Duke University Nicholas School

Master's Project

BUSINESS PLAN FOR SUSTAINABLE ETHANOL COOKING FUEL IN DEVELOPING WORLD

Prepared for Project Gaia

Authors:

Wenjing Shi: MEM'14

Kerui Zhou: MEM'14

Contents

Figures and Tables

Executive Summary

Ethanol is considered as a promising cooking fuel in developing countries, particularly in South Asia and Africa, because of its economic, environmental and health benefits. It can be cheaply produced at lower costs than biomass resources and charcoal; it can reduce in-door exposures to pollutants resulting from in-door combustion; it can eliminate the need of women and children to spend hours every day gathering fuel wood and the dangers that accompany it, such as corporal threats, threats from wild animals, and physical exhaustion.

In order to find a clean and ideal solution to meet the cooking demand of developing world, we believe an ideal technology is where stove and fuel can work in harmony to yield benefits cost-effectively. Since our client Project Gaia's Cleancook stove requires local and affordable ethanol supply, we assessed the technical and economic feasibility of a local representative, small-scale ethanol plant, based on a fully-integrated solution, encompassing feedstock supply, which is at the beginning of supply chain, through to ethanol product distribution and retailing plans.

The local production of ethanol in a small-scale plant (i.e., 5,000 liters per day) proved to be cost-effective based on estimates developed from a spreadsheet cost model. In the model, the capital requirements were amortized (i.e., including equipment investment requirements, land acquisition costs, fixed operations and maintenance costs, etc.) and variable costs (e.g. feedstock costs, water costs, yeast costs, etc.) were taken into consideration. The results suggest that a small-scale local ethanol plant is economically feasible because the ethanol cost turns out to be $0.65 per liter which compares favorably to alternatives such as charcoal which costs $0.68 per day.

Cooperation between plant and local farmers is a win-win situation. The ethanol plant needs to purchase feedstock (e.g. sweet sorghum and sugarcane) from nearby farmers. Generally, 50-75 small farmers can provide enough feedstock supply to keep the plant producing at full capacity. The farmers can earn extra cash from selling the feedstock and improve their life. A core group of farmers and can fully support the production of plant.

Plans for the distribution of ethanol fuel and the recycle of ethanol bottles are also considered. Ethanol – in small-sized bottles made of durable plastic – can be distributed through designated stores in villages, towns or at local market places. Additionally, ethanol can be delivered to subscribers in town once or twice a week. Furthermore, we believe selling carbon credits generated from the use of clean cooking stoves to external investors may be an effective way to finance the purchase of stove for low-income residents, who live on a daily income around 2 dollars and cannot afford a Cleancook stove.

Local ethanol production and the Cleancook stove can benefit the farmers, the local community and the country. This approach will create jobs for adults as workers in distilleries that produce ethanol fuel, increase farmers' income by signing long-term feedstock supply agreements, yield environmental benefits and health benefits to local community and residents, and potentially provide carbon finance products to external investors.

Background

Current Household Energy Use in Developing Countries

Energy is a necessity for daily life, but more than 2.6 billion people in developing countries have little or even no access to modern types of energy. They have to still rely on traditional biomass for cooking (International Energy Agency (IEA, 2010). This implies that, 4 out of 10 persons in the world live without modern energy supplies. As shown in Figure 1, the problem is very serious in South Asia and Africa where the suburban and rural population mostly rely on biomass including fuel-wood or agricultural residues for energy demands.

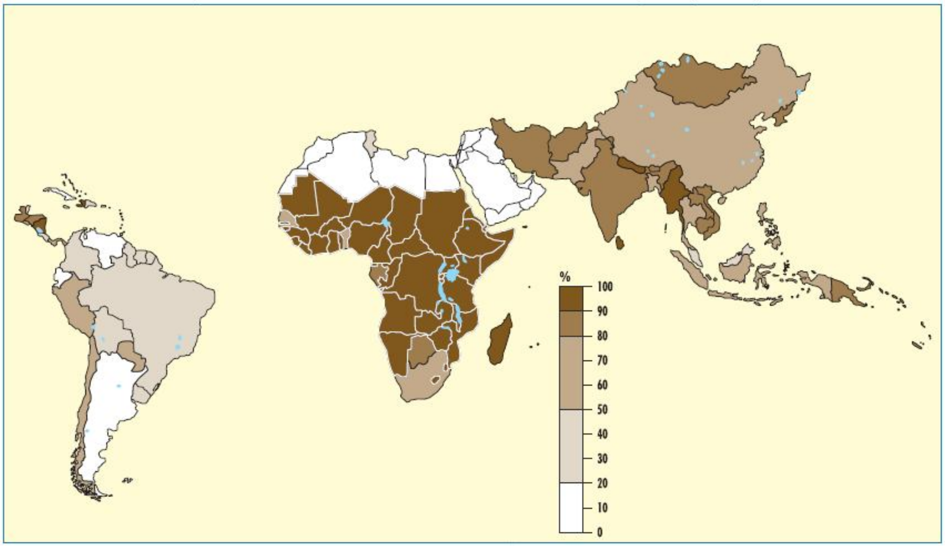

Figure 1 Percentage of Biomass in Residential Consumption by Countries

(Source: IEA, 2010)

According to estimates from United Nations Development Programme (UNDP) and IEA, residential energy use in developing world was 1090 Million of Tonne of Oil Equivalent (Mtoe) in 2004, which accounted for 10% of world primary energy demand. Moreover, 88% of biomass demand in developing countries comes from household use, which is in sharp contrast with developed countries since most of biomass energy demand in developed countries comes from industrial and power generation sector (IEA, 2010).

As to the structure of household energy use in developing countries, it is dramatically varied due to the economic level and income level of each country. Generally, in developing world, the major energy use in households is cooking, followed by lighting and heating (IEA, 2006). In fact, cooking would appear to be the dominant in household energy use for all households, since the demand for space and water heating varies with different geographic locations and climate conditions.

The source of household energy also varies on the basis of income levels. As shown in Figure 2, countries with different income levels have different combinations of household energy supply (IEA WEO, 2010). In low income countries, final per-capita consumption of energy is comprised of biomass. However, as the income level increases, the share of modern energy (petroleum-related products, electricity, etc.) significantly increases because of people's improved access to modern energy and increasing demand for mobility.

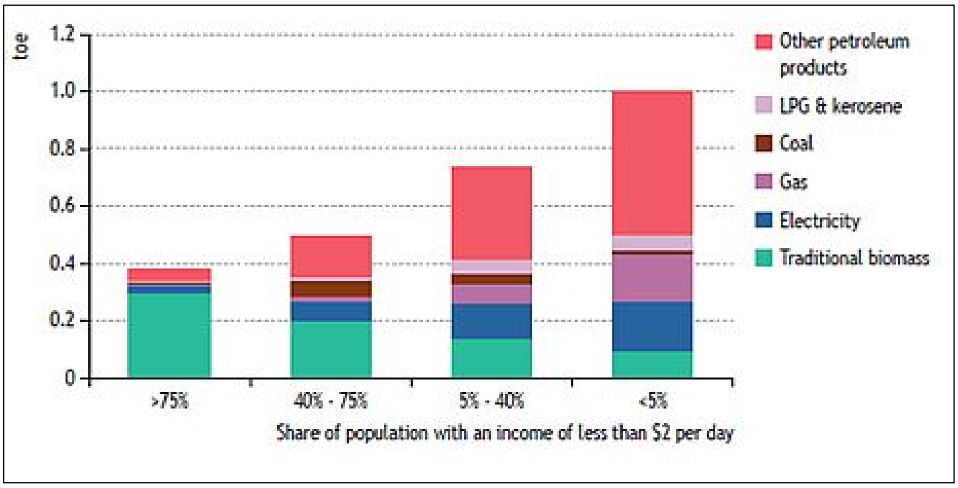

Figure 2 Per-capita Income and Per-capita Energy Consumption in Developing Countries

(Source: IEA World Energy Outlook (WEO), 2010)

Furthermore, different countries have different combinations of biomass energy. Generally speaking, biomass for cooking could be categorized as traditional (e.g. fuel-wood, dung, agricultural residues, etc.), intermediate (e.g., charcoal, kerosene, etc.) or modern (e.g., LPG, biogas, ethanol gel, electricity, etc.). However, even in the same country, dramatic difference in household energy use may exist between rural regions and urban regions. For instance, fuel-wood cooking fuel is approximate 3 times more prevalent in rural regions than that in urban regions of both South Asia and Africa (IEA, 2006). As shown in Figure 3, about 600 million people depend on biomass resources for cooking in Africa, while in the rest of the world, there are more than 1.5 billion people cooking by using biomass resources.

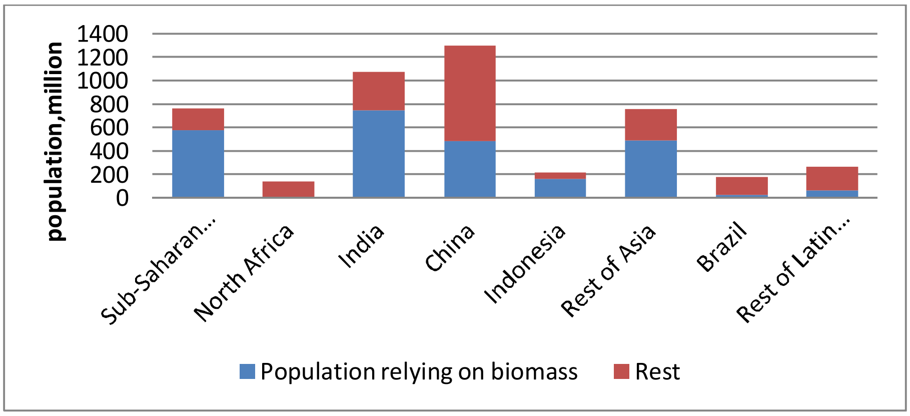

Figure 3 Population living on biomass resources as cooking fuel, 2004

(Source: IEA, 2010)

Health and Environmental Impacts of Current Household Energy

As the combustion of biomass resources is always an incomplete chemical process, the intense use of biomass in developing countries has several impacts on human health, socio-economic conditions and the environment.

According to estimates from World Health Organization, 1.5 million premature deaths result from indoor air pollution brought by solid fuels combustion. More than 85% of these deaths are caused by biomass use (WHO, 2006). Incomplete combustion of biomass results in air pollutants emissions such as CO, NOx, and fine particulate matter such as $PM_{2.5}$ and PM_{10} (which refer to particulate matter smaller than 2.5 and 10 micrometers, respectively[1]) (SEI, 2009). Studies have revealed that, in homes where combustion occurs, typical 24-hour PM_{10} levels can range from 300 to 3,000 $\mu g/m^3$, which is 2-20 times as high as U.S. regulation standard of 150$\mu g/m^3$(WHO, 2006). This has the potential to engender health problems in entire populations, especially in children. Evidence has proved a causal relation between PM exposure and Children's acute respiratory infections, particularly pneumonia, which can lead to death in children less than 5 years old (IEA, 2006). As indicated by Figure 3, the total amount of deaths is highest in Africa and Southeast Asia (WHO, 2006).

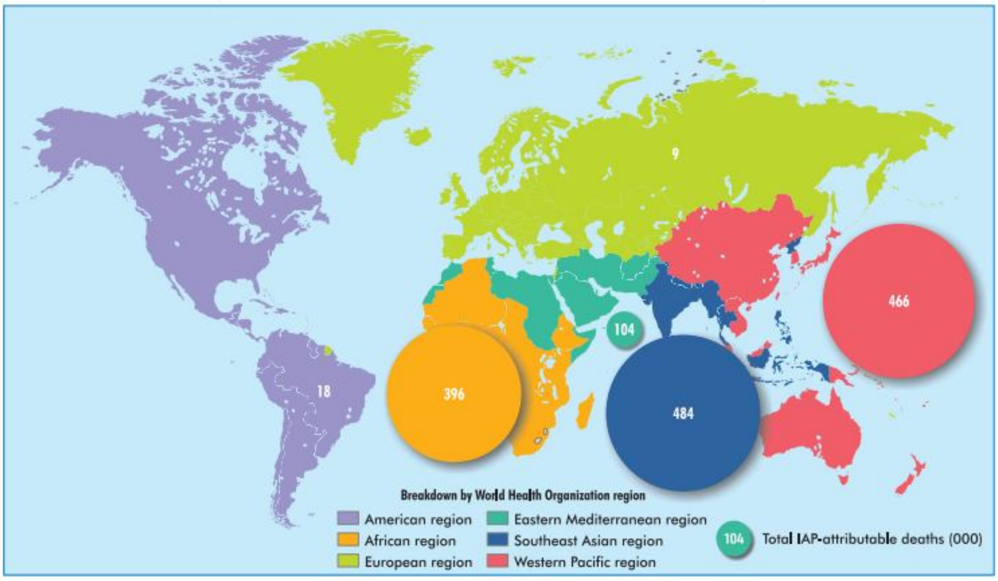

Figure 4 Annual Deaths Caused by Indoor Air Pollution (thousands)

(Source: WHO, 2006)

Women and children are believed to be the most susceptible to indoor air pollution because they tend to assume the responsibility of cooking and doing housework and spend hours staying beside fire stoves. These exposure consequences of indoor air pollution rely on several factors, such as what type the fuel and stove is, how housing and ventilation system are designed, and how much time individuals will

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[1] Particles with less than 10 micrometers in diameter (PM10) can bring negative influence to human health since they can be inhaled into human's respiratory system and accumulate in there. Particles with less than 2.5 micrometers in diameter (PM2.5) are defined to as "fine" particles and are believed to cause the most significant health risk. Fine particles can be deposited inside the lungs for a long time. (www.epa.gov)

spend inside the house. As WHO indicates, indoor air pollution is prevalent in countries with daily income less than $1 per capita (IEA, 2006). This is because the poor families will use low-quality cheap fuels on an old-fashioned stove in an old house without ventilation.

WHO also indicates that women who always get exposed to indoor smoke are 3 times more likely to suffer from pulmonary disease than those who cook with modern electricity stoves (WHO, 2005). Moreover, a child exposed to indoor air pollution is also 2-3 times more likely to suffer from pneumonia infection. In addition, indoor smoke will shorten the lives of those who have chronic diseases. 80% of deaths caused by chronic diseases occur in low to middle income developing countries (WHO, 2005).

Besides the health impacts, the demands for gathering biomass resources (i.e., collection of fuel-wood) are generally assigned to women and children. As shown in Figure 4, women and children in Tanzania spend several hours a day collecting fuel-wood for household use (IEA, 2006). This causes a dramatic opportunity cost in terms of lost education chances and limiting other possibilities generating income.

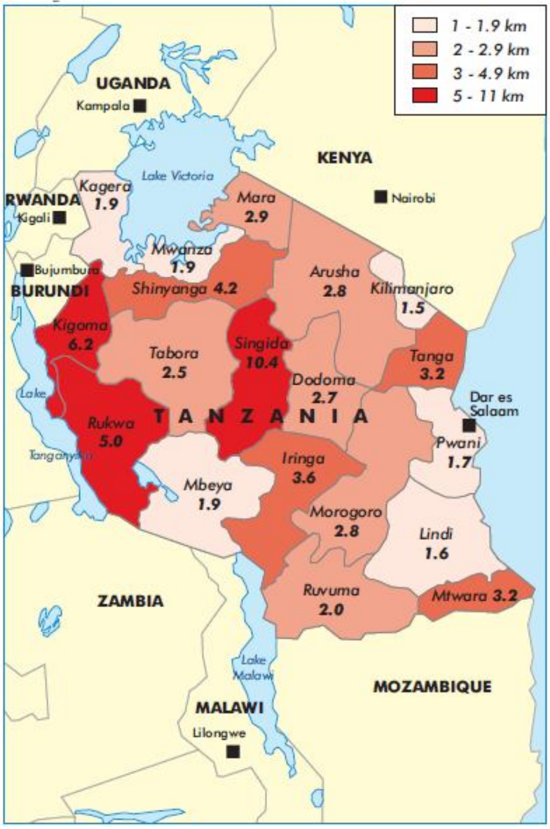

Figure 5 Distance to Collect Fuel-wood in Rural Tanzania

(Source: IEA, 2006)

In addition, the massive household use of biomass has caused several environmental problems. Currently, cooking with biomass accounts for 18% of current global GHG emissions (Bond, 2007). In contrast with oil fuels, biomass not only emits typical greenhouse gases, but also produces black carbon remains. Generally, black carbon soot typically lasts in the air and atmosphere for several weeks, thus reducing black carbon by controlling the use of biomass energy has the potential to diminish the warming effect on the atmosphere relatively quickly. Also, massive use of biomass can create additional pressure on local forests and ecological systems. Although the collection of fuel-wood does not directly cause deforestation because the branches are mainly collected from roadsides or agricultural lands, the production of charcoal from fuel-wood burning has been proved to exacerbate land degradation in sub-Saharan Africa (IEA, 2006). Finally, if fuel-wood and charcoal resources are not sufficiently available, the use of animal dung and agricultural remains for fuel would have to increase, resulting in a reduction of soil fertility.

Ethanol is a Promising Alternative Cooking Fuel

In 2006, United Nations Development Program (UNDP) initiated the Millennium Project to help developing countries to get rid of poverty. UNDP called for adopting the following target of energy consumption in order to help achieve the Millennium Development Goals:

"By 2015, enable the use of modern fuels for 50 percent of those who at present use traditional biomass for cooking. In addition, support (a) efforts to develop and adopt the use of improved cook stoves, (b) measures to reduce the adverse health impacts from cooking with biomass, and (c) measures to increase sustainable biomass production." (UNDP, 2006)

This challenging goal is hard to achieve because the size of the population relying on biomass is going to increase in next one or two decades (IEA, 2006). By 2015, it is expected that there will be 2.6 billion people relying on traditional biomass, with 90% of them living in Africa and Asia. Although in some mid-income developing countries such as China, Brazil and Indonesia, the number of people relying on traditional biomass will decline because of growing economies and massive infrastructure investments, people in the rest of Asia and Africa are still expected to consume a great amount of biomass resources (IEA, 2006). Therefore, measures should be taken to better utilize the biomass resources and minimize the negative effects.

In general, the phase-out of traditional biomass energy from household use could be implemented by improving the way biomass is used and by introducing modern cooking appliances. For example, transforming biomass into less polluting forms of fuel could be a promising approach. Compared with fuel-wood, ethanol, plant oils and biogas are cleaner fuels with much higher heat content. Many of them have achieved worldwide adoption (IEA, 2006).

In addition to the development and promotion of alternative fuels, modern cooking stoves may be another attractive approach to providing clean energy to developing countries. Adding chimneys to stoves, increasing housing ventilation, applying highly efficient stoves are all economically feasible (IEA, 2006). As shown in Figure 5, household cooking stoves are expected to be upgraded with the increase of income level (IEA, 2010). Furthermore, ethanol is a promising alternative fuel in developing countries. As ethanol gel is economically effective in areas with enough feedstock, it has been promoted in some African and Asian countries as a safe and clean biomass fuel. Ethanol gel is viable particularly in areas with large sugar cane plantations that produce ethanol. It is popular in several African and south Asian countries (IEA, 2006). Among these alternative fuels, biogas is commercially available and has become an important option for rural areas in China and other countries of Asia. Biogas is produced by the bacterial decomposition of organic wastes and can yield cost-effectiveness at a larger scale. The production of biogas requires a certain scale of facilities, thus it is favored in dense villages in China and other parts of Asia (IEA, 2006). However, biogas does not work well in Africa due to dispersed villages and insufficient supply of organic wastes. Alternatively, Plant oils, which function like kerosene, have also been deployed around the world. Plant oils are safer and cleaner than traditional biomass, and can be produced locally from certain plants.

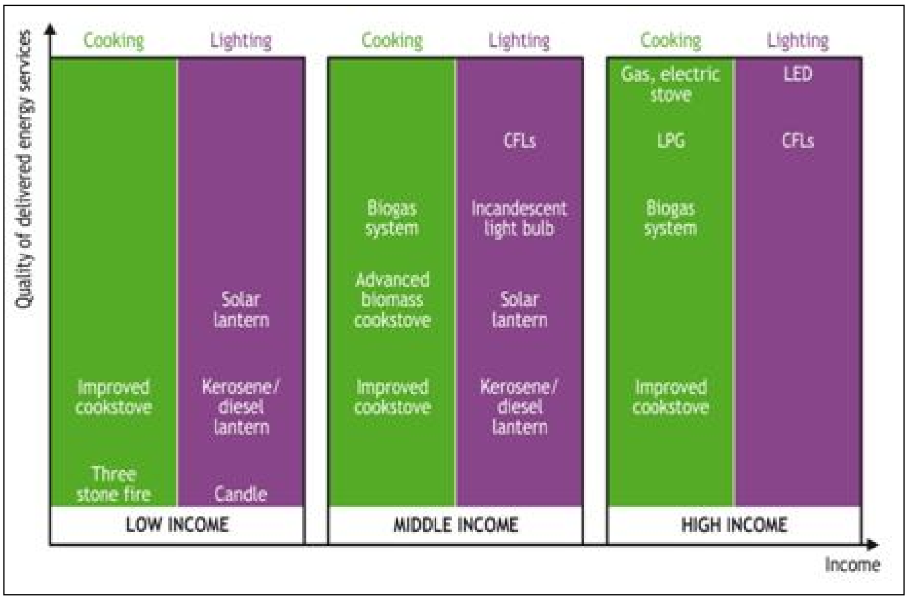

Figure 6 Quality of Energy Service and Household Income

(Source: IEA, 2010)

Studies suggest that improved biomass stoves could save 10%-50% biomass consumption given the same cooking service (REN21, 2005). Currently, hundreds of millions of improved stoves (i.e., including stoves with enhanced ventilation, retained heat cookers, fan stoves or rocket stoves) have been distributed worldwide and achieved different degrees of success. However, as shown in Table 1, in order to meet the target of enabling modern fuels use to account for 50% of those who use traditional biomass cooking fuel at this stage (UNDP, 2006), 1.3 billion people would switch their cooking energy to modern fuels by 2015. This transformation implies great market potential for modern cooking stoves and alternative fuels.

	2004 - 2015	**2015 - 2030**
Sub-Saharan Africa	314	406

North Africa	2	3
India	389	394
China	226	168
Indonesia	85	94
Rest of Asia	261	300
Brazil	13	14
Rest of Latin America	30	28
Total	**1320**	**1407**

Table 1 Additional Number of People Needing to Gain Access to Modern Fuels (millions)

(Source: IEA, 2006)

Product Specifics

We intend to provide the market with two products: an ethanol cooking stove; and supporting ethanol fuel production system. Due to low-accessibility in developing countries and plentiful land for feedstock plantation, we aim to provide the ethanol fuel by local production.

Ethanol Cooking Fuel

The use of ethanol can be traced back to one century ago. Ethanol production was stimulated by oil shock in the 1970s and the several oil disruptions in the 1980s and 1990s, especially in countries such as Brazil, U.S. and Europe. Nowadays, the scale of global ethanol production has exceeded 40 billion liters, which accounts for less than 2% of global petroleum consumption. According to IEA's projections, ethanol can account for 10% and 30% of world gasoline consumption by 2025 and 2050 respectively.

Ethanol has two forms, hydrous ethanol and anhydrous ethanol. The latter requires additional steps of distillation to eliminate water content in ethanol. More specifically, ethanol with 95% purity will be processed by Azeotropic processes or molecular sieve processes to be dehydrated. In terms of the demand of our business plan, ethanol with purity more than 91% is needed. Therefore, we don't need multi-steps of distillation in our production phase. We will further discuss about the production flows in next sections.

Ethanol Cooking Stove

Our product, the Cleancook stove, is produced by Swedish company Dometic AB. The stove is best known for its superior safety, durability and stability of power supply. Its two burners are made of stainless steel, and its body is made of aluminum alloy. Furthermore, the Cleancook stove can be used for a lifetime as long as 10 years, and will consume 1-1.2 liters of ethanol per day to meet the cooking demand of a general African household which consists of 5 people. Additionally, the stove has power efficiency as high as 65%, and will produce low emissions and little soot. The stove has been used in African market for a couple of years and is well-reviewed.

Figure 7 Clean Cook Stove: Appearance

(Source: Courtesy Domestic AB)

Cleancook stove can provide many kinds of benefits to residences in Africa, including health benefits, economic benefits and environmental benefits. First, the households will no longer suffer from cooking smoke and gases generated from the use of solid fuels such as charcoal or fuelwood. Furthermore, the stove is much safer than previous ones and three-stone primitive stoves because it has a non-pressurized fuel tank with special absorptive fiber inside the tank to prevent spill. The stove can adjust the flame of the burner and extinguish the fire by a small regulator. In addition, as mentioned before, durable stainless steel and aluminum alloy stove body can yield benefits in terms of long-term stability and low maintenance demands for stove users. Last but not least, cooking with ethanol can generate environmental benefits by reducing demand for wood, decelerate deforestation and reduce greenhouse gas emissions.

	CleanCook M1/A1	CleanCook M2/A2
Materials	All stainless steel burner parts, body of stainless steel, galvanized steel, high quality enamel finish or aluminum	
Number of Burners	1	2
Bearing Weight	Max 20 kg	
Product Weight	3.1 kg	5.7 kg
Fuel Canister	Fuel tank empty: 0.59 kg/ full: 1.79kg	
Fuel Requirements	Ethanol fuel with less than 10% of water content	
Fuel Capacity	1.2 litres	1.2 liters
Power on High	1.5 kW	
Power on Low	0.3 kW	
Cooking Time	4.5 hours on high power, up to 9 hours on low power	
Average Cooking Capacity	1 liter of fuel per day will provide cooking for a family of five	
Efficiency	Greater than 60%	
Emissions	Negligible soot or carbon, meet World Health Organization standards for Carbon Monoxide Emissions	
Dimensions	320*290*160 mm	596*326*137 mm
Source: Domestic AB Group		

Table 2 Technical Specifics of CleanCook Stove

Source: Domestic AB Group

Overview of Representative Developing Country: Kenya

Our target market is Kenya, especially rural Kenya. Kenya is a developing country in Africa with a population of 44 million people living in a low resource environment. The GDP per capita in Kenya in 2012 is $943, and the unemployment rate is as high as 40% (World Bank 2013). Kenya has a mean household size of 5.1 persons.[2]

Kenya has heavy dependency on wood fuel and other biomass. As the poverty level worsens, there exists a significant shift back to traditional biomass fuels. The proportion of households biomass consumption has increased to 83% from 73% in 1980. Charcoal, firewood, paraffin, and LPG continue to be the main sources of cooking fuel. At the national level 68.8% of the households use firewood as the main cooking fuel (Energypedia). Almost 90% of the rural population is dependent on firewood for cooking and heating (Energypedia), whilst in urban areas approximately 10% of the population use firewood. Charcoal, on the other hand, is mainly an urban fuel, 82% of urban households depend on it as part of their energy mix, compared to 34% of households use charcoal in rural areas.

Electricity access in Kenya is low despite the government's ambitious target to increase electricity connectivity from the current 15% to at least 65% by the year 2022. Currently, domestic households need to pay 17.20 KSH (~US$0.20) per kWh, which is very expensive (source: Business Daily Africa) in comparison to the GDP. Furthermore, it costs ~KSH 35,000 (~US$410) to connect to the national grid; thus, the high connection costs pose a main obstacle to the expansion of electricity connections to low-income households and small businesses. Moreover, high renewable energy installation costs, such as LPG and solar energy, prevent the lower income groups from utilizing these cooking fuels (COFEK, 2010). Therefore, ethanol as a form of biomass energy has great potential in Kenya.

Feasibility of Local Ethanol Production

Feedstock Selection

Currently, ethanol feedstock has three major groups: sugar crops (such as sugarcane, sugar beet, and sweet sorghum), starch crops (such as corn, wheat, rice, potatoes, cassava, sweet potatoes and barley), and lingo-cellulosic biomass (such as wood, straw and grasses).

As shown in Table 3, cassava has the highest annual ethanol yield per hectare, but its production cost is higher than other options. Although sugarcane and corn are most widely used for production at present, sweet sorghum has become more and more promising in future ethanol production.

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[2] Kenya Integrated Household Budget Survey (2005-2006) KIHBS – Basic Report, ISBN: 9966-767-07-X, Available from https://opendata.go.ke/api/assets/BD46451B-3158-4698-8E38-6703631AB578

Type	Annual Yield (ton/ha)	Conversion Rate to sugar or starch (%)	Conversion rate to ethanol (l/ton)	Annual ethanol yield (kg/ha)	Cost ($US/m3)
Sugarcane	70	12.5	70	4900	160
Cassava	40	25	150	6000	700
Sweet Sorghum	35	14	80	2800	200-300
Corn	5	69	410	2050	250-420
Wheat	4	66	390	1560	380-480

Table 3 Production cost and bio-ethanol yield potential from different energy crops

(Source: Balat, M. et al., 2009)

Sweet sorghum is similar to grain sorghum but could grow much faster with higher biomass yields. It could also be widely adapted to different climate and soil conditions, especially in semi-arid tropics, where other crops such as maize fail to thrive (Reddy V.S.B. et al., 2007). Therefore, sweet sorghum has great potential in tropical or sub-tropical areas, for example south Asia and sub-Saharan Africa.

Sweet sorghum has advantages over other feedstock in several aspects. First, it produces both grain and stalks, providing new market opportunities for small household farmers and at the same time does not threaten food supply. In addition, it has much shorter growing period and water requirement than those of sugarcane as indicated in Table 3 (PRAJ, 2012). Moreover, sweet sorghum juice is better suited for ethanol production because sugar can more easily be reduced from it. Therefore, as sweet sorghum offers good prospects for ethanol production economically and environmentally, it is given high priority by many developing countries in Asia and Africa as a complement to traditional feedstock production (Balat, M. et al., 2009).

Parameters	Sugarcane	Sweet Sorghum
Harvesting Cycle	9-14 months	4 months
No of cyell in a year	one	two
Water Requirement	100%	65-70%
Fertilizer Requirement	100%	35-40%
Stalks Production, mt/ha/cycle	65 to 80	42 to 55 for one cycle, 84 to 110 for two cycles per year
Fermentable sugars concentration in stalk, % weight/weight	10.0 to 14.0	9.0 to 12.0
Yield of fermentable sugar, MT/ha/cycle	6-10.5	3.6-6.2 for one cycle, 7.2-12.4 for two cycles
Ethanol (100%) yield, liters/ga/cycle	3400 to 6000	2020 to 3500 for one cycle, 4000-7000 for two cycles
Bagasse MT/ha/cycle, 50% w/w moisture	19 to 24	10 to 14 for one cycle, 20 to 28 for two cycles

Table 4 Comparison of Sugarcane and Sweet Sorghum[3]

(Source: PRAJ)

Technical Feasibility of Local Ethanol Production

Given the advantage of sweet sorghum in Africa, we want to develop the ethanol production model based on sweet sorghum as the feedstock. The sweet sorghum crop cycle is shorter, around 3.5-4 months. In this way, two cycles are possible for the same land in each year. The flow chart for ethanol production is shown in Figure 8: green blocks represent the main line for the conversion of sweet sorghum into ethanol, while blue blocks show the conversion of by-product bagasse into electrical power energy. The major plant components include sweet sorghum delivery and storage, smash equipment, juice extraction, fermentation, distillation and dehydration equipment.

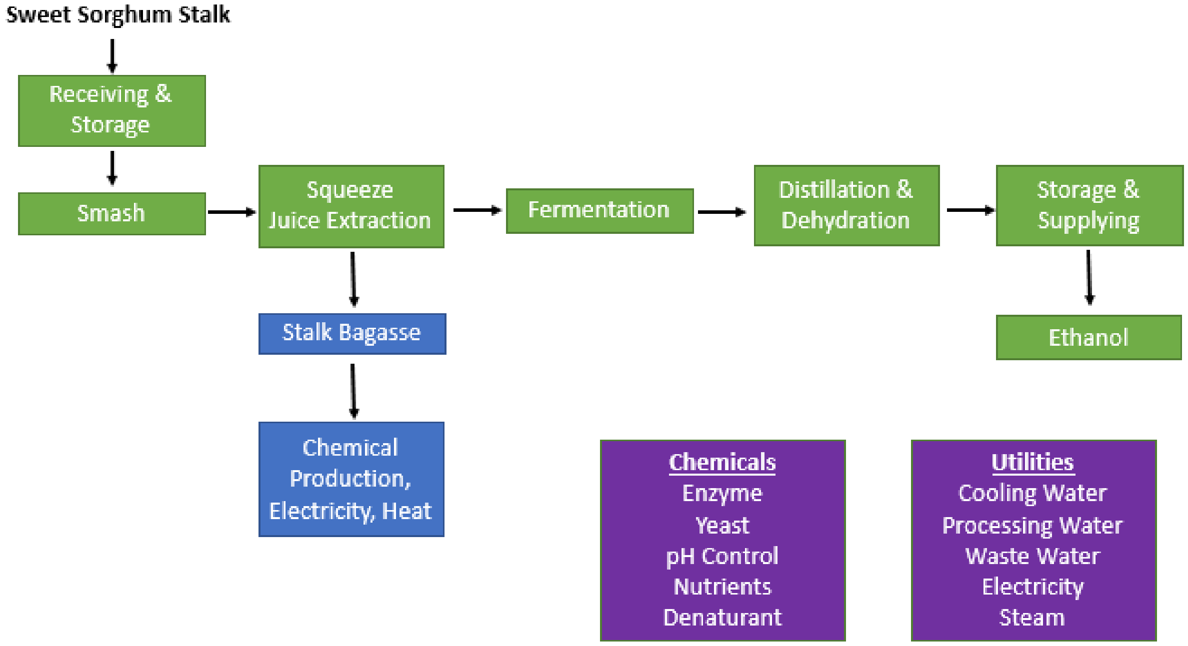

Figure 8 Flow Chart of a Localized Ethanol Plant

Receiving & Storage: In order to break down the ethanol production model, first, a receiving and storage place is needed to store sweet sorghum as the feedstock. Sweet sorghum is delivered by truck or rail to the ethanol plant storage place. Generally, the storage bins should be able to hold enough grain to supply the ethanol plant for 7-10 days.[4]

Juice Extraction: Generally it takes 3 to 5 hours to process sweet sorghum stalk juice into ethanol.[5] The first step is to extract the juice contained in sweet sorghum stalks. The juice generally has 15% sugar

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[3] Sweet Sorghum Basics, available from http://www.praj.net/media/sweetsorghum.pdf

[4] Ethanol Production Process, ICMINC, available from http://www.icminc.com/innovation/ethanol/ethanol-production-process.html

[5] Feasibility Study for an Integrated Anhydrous Alcohol Production Plant using Sweet Sorghum as Feedstock, International Society for Southeast Asian Agricultural Sciences (ISSAAS), Inc., Rm. 411a, Vega Center, Los Baños,

content,[6] and the sugar will be further converted. Bagasse is produced at this stage as the by-product, which can be burnt for electrical power generation in the fuel boiler. In future it could be used in the second ethanol production as the energy input.

Juice Fermentation: Second, fermentation process is needed to ferment the extracted juice with the help of standard yeasts and enzymes. The enzymes break down the dextrose into glucose, which is a simple sugar that is converted by the yeast into ethanol and carbon dioxide. The product is the mixture as mash. The fermenter temperature is controlled with mash circulation through individual fermenter coolers. The mash typically ferments for 48 hours,[7] and results in an approximate 8-14% of alcohol content.[8] The empty fermenter units would be rinsed and cleaned in order to prepare for the next cycle. The hot rinse water have been used in cleaning will be piped to holding tank and reused for cooling water.

Distillation and Dehydration: The mash would be continuously pumped to the top of the distillation system. Steam can be injected at the bottom of a rectifier column, and ethanol will go up the column as a vapor. The distillation configuration separates the alcohol from water with additional heat, to produce two different streams: an alcoholic stream with 93-95% concentration by volume, and a water stream with organic compounds contained in sweet sorghum juice. After that, the alcohol stream needs dehydration configuration to further increase the ethanol concentration up to 99.7% according to ASTM specification for the fuel-ethanol.[9]

Storage: The pure ethanol would be pumped from the day holding tank to the ethanol storage tank. The tank farm includes loading facilities for truck shipment. The ethanol will be waiting to be sold to the local community for the cooking usage.

By-product Bagasse: Bagasse is produced in the sweet sorghum stalk fermentation process. Bagasse could be further used in chemical production, electricity and heat generation.

Economic Feasibility of Ethanol Production

Proper Plant Size

Since rural population of Kenya lives in small remote villages, a large-scale centralized ethanol plant is not a good option because of the barriers in remote delivery. Therefore, small-scale ethanol plant seems

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Laguna.
In order to simply our analysis, we only consider sweet sorghum stalk rather than sweet sorghum grain, since sweet sorghum stalk has obvious advantages over sweet sorghum grain on both energy content and feedstock price.

[6] A Proposal for a Small-scale Bioethanol Factory in Tuscany (Italy) Based on Sweet Sorghum, Eugenio Macchia, December 09 2010, available from http://esse-community.eu/articles/a-proposal-for-a-small-scale-bioethanol-factory-in-tuscany-italy-based-on-sweet-sorghum/

[7] Ethanol Production Process, ICMINC, available from http://www.icminc.com/innovation/ethanol/ethanol-production-process.html

[8] A Proposal for a Small-scale Bioethanol Factory in Tuscany (Italy) Based on Sweet Sorghum, Eugenio Macchia, December 09 2010, available from http://esse-community.eu/articles/a-proposal-for-a-small-scale-bioethanol-factory-in-tuscany-italy-based-on-sweet-sorghum/

[9] American Society for Testing and Materials International Standard Specification for the Fuel-ethanol

to be a better choice. Based on survey data of Millennium Project of UNEP, we assume a typical rural village in Kenya has 9,000 people. Since average size of household in Kenya is 5.1 (Statistical Bureau of Kenya), a typical village has approximately 1,800 households (9,000/5.1). Technical specifics of CleanCook stove indicate that a typical African household needs to consume 1 liter of ethanol for the cooking in an entire day (i.e., 4.5 hours in total at high power). Therefore, a supply of 2,160 liters of ethanol per day (or 788,400 liters per year) is required to fully meet the cooking demands of village residents.

Due to the scale economy and learning curve savings of micro-distillery units, it is more reasonable to build up one micro-distillery unit for two villages. Therefore, a supply of 5,000 liters of ethanol per day is required. Since the UBM micro-distillery system can keep operating stably for a long time (i.e., 24 hours per day, 6.5 days per week, 48 weeks per year) and simply require half-day off per week for cleaning and maintenance, equivalently, UBM distillery system can operate 312 days in a year $\left(\frac{24*6.5*48}{24*365}\right)$. Therefore, daily production capacity of 5053 liters of ethanol is required.

Based on the proposed ethanol plant size, we build a cost model which takes fixed costs and variable costs into consideration to evaluate the economic feasibility of micro ethanol distillery plant. Fixed cost includes initial capital investment, land acquisition costs, machinery purchase and relevant import expenses. We assume these costs can be amortized evenly over the entire lifetime of the plant. Variable cost includes feedstock cost, feedstock delivery cost, processing materials cost (thermal energy, electricity, water, yeast and chemicals), labor cost, O&M cost, and ethanol transportation cost.

Feedstock Supply

Among the variable cost, feedstock cost is predominant. Feedstock can be produced in local communities, which can significantly reduce the delivery cost of feedstock. Since sweet sorghum stalk and sugarcane stalk will lose sugar content after 3-4 hours from cutting, the farmlands where feedstock is growing should be adjacent to the plant (i.e., less than 10 miles away from the plant). A maximum distance of 10-mile can guarantee that farmers could deliver newly-cut stalks to the plant in 2 hours by donkey or horse carts. Generally, 15 tons of fresh sweet sorghum stalk or sugarcane stalk are needed by a 1,000 –liter-per-day micro-distillery (Project Gaia, 2010), thus our micro-distillery needs 75 tons of fresh stalks per day, which is equivalent to 25-50 cartloads per day. A core group of 50-75 small farmers can completely provide the ethanol plant enough feedstock, and the farmers can make cash profits by selling feedstock to the plant. Therefore, considering the high unemployment rate of 40% in Kenya (Kenya Statistical Bureau, 2011) and several hours per day women and children spend in collecting fuel-wood, the collaboration between local farmers and local ethanol plant is definitely a win-win agreement.

Storage

After ethanol is produced in the plant, the factory is required to have several storage tanks to provide capacity to store ethanol liquid before distribution. In case if the plant is closed, the stored ethanol can continue meeting residents' cooking demand. Generally, the plant may require a storage capacity that is equal to production volume in 15-20 days.

Ethanol can be stored in large steel or plastic containers with capacity of several hundred liters. Since ethanol is easily evaporated, it has to be kept in a cool environment with sealed containers. The ethanol storage facility has to be centralized to reduce operation & maintenance costs, labor costs and safety concerns. Therefore, due to the poor infrastructure conditions and transportation conditions in rural Kenya, it is not feasible to build up storage facilities for each village.

Model Results

As shown in Table 5, the model indicates that the per-liter cost of ethanol is $0.418. If the plant asks for a profit hurdle rate of 30%, and based on our estimates on distribution costs from plant to retailers, the ethanol wholesale price is $0.54 per liter of ethanol. After considered distribution costs from retailers to consumers and consumers' terminal use costs (i.e., amortization of stoves and stove O&M costs), their final cooking energy cost is 0.64 per liter of ethanol.

Since a typical household of 5.1 people in Kenya will consume 1 liters of ethanol for cooking, they will spend $0.64 on their cooking demand per day. Currently in Kenya the traditional three-stone fire cooking cost is about $0.78 per day per household.[10] Ethanol is only a bit cheaper than fuel-wood according to our model estimates, which can be attributed to the high profit hurdle rate we assumed in the model.

Variable	Value	Unit
Plant Capacity	5.00	Klpd
Plant Life Time	15.00	Years
Operation Day per year	312	Days
Fixed Cost		
Plant and Machineries	51,800.00	$/year
Land	405.09	$/year
Total fixed cost	52,205.09	$/year
Variable Cost		
Feedstock Cost	234,000.00	$/year
Feedstock Delivery Cost	15,600.00	$/year
Processing Materials	186,453.24	$/year
Thermal energy	57,734.04	$/year
Electricity	66,019.20	$/year
Water	54,000.00	$/year
Yeast and Chemicals	8,700.00	$/year
Labor Cost	100,800.00	$/year
O&M Cost	78,000.00	$/year
Total variable cost	599,253.24	$/year
Total Cost	651,458.33	$/year
Total cost per liter per day	0.418	$ per liter per day

Table 5 Total Production Cost of Ethanol Production

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[10] http://www.cleancookstoves.org/resources_files/dynamic-market-for-improved-cooking-devices-in-kenya.pdf

Plan for Ethanol Distribution and Retailing

Two types of ethanol distribution are considered: distribution between the plant and retailer, and the distribution between the retailer and household. Suppose the distance between the plant and the retailer is 10 mile in average, in which way takes the horse cart 2-3 hours to deliver the ethanol bottles. Suppose the distance between the retailer and the household is 5 mile in average, which enables the households to come to the retailer on a weekly basis in poor public transportation condition.

The distribution cost between the plant and the retailer is added to the ethanol price for the retailers, and the distribution cost between the retailer and the household is added to the ethanol price for the households.

Specifics of Ethanol Bottles

Ethanol bottles are required to be recyclable, in small size and be marked to prevent other uses. In order to guarantee safety in retail and use and low production cost, ethanol containers can be made of durable plastic such as HDPE or PET. In addition, the screw caps should have good quality thus they can be screwed frequently in a long time and can prevent ethanol from evaporation. In addition, ethanol bottles should have small sizes, for example, 1-liter bottle (1-day use of a household), 6-liter bottle (approximately 5-day use of a household) and so forth. Moreover, since residents might use the bottles in other ways, which will reduce the recycling rate of ethanol bottles and cause additional losses of the bottles, the bottles are required to be marked in certain colors (e.g. light blue). The plant should set a price for each bottle and ask for cash deposits before purchase.

Figure 9 5-liter ethanol fuel bottle in U.K.

(Source: Vango Company)

Distribution in Designated Stores

Ethanol fuel is first refilled at bulk storage tanks and distributed in bottles as discussed above. Since ethanol is locally produced, ethanol plant is not far away from a nearby village, town or marketplace. Therefore, the plant can designate one or two stores in the marketplace to sell ethanol. The amount of stores selling ethanol should be limited for convenience of tracking sales and recycling bottles.

Residents can purchase ethanol from the stores at the same time when they are purchasing life necessities at stores or marketplaces. On one hand, if the stores open every day, then residents can purchase fuel every day. On the other hand, if the village have open-air marketplace twice a week, the residents can also obtain new ethanol bottles on time.

Milkman Delivery Model

Another way to distribute ethanol to households is to deliver ethanol in the same way with milk. Several ethanol bottles (e.g. 4 or 6) can be put in one crate and delivered to households. This distribution method is very feasible for in-town delivery in village towns or suburban areas with better accessibility. Once per week seems to be enough for in-town delivery. However, as to some remote villages, it is also possible to deliver less frequently by donkeys, but may cause higher labor costs and delivery expenses.

Distribution Cost Model

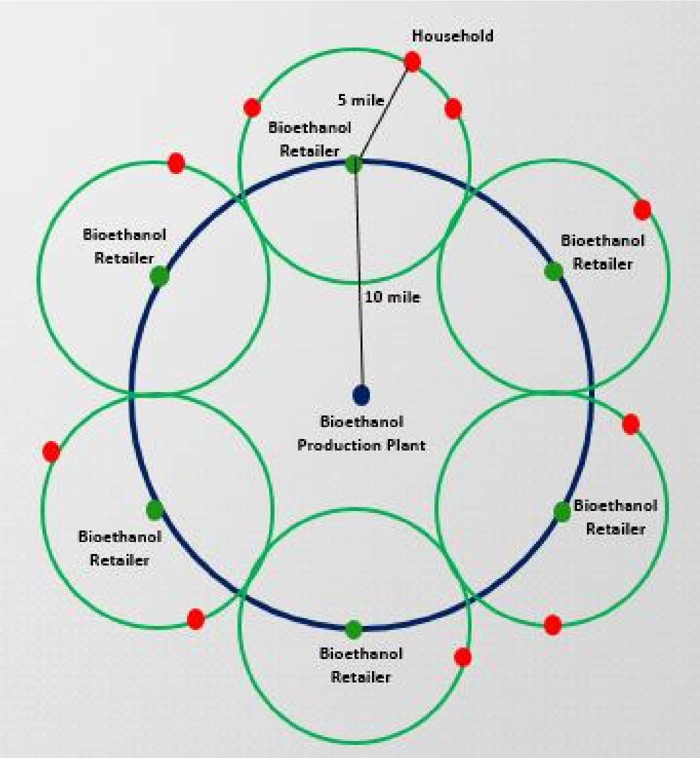

Figure 10 Distribution Cost Model

As shown in Figure 10, the distribution cost between the plant and the retailer is $0.025 per liter of ethanol, and the distribution cost between the retailer and the household is $0.013 per liter of ethanol.

In this way, the distribution cost is tiny compared to the ethanol production cost at $0.418 per liter of ethanol per day per household.

Ethanol Consumption at Home

Implementation of ethanol as a cooking fuel involves stove promotion, supply of ethanol and maintenance service of stoves. We further develop an implementation model based on above information. If the stove is assumed to have a lifetime of 5 years and the purchase price can be evenly amortized to each day, we could estimate the use cost of the stove per household per day. Furthermore, we must make assumptions on the maintenance service cost of the stove and amortize this cost item into each day.

Moreover, amortization analysis can be used as a reference for developing financing plan for the stove promotion. Since the families do not have enough purchasing power to buy the stove outright, some financing plan, such as a lease or rent can facilitate the spread of stove.

As a result, after combining the terminal ethanol price and the amortized stove use cost, a final ethanol cost as cooking fuel per household per day can be yielded and compared with current energy cost, for example, a typical Kenyan rural family which collect and buy firewood and cook with three-stone fire will spend 2,000 KES (or 24 dollars) on cooking per month (EnDev, 2012), or equivalently 0.78 dollars per household per day. Therefore, since the final cost of ethanol is lower than its counterpart, the business plan is promising.

Variable	Value	Unit
Lifetime	5	Years
Price	$20.00	Dollars
Annual maintenance cost	$10.00	Dollars
Stove using days per year	365	Days
Amortized purchase price of the stove (per day)	**0.011**	dollars per day
Amortized O&M Cost per day	**0.027**	dollars per day
Total stove use cost	**0.038**	dollars per day

Table 6 Residential Final Consumption Model

Profitability Analysis

We further analyze the profit of this plant. We assume that the plant can produce ethanol at full capacity throughout its lifetime of 15 years. This assumption might be optimistic, but it can indicate a best case. When the social discounting rate is 7% (Kenya Central Bank, 2014) and the profit hurdle rate of the project is 30%, the investor can earn his money back in the 4th year as the cell highlighted in yellow shown. Throughout 15 years, the project can yield a net present value of $1,912,506.

The retailers can also make profits by distributing ethanol. In total, all retailers can earn a net present value of $639,314 in 15 years if their profit rate is assumed to be 3%.

Our profit model may underestimate the total profit of the plant. We do not take the marketable carbon credits generated from this project and from CleanCook stove use into consideration. Moreover, we do not consider the value of by-products of ethanol production. Besides, government may provide additional subsidies or financial incentives, which can improve the financial status of this project.

Inputs	
Profit hurdle rate of the plant	30%
Discount rate	7%
Ethanol Production Cost	$0.418
Profit rate of the retailer	3%
Initial Capital Investment	$777,405.09
Outputs	
Ethanol wholesale price	$0.54
Ethanol retail price	$0.59
Cooking fuel use price	$0.64
Total Profit for Ethanol Production	$1,912,506
Total Profit for Retailer	$639,314

Table 7 Profitability Input and Output of the Plant

Sensitivity Analysis

Since feedstock cost accounts for about one-third of the total production cost, the profitability and financial performances of our business plan will depend on feedstock supply. Therefore, we conduct sensitivity analysis on the basis of feedstock price which is measured in dollars per liter of ethanol.

As shown in Figure 11, when feedstock price increases, the final ethanol price for households increases. In the meantime, profits for ethanol production increase if profit rate is assumed to be fixed. However, total profit for retailers does not change. We can also notice that when feedstock price exceeds $0.2/liter of ethanol, ethanol fuel will lose its competitiveness compared with charcoal.

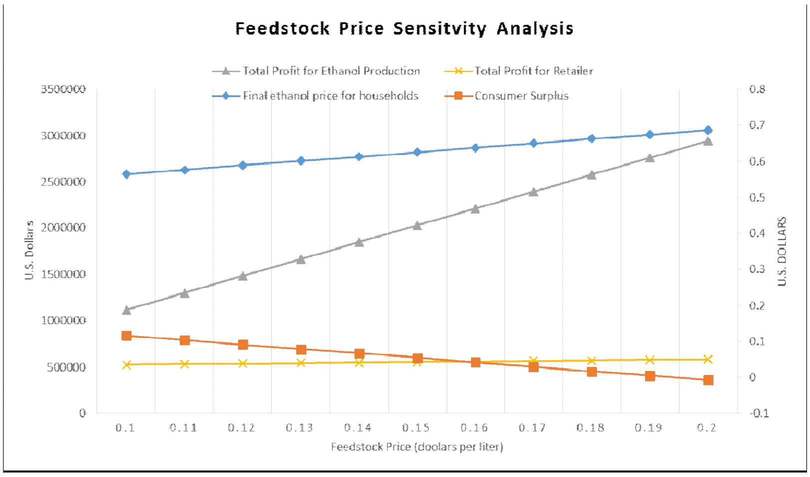

Figure 11 Sensitivity Analysis

Conclusions

A business plan for ethanol production and retailing in developing countries such as Kenya is brought forward in the above report. In the plan, sweet sorghum is chosen as the most appropriate feedstock for semi-arid climate in sub-Saharan Africa. Plantation of sweet sorghum can yield benefits for local farmers, since the leaves of sweet sorghum can be used to feed livestock, the grains of sweet sorghum can be served as food, and the stalks of sweet sorghum are what we need for ethanol production. According to our estimate, a group of 50-75 small farmers is required to supply enough sweet sorghum stalks to our plant. Our plant can produce about 5,000 liters of ethanol per day, which needs 75 tons of fresh sweet sorghum stalks in each day.

In the production phase, we are going to install 13 sets of UBM micro-distillery production units because each unit can produce 400 liters of ethanol per day. The cost of equipment purchase, installation and maintenance costs are calculated and incorporated into the spreadsheet production model. Besides, diverse variable costs including water, energy, yeast, feedstock and so forth are taken into consideration. Based on the production model, the production cost of ethanol is $0.418 per liter.

In the distribution and retailing phase, we establish distribution cost model to quantify the delivery cost of ethanol from plant to retailers and from retailers to residents. The distribution cost of bioethanol between plant and retailers is $0.025/liter, while the distribution cost of bioethanol between retailer and residents is $0.013/liter. We further amortize purchase cost of stoves and yearly maintenance cost of stoves into our model and yield a final ethanol cooking cost of $0.64/liter. In comparison with charcoal cooking cost of $0.68 per day in Kenya (i.e., $20 per month), ethanol seems to be a promising alternative to households in rural and suburban Kenya.

This business plan does not take marketable carbon credits generated from the construction and operation of ethanol plants into consideration. Furthermore, the plan does not calculate market values of byproducts such as bagasse and potential government subsidies or financial incentives. Further research are required to take all these profit-related factors into consideration in order to figure out a more detailed profitability estimate of local ethanol production in developing countries.

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