tasks. In many ways the ethanol stove began being treated like a gas burner, used to boil water and for quick, special tasks. Table 1 shows that the cost of ethanol is not competitive with charcoal or wood thus ethanol will be competing in the butane gas market. Around this time, we made the stoves available to anyone able to buy fuel regularly and thereby demonstrate the potential marketability of ethanol. While we intentionally selected average income women for the research phase we chose to allow anyone to buy in for this market traction phase. Thus, the participants were mainly high income men, many of whom regularly used gas burners.

"I love the stove it is so fast and there is no smoke but the cost. It is too much cost. The wood is 2000 [leones]. We will use the wood."

Table 1: Realized Cost of Cooking Fuel in Bo Region

	Average cost per unit	Average quantity used per household each day	Average cost per household each day
Fuelwood	$0.012/kg	20 kg	$0.24
Charcoal	$0.10/kg	2.4 kg	$0.24
Butane Gas	$1.25/liter	0.55 liters	$0.69
Ethanol	$0.95/liter (projected)	1 liter	$0.95

Data: (Kailie, 2018) and (Murren and Debebe, 2006).

Local Ethanol Stove Prototyping

The Ethanol Pilot and Market Traction phases were carried out using double burner CleanCook Nova 2 stoves imported from South Africa. We obtained these stoves at a reduced cost through partnership with US based NGO, Project Gaia, an organization dedicated to spreading clean cooking technology. Even with this reduced cost the stoves cost us over $3000 due to shipping fees and import duties. This stove model retails for $55 in South Africa and with the addition of import duties and shipping and handling fees, each of these stoves would cost more than $80 in Sierra Leone. This price is not at all competitive in the Freetown or Bo market where a gas burner can be obtained for $18. In addition, the double burner design of the NOVA 2 proved to be inappropriate for this market as although families use two fires to cook, very few of our research participants chose to use ethanol for proper cooking and instead only used one burner for quick tasks like boiling water. These problems with the NOVA 2 suggest a need for a different stove model for this market.

One potential alternative is the CleanCook COMET 1 ethanol stove which is also produced in South Africa but designed for local assembly from a flat packed galvanized-steel template. This option would still incur high costs from import duties meaning these stoves would remain inaccessible to most of the market. A more accessible alternative would be to fabricate stoves locally to avoid import fees, provide opportunities for local fabricators, and create the most appropriate design through a community co-design process.

Methodology

In order to explore the local fabrication option our team partnered with three local fabricators in the Bo region. We identified the key features of the CleanCook NOVA 2 and surveyed our research participants to discover what stove attributes were most important for users. From this information we determined the following design criteria:

1. Incorporates induction chimney to increase heat
2. Incorporates device for flame regulation
3. Uses cheap, locally available materials
4. Must be safe and easy to use
5. Uses simple, available fabrication tools and techniques

Each fabricator shop was given a CleanCook stove to examine and asked to attempt to redesign a cheaper version of the imported stove using local materials. This approach assumed the fabricators would be comfortable undertaking a design process to create a unique stove design. This assumption was incorrect, and we were surprised when the first two shops built two exact replicas of the CleanCook model that painstakingly imitated every minute detail of the CleanCook while overlooking the function and cost of the work. These prototypes did not take account for the design criteria but were innovative as each found unique ways to replica the appearance of the imported stove. But appearance was not the goal and these techniques were labor and cost intensive. One fabricator suggested we charge 1 million leones ($100 usd) for each stove. It was clear the objective to change the design to reduce cost had not been understood.

To ensure the design objective was understood, Peter got directly involved and began working with our third fabricator shop, a recycling center specializing in charcoal coalpots production. Wanting to keep the stove design simple and familiar we chose to borrow design and fabrication attributes from the coalpots the fabricators were used to building. Simply adapting one of the coalpot designs to fit the cleancook canister resulted in our first prototype.

The coalpots our fabricators normally produced using sheet metal and simple bending and folding techniques

The first ethanol stove prototype, built using familiar coalpot design and fabrication techniques

This prototype was crude, and the round shape made exact measurements difficult. For the final prototype we abandoned the use of coalpot fabrication techniques and looked instead to the CleanCook COMET 1 for inspiration. This final prototype is built from a single sheet of folded sheet metal with a separate pot stand. We named this stove the GONDAEGOTI stove after the Mende word for cookstove. This stove will cost a projected $2 to build and is designed to use a CleanCook canister which can be imported for $7.

Outcomes

The local ethanol stove design process revealed a lot about the economy of things in Sierra Leone. The reception of our initial prototypes by users was extremely poor based solely on the aesthetic appearance of the stove. This revealed that aesthetics can be just as important as utility even when launching products in a developing economy. Thus, it was essential our final prototype was more polished to appeal to the users. Ultimately the option to produce Gondaegoti Stoves in Sierra Leone would reduce the buy-in cost of ethanol technology from $80 to $10, a dramatic reduction which would make the technology accessible to a larger portion of the market. A comparison of the CleanCook NOVA 2 and Gondaegoti stove is provided below.

Stove Metrics

CLEANCOOK

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	Neligigble soot or carbon. Meets WHO standards for carbon monoxide emissions
Dimensions (WxDxH	608 x 288 x 168
Cost	

GONDAEGOTI STOVE

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	Neligigble soot or carbon. Meets WHO standards for carbon monoxide emissions
Dimensions (WxDxH	608 x 288 x 168
Cost	

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
Cost	

Learnings and Project Continuation

Though the research we undertook seemed straightforward at first, we were often surprised by the results, particularly when they highlighted cultural differences in mindset, decision making, and general way of life. During the Energy Market Analysis phase, we were consistently surprised to learn that retailers of charcoal and wood often took no account of their earnings, stock, or sales. Furthermore, fuel consumers did not always know their income or expenses. Most consumers did not know that other cooking fuels existed which posed a challenge when we attempted to explain the benefits of ethanol technology. In many ways this increased the importance of the cookstove in relation to the project as it was only through the cookstove that people could understand the uses and benefits of ethanol. Although the project goal is to create a shift in the energy market, understanding the consumer market for the stove became a top priority. Our research participants frequently expressed great appreciation for the stove despite the fact that a relative few chose to purchase fuel. 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 to prototype a local ethanol stove, stoves must be pretty.

The process of conducting this research was also nonstop string of surprises and unanticipated outcomes. One key observation from the energy market analysis was the preference for buying all consumable products in very small quantities for single use. This is the exact opposite of the American cultural preference for buying in bulk and we had to adapt our ethanol sales technique selling fuel in 330ml bottles rather than gallons as we planned. This relationship eventually inverted when we entered the market traction phase as our 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 as they rarely visited the marketplace.

Ethanol fuel has massive market potential in Sierra Leone. The future of this project and the widespread adoption of ethanol depend on several key challenges. First, a reliable ethanol distribution system must be put in place. The infrastructure of the county makes this challenging, a good approach would be to establish a distribution network around the production plant in Makeni with regional hubs to store ethanol and distribute ethanol within each district. Ensuring a low and stable price for ethanol will be another major challenge as all the production is controlled by a single company, Sunbird Bioenergy. Partnership with Sunbird is critical and all though they were hugely supportive of this pilot study the company has recently come under new ownership, so our partnership must be reestablished. The final challenge will be bringing safe reliable ethanol stoves into the market for a marketable price. This could be achieved through production of local Gondaegoti ethanol stoves or through a successful funding application to import CleanCook COMET 1 stoves. Martin Kailie will remain in charge of this project and intends to pursue funding options for the future project development.

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