Holistic Feasibility Study of a National Scale-up Program Regarding Bio-ethanol Stoves and Micro Distilleries

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List of Abbreviations

ARDU	Arsi Rural Development Unit
EIAR	Ethiopian Institute of Agricultural Research
EU	European Union
EMD	Ethanol Micro Distilleries
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse Gases
GMO	Genetically Modified Organism
GTP	Growth and Transformation Plan
ha	Hectare
HCN	Hydrocyanic Acid
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
Kg	Kilogram
km	Kilometer
MW	Megawatt
MoU	Memorandum of Understanding
NGO	Non-Government Organization
q	Quintal
PA	Peasant Association
SNNP	Southern Nations and Nationalities Peoples Regional State
UNIDO	United Nations Industrial Development Organization

Executive Summary

Bio-ethanol and fermentation technology have been with humanity since biblical times, mainly for food and drink. Bio-ethanol was used in alchemy in medieval times, used to produce heat and fire. In modern times, it has increasingly been used as a source of renewable energy. It was burned in lamps in place of whale oil. In 1896, Henry Ford tested his first Ford A1 prototype vehicle using bio-ethanol. In 1903 Brazil initiated bio-ethanol research for transportation. Today, bio-ethanol is being used for transportation and household energy purposes around the world.

The global production of bio-ethanol reached 90 billion liters in 2013. While the US is the major producer (51 .8 million m^3 in 2013) of bio-ethanol, Brazil (23.1 million m^3 in 2013) is the main exporter globally. Ethiopia produced 299,444 liters in 2001, 13 million liters in 2011 and 20 million liters of bio-ethanol in 2013, with a projection of 180 million liters in 2015.

The total biomass supply of Ethiopia is estimated at 990 billion tons annually. Woody biomass constitutes 95%, animal dung 3% and crop residue 2%. It is estimated that 92% of woody biomass consumed in Ethiopia is consumed by households, which causes deforestation, desertification, soil erosion, and decline in soil fertility and crop productivity. Hence environmentally sustainable, i.e. renewable, sources of household energy such as bio-ethanol for cooking can contribute to food security, resource protection, ecosystem maintenance and also affect climate, slowing climate change.

Bio-ethanol can be obtained from crops containing sugar, for example sugarcane, sweet sorghum and sugar beets, through fermentation. It can also be obtained from starchy crops such as cassava, corn, sweet potato, wheat, etc. In this case, starch is converted to fermentable sugars and then bio-ethanol.

This report examines the ecology, production and productivity of various feedstocks as raw material for bio-ethanol to be produced in micro distilleries (EMD). A micro distillery is defined, for convenience, as sized to produce up to 5,000 liters per day, after which we might refer to it as a small distillery. This size distinction is important with regard to footprint, feedstock and utility demand, and contextual scale. Will the micro distillery operate within the context of a community of small farms?

The bio-ethanol from the EMD is intended to be used primarily for bio-ethanol cooking stoves but perhaps for other household energy needs as well—heating, lighting, refrigeration and power. Feedstocks studied were: sugarcane molasses from sugar factories, sugarcane produced by smallholders, sugarcane produced by out growers for Wonji sugar factory, sweet sorghum, sweet potato, taro, cactus pear and mango fruit.

The sugarcane molasses from factories is an excellent source of feedstock but the factories are usually under maintenance from June to October. Sugarcane juice can be a good source of bio-ethanol feedstock during July to October. It can be produced by entrepreneurs on a contractual basis or in farmer cooperatives.

Among fruits, mango seeds are very difficult to collect from juice houses. On the other hand cactus pear produced mainly in Erob Woreda of Eastern Zone of Tigray is a very good source of feedstock. Cactus pear has a brix value of 14. The plant has an excellent niche only in Erob. However the production of cactus pear is now seriously threatened by cochineal infestation.

Root crops, particularly taro and sweet potato, are very productive and can be used as bio-ethanol feedstock as well as food. These crops can be economically produced as a feedstock if produced by entrepreneurs. Cassava is very productive and an excellent source of starch. Improved varieties and production technologies (package practices) of sweet sorghum, taro, sweet potato and cassava are available.

Fast growing invasive plant species like *Prosopis juliflora*, *Parthennium hysterophorus* and *Lantana camara* can be used as sources for cellulosic bio-ethanol. These invasive alien species are not used for food, feed or any other useful purpose. They occupy potentially arable, irrigable and grazing land. *Prosopis juliflora* has occupied 700,000 ha in Afar Region alone. However, to use *Prosopis* will require a significant research and development effort in chemical engineering, microbiology and enzymology to learn how to convert it to ethanol.

In addition to their contribution to food security, reduction in GHG emissions and environmental protection, bio-ethanol-based stoves and micro distilleries should serve as employment generators all along the ethanol value chain.

Bio-ethanol stoves and micro distilleries can be developed in partnership by the public and private sectors. The public sector should concentrate on policy development, quality control, regulation, research on bio-ethanol technology development and extension, and finance. It is very important that Ethiopia establishes sugarcane breeding and genetic research immediately. It is likewise important that an Ethiopian Institute of Bio-fuel Research be established. The private sector can take the lead on manufacturing of stoves and distillery components, and the distribution of stoves and bio-ethanol fuel. The private banks could also deliver credit for manufacturing of stoves and micro distilleries and for the development of the stove and fuel supply chains.

This study draws the following conclusions and recommendations.

1. Bio-ethanol cooking stoves and micro distilleries can contribute significantly to the food security, natural resource conservation and climate change mitigation of the nation, hence scaling up of these technologies requires immediate attention.
2. There are several feedstocks that can be used as raw material for bio-ethanol micro distilleries. However, molasses from sugar factories, cactus pear, sweet sorghum and reject haricot bean are first choices. In addition, sweet potato and taro can be alternatives if grown by entrepreneurs for feedstock purposes.

3. The research on sweet sorghum must be geared to develop a variety with high grain and stock yield and adapted to major sorghum growing areas. Collaborative research between EIAR and ICRISAT can be initiated.
4. Feedstocks can be best cultivated by entrepreneurs themselves or on a contractual basis. The contract growing of sugarcane by unions in Wonji is a good example.
5. Among the regional states, Oromia and SNNP grow all feedstocks assessed in this study, followed by Amhara and Benishangul Gumz. Tigray Afar Region, Gambella and Somali cultivate the least. Among feedstocks, sweet potato, taro, cassava and sugarcane are very productive.

1. Background

1.1 Bio-ethanol Technology

Humans have been producing wine using fermentation since antiquity. In the Bible "Noah a man of the soil proceeded to plant a Vineyard. When he drank some of the wine, he became drunk and lay uncovered inside his tent" (Genesis Chapter 9, versus 18-21). Hence bio-ethanol technology and fermentation have been used for a very long time in human history. The first prototype of the Ford Model A car was tested using ethanol in 1896 in the U.S. In Brazil, bio-ethanol from sugarcane molasses has been utilized for automotive fuel since the 1920s (BNDES and CGEE 2008).

Bio-ethanol feedstocks can be divided into three major groups, namely:

1. Sucrose-containing feedstocks such as sugarcane, sugar beets and sweet sorghum;
2. Starchy materials such as corn, sweet potatoes, cassava, wheat and barley;
3. Woody and grassy materials from agricultural and forest residues.

In the short term the production of bio-ethanol is dependent on sugary and starchy crops. The potential drawback of using sugar and starch crops is that they may be expensive to produce and may be needed for other uses. Lignocellulosic biomass has been envisaged to be the ultimate feedstock to provide large volumes of ethanol in the medium to longer term due to its low cost and high availability. Currently about 60% of the bio-ethanol produced globally comes from sugarcane and 40% comes from other crops (BNDES and CGEE 2008).

The technology to produce bio-ethanol from sugary and starchy crops is known as "first generation" while the procedure of producing from lignocellulose is referred to as "second generation." The first generation technologies have been in use for a long time (NREL 2007). With first generation technology, crops such as sugarcane, sweet sorghum and sugar beet are directly converted to bio-ethanol by yeasts. This is because these crops contain either glucose or sucrose. In contrast, bio-ethanol from starchy crops such as corn and cassava requires the conversion of starch to simple fermentable sugars and then to bio-ethanol. However, the volume of bio-ethanol per unit area of crops varies considerably (Figure 1). As can be seen in Figure 1, sugarcane is more productive than sweet sorghum and sugar beets. However, it takes longer to grow and harvest.

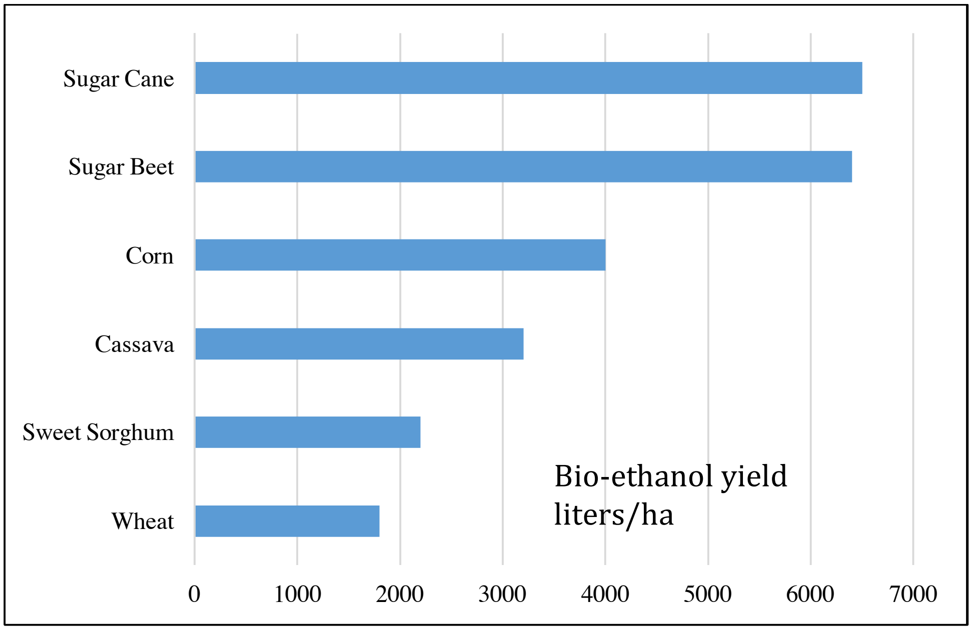

Figure 1: Bio-ethanol productivity per unit area for different crops (BNDES and CGEE 2008)

Sugarcane takes up to 18 months to harvest compared to corn, sweet sorghum and wheat, which take only four to six months. Second generation bio-ethanol technology is developing and involves the conversion of cellulose and hemicelluloses from plant sources such as tree plantations, agricultural crops and residues, invasive alien weeds, and fast growing plants such as grasses into simple sugars and then to bio-ethanol using fermentation (Badger 2002). Cellulose is a complex carbohydrate consisting of chains of glucose molecules (NREL 2007). The links holding together the glucose molecules in cellulose are different from those of starch. There are few identified organisms with enzymes that easily break down cellulose. Cellulose molecules are packed into tight crystalline form and then wrapped up in lignin and hemicelluloses. To access the cellulose molecule we first have to disentangle it from the other molecules and unpack the crystal. This process is called pre-treatment and is the most expensive process. This process can be done using strong acids, enzymes and genetically engineered bacteria.

Despite higher capital investment, this technology has enormous potential because of the increase in supply and flexibility of feedstock, once cellulose can be processed with costs comparable to starch. Making ethanol from cellulose for engine fuel was a dream of Henry Ford and Thomas Edison at the beginning of the 20th Century (Kovarik 1998). The chemistry of this process dates to 1819 with the work of French chemist Henri Braconnot. A historic milestone is achieved this year with the opening in the U.S. of the first commercial cellulose-to-ethanol plants in the month of October. The POET-DSM plant in northern Iowa, the DuPont Cellulosic Ethanol Facility in Nevada, Iowa and the Abengoa plant in Hugoton, Kansas are the first plants to begin commercial production (Minneapolis Star Tribune 10-24-14). A cellulosic plant is under construction in Brazil, and DuPont has signed an agreement to build a cellulosic plant in Macedonia to serve the European market (Ethanol Producer Magazine 10-20-14). The U.S. and

Brazil no doubt led in the production of cellulosic bio-ethanol because of the large research and development commitment that the technology required. The U.S. Government invested more than $1 billion through its Department of Energy. Now that the first plants are running, it is expected that new plants will be built around the world. China is investing in second generation ethanol—both in China and the U.S.

1.2 Bio-ethanol Production around the World

Global production of bio-ethanol increased substantially during 2005 to 2013 (Figure 2). In 2005 the total amount of bio-ethanol was estimated as 30 million m^3 and increased to about 90 million m^3 in 2013. The leading producer of bio-ethanol is the United States followed by Brazil. Whereas corn is the major source of bio-ethanol in the U.S., sugarcane and sugarcane molasses are the major sources in Brazil (Balat and Balat 2009). In 2007 the U.S. and Brazil signed an MoU to:

1. Advance research and development bilaterally
2. Help build bio-fuel industries in third-party countries
3. Work multilaterally to advance the global development of befouls.

Most of the bio-ethanol in the EU is produced from sugar beet molasses. The bio-ethanol sector in EU member states has responded to policy initiatives and has started growing rapidly. The demand for bio-ethanol for transportation was 12.6 billion liters in 2010.

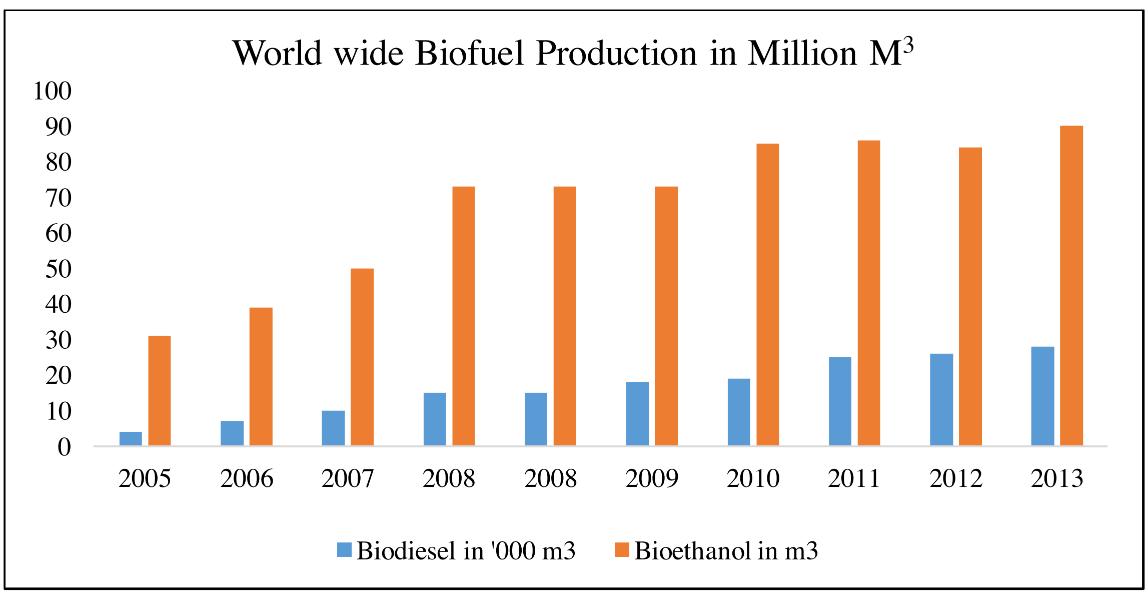

Figure 2: World-wide liquid bio-fuel production 2005-2013 (source Crop Energies AG 2014)

1.3 Bio-ethanol in Ethiopia

Bio-ethanol from sugarcane molasses was produced for the first time at Finchaa Sugar Factory. Since then the production of bio-ethanol increased from 299,444 liters in 2001 to 13 million liters in 2011 (Sugar Corporation 2014, Shemelis et al. 2013). The current production capacity of bio-ethanol stands at 20 million liters. In 2010/11 annual production of Finchaa sugar Estate reached 8 million liters per annum while that of Metehara was 12.5 million liters per annum. Ethiopia is establishing several sugar estates and nine of them shall start production by 2014/15. When the new factories commence production and the expansion to Wonji, Metehara and Finchaa is complete, the annual production of bio-ethanol from sugarcane molasses will be substantially increased.

A short history of bio-ethanol is as follows (Negera Bashana 2001):

In 1979, the Ethiopian Sugar Corporation initiated the program of alcohol production from molasses. The promoters were the Ministry of Industry and UNIDO and they paid the costs of the feasibility study by the Alcohol Monopoly of Finland.

In 1984 the French Company SOFRECO conducted a feasibility study for the production of bio-ethanol using baker's yeast and molasses in Ethiopia.

In July 1999 a technical committee was established consisting of the Ethiopian Petroleum Enterprise, oil companies, Finchaa Sugar Factory, and the Ethiopian Sugar Industry Support Center to address the commercialization of bio-ethanol fuel under Ethiopian conditions. The major issues were vehicle effect and distribution.

In April 2000, following the completion of the technical and economic studies, the Council of Ministers of Ethiopia issued a directive on bio-ethanol production, distribution and control of blended fuel.

In October 2007 a National Bio-fuel Development and Utilization Strategy was issued by the Council of Ministers. Currently, the government of Ethiopia has revised the Energy Policy of the country giving additional emphasis for befouls. It is expected that this will be ratified by the Parliament very soon.

It is also relevant to mention that the Ethiopian Sugar Corporation encouraged Project Gaia Research Studies to come to Ethiopia in 2003 to field test a liquid alcohol stove, based on the Swedish Origo 3000 stove, a sample of which had been brought from Sweden to Ethiopia. Project Gaia was testing stoves in Nigeria and South Africa. A World Bank program, Millennium Gel fuel, had been run in Ethiopia with mixed results because the gel fuel stove did not have adequate power to cook food in the accustomed manner (Hades, Utria 2004). The liquid fuel Origo stove showed much superior burner power and better consumer interface.

In 2004 Project Gaia commenced a 1,000-stove pilot study in Addis Ababa with ethanol fuel provided by Finchaa Sugar Company. This study was underwritten by the Shell Foundation. At the same time, a parallel study was commenced by the Sugar Corporation involving the blending of ethanol into kerosene for stove fuel, known as K-50, for use in typical kerosene wick stoves (Addis Tribune 2002). This study was abruptly discontinued when it was found that the volatile kerosene-ethanol mix was quite dangerous in the wick stoves and was causing the fuel chamber of the stove to explode (Takema 2011).

In contrast, the ethanol stove performed well, with no reported accidents or complaints (Stokes 2005). By 2006, Project Gaia had also tested stoves in Ethiopia's refugee camps, with favorable results (O'Brien 2006). It registered as an Ethiopian non-governmental organization and became an Implementing Partner to the UNHCR in Ethiopia, for which it provided stoves for refugee camps, especially in the southeast near Jijiga. This resulted in the purchase by the UNHCR of ethanol fuel for stoves from Finchaa Sugar Company and the Ethiopian Sugar Corporation (Lambe 2007).

In 2008, the stove was being commercialized in Addis Ababa but, as ethanol fuel supplies were limited, the Ethiopian government, in 2009-2010, directed most of the ethanol fuel into the fuel blending program and as a result away from the stoves (Doroski 2008) (Takema 2011). UNHCR has purchased ethanol fuel for stoves each year since 2006, with a fuel interruption in 2009, and in mid-2010 ethanol fuel began flowing again to the UNHCR and to Addis Ababa for the limited number of stoves in use (approximately 4,000). This number has remained steady or increased slightly since that time, as the limiting factor for stoves remains the fuel availability. However, the supply of ethanol fuel appears to be easing and the UNHCR has purchased 5,000 additional stoves for a scale-up in new camps in 2015. There are plans to increase the number of stoves in Addis Ababa as well.

1.4 Biomass Energy Consumption in Ethiopia

In Ethiopia, most of the energy comes from biomass and approximately 92% of the biomass energy is consumed by households, 3% by the service industry and < 1% by agriculture (Dawit 2012). Fuelwood accounts for 80% of the household energy supply. The annual production of biomass in Ethiopia is shown in Figure 3. Trends in energy supply during 1996 to 2010 shows that the biomass energy consumption decreased from 96% to 92%. As shown in the figure below, huge amounts of biomass are used for household energy, which otherwise could have been retained and managed to prevent erosion and maintain the soil.

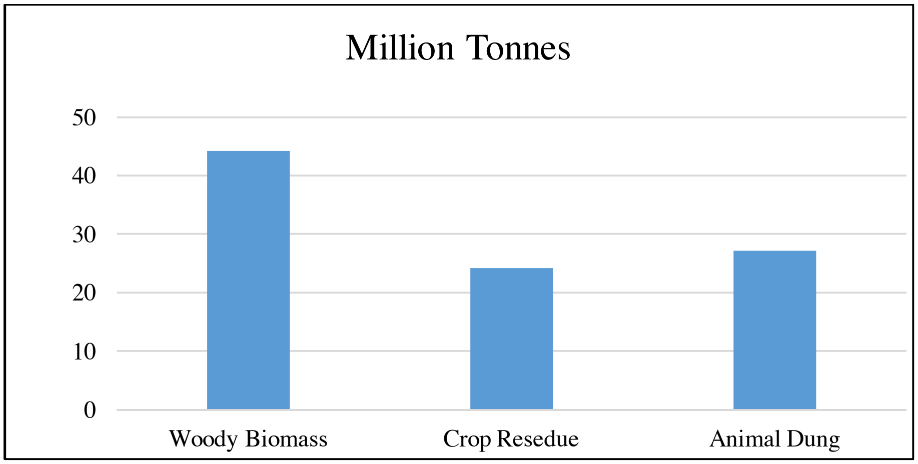

Figure 3: Biomass production potential in Ethiopia (Dawit Driba 2012)

Woody biomass constitutes 95% of total potential supply (Dawit 2012). Animal dung and crop residues account mainly for 3% and 2% respectively. Figure 3 shows that more animal dung is produced than crop residue; however, most crop residue is used as feed and converted to animal dung. In Ethiopia, crop residue is a major source of animal feed. Regional distribution reveals that Oromia supplies about 40% of biomass resources followed by SNNP (24%) and Amhara (15%).

2. The National Bio-fuel Development and Utilization Strategy and Its Relevance to the Scaling up of Bio-ethanol Micro Distilleries and Stoves

Ethiopia is now in its fourth year of the first five-year Growth and Transformation Plan. Under this plan, various sectors of energy development, namely hydropower, wind power, geothermal, bio-fuel and fossil fuel exploration are given priorities. High among these priorities are bio-fuels and renewable. Ethiopia serves as an example of a "green" energy economy for other African countries. Under GTP I, it is expected that hydropower generation capacity will reach 10,000 MW. Gilgel Gibe III and the Great Renaissance Electric Dam (GRED) with capacities of 1870 MW and 6000 MW respectively, are under construction. When these projects are complete, Ethiopia will become a net generator of electricity for Africa that could supply a significant amount of power to the African grid. Ethiopia has started supplying electric power to Sudan and Djibouti. The Adama and Ashengoda wind farms have also now been inaugurated.

On the other hand, Ethiopia spends close to two billion USD on the importation of fossil fuel. In addition, Ethiopia is facing soil erosion, loss of watersheds, and desertification as a result of deforestation stemming from fuelwood collection and charcoal production. The dry land forests that do not regenerate easily are sources of charcoal. Ethiopia is also a member of the global community that makes an effort to reduce carbon emissions and supports climate change mitigation and resilience. Hence, a concerted effort is being made for alternative and renewable energy source as well as fossil fuel exploration in lower Afar, Omo, Gambella and Amhara regions.

Ethiopia has been implementing its bio-fuel development and utilization strategy since October of 2007. The driving factors of this strategy are:

1. **Economic**: The country is spending the largest proportion of its foreign exchange earnings on the importation of fossil fuels. The cost of petroleum fuel is increasing and there is no evidence that it will come down. In recent memory, the price of petroleum fuel reached 150 USD per barrel. This led to the drafting of the Bio-fuel Development and Utilization Strategy and the approval by the Council of Ministers to support sustainable production of befouls to be used for transportation, rural electrification, water pumping and household energy purposes. These fuels are becoming more and more important in the world market.
2. **Political:** As a landlocked country and net importer of energy, Ethiopia would like to be energy secure. Any problem that affects the importation of petroleum into Ethiopia would have the potential to quickly disrupt the entire economy. Thus, energy security is a key consideration in the country's bio-fuel development and utilization strategy.
3. **Natural Resources:** Forest depletion and soil erosion are widespread phenomena particularly in the highlands. With the increase of population, the growing need for construction, furniture and fuelwood accelerates the depletion of natural forest. Increases in human and livestock populations exert enormous pressure on land and water resources. It is expected that sources of energy that provide alternatives to fuelwood would improve quality of life as well as natural resource regeneration and improvement in soil fertility.
4. **Climate Change**: Fossil fuels increase the accumulation of carbon dioxide, particulates and toxic gases in the atmosphere. The rising carbon dioxide levels increase temperatures in the atmosphere, a phenomenon that is commonly known as the greenhouse effect.
5. **Rural Development**: During the past ten years, the local as well as the international market for befouls has been expanding. Hence, there may be an opportunity to export befouls, creating business opportunities and employment for rural people.

In the Ethiopian context befouls includes biodiesel and bio-ethanol. Biodiesel is obtained from transesterification of vegetable oils such as from palm, castor and physic nut, or *Jatropha curcas*. In this report only the strategy relating to bio-ethanol is assessed. This is the strategy to produce bio-ethanol from sugarcane molasses and other plant sources primarily for transportation. Bio-ethanol has been blended with gasoline at 5% and has been available to gas stations in Addis Ababa since 2010. In 2012/13, 6.54 million liters of ethanol was produced and 8.63 million was blended. Although the strategy is largely concerned with bio-ethanol for transportation, it also stresses the use of pure bio-ethanol for cooking to replace kerosene for household purposes.

Ethiopia has 0.7 million hectares of suitable land for sugarcane production. If all of this land is fully utilized, the amount of ethanol that could be produced is estimated at one billion liters per year (Legesse Gebremeskel 2008). Currently, there are two private and nine government sugar estates with a total land holding of 342,000 ha. The productivity of these land holdings could be supplemented with other crops than sugarcane, such as sweet sorghum and sugar beets.

The general and specific objectives of the strategy stress import substitution of petroleum products by renewable fuels and support for the economy through import substitution and export, climate change mitigation, employment generation and support of the agro-processing sector. The values and principles of the strategy are:

- Production will not compete with food production,
- Production will not compete with grazing and farmlands as well as water,
- Production will include participation of farmers, pastoralists and agro-pastoralists,
- Production will not threaten biodiversity,
- The byproducts have no harm to the environment and shall be used for other purposes,
- Production will be implemented in accordance with international agreements and protocols.

The strategy invites participation of the private sector in feedstock production as well as bio-ethanol processing. The feedstocks identified in the strategy are “sugarcane and other plant sources.” The term “other plant sources” can only mean sweet sorghum and sugar beet. The strategy indicates that the private sector should be encouraged to produce bio-ethanol from sugarcane and other plant sources and create domestic and foreign market channels, as well as substitutes for kerosene and household fossil fuel use.

The strategy encourages research towards development and manufacture of bio-ethanol-fueled stoves for household purposes. In addition, it is indicated that the manufacture of stoves locally has been given great importance.

The scaling up of bio-ethanol micro distilleries with cook stoves is complementary to the bio-fuel development and utilization strategy because of the following reasons:

1. **Natural Resources:** Bio-ethanol cook stoves save forests by reducing the amount of firewood taken and enrich the soil through increasing the availability of organic matter. Bio-ethanol cook stoves save some amount of biomass that can be utilized as animal feed. They also significantly reduce greenhouse gas emission compared to the burning of kerosene or wood fuels.
2. **Food Security:** In many instances the major reason for decline of soil fertility is the use of crop residues and animal waste for burning. Bio-ethanol cook stoves improve soil fertility by increasing the level of organic matter, organic carbon and nitrogen to the soil. Improving soil fertility increases food crop production particularly those in homesteads, such as ensete (false banana) and coffee. Food security cannot be improved by crop production alone.
3. **Employment and Business:** bio-ethanol micro distilleries and cook stoves can generate employment opportunities in urban and rural areas. First, production of feedstocks involves the participation of the rural poor. Second, bio-ethanol may generate business opportunities in retail markets similar to those of kerosene and cooking oil. Third, micro distilleries will be handled by the private sector and will involve the employment of the rural poor.
4. **Economic:** Bio-ethanol is a potential substitute for kerosene, which requires foreign currency to import.
5. **Health:** Unlike other cook stoves fueled by biomass or even kerosene, bio-ethanol stoves do not produce the smoke and smell that affects the health of mothers and children. Bio-ethanol does not emit sulfur dioxide, sulfur monoxide, nitrous oxide, volatile organic compounds or elevated levels of carbon monoxide. Rather, it allows for a healthier environment at home as compared to kerosene, charcoal and firewood.
6. **Social:** Bio-ethanol cook stoves decrease the time and effort wasted by women and mothers to gather firewood, prepare fires, cook over inefficiently produced heat and cleans dirty pots. Some consumers may be able to use charcoal if it is affordable, but cooking with charcoal doubles or triples the time required to cook on a good quality ethanol stove. Moreover, burning charcoal releases dangerous amounts of carbon monoxide and can only be used safely in well ventilated areas. The availability of bio-ethanol cooking stoves saves enormous time and effort for women and increases the time they can spend with their children. In addition, the time used by children to gather firewood could be spent in for school studies or in play.
7. **Carbon Financing:** The end user or the disseminator of clean cook stoves can benefit financially from carbon financing because the stove reduces CO2 emission from kerosene and traditional solid fuels, as well as reducing deforestation.

Therefore scaling up of bio-ethanol micro distilleries and cook stoves is compatible with the government strategy. The strategy stresses the participation of the private sector including small-scale farmers for feedstock production, bio-ethanol processing, stove manufacturing and retail.

The bio-fuel development and utilization strategy seeks to encourage private sector participation through financial assistance and provision of technology and scaling up support. Public institutions, namely the Ethiopian Agricultural Research Institute, the Research and Training Directorate of the Sugar Corporation and various universities, are provided with finance to carry out research on feedstock production and bio-ethanol processing technology. All of the conditions for the development of bio-ethanol micro distilleries and cook stoves in the Ethiopian economy should be in place, provided that government policy and programs are properly implemented.

The National Bio-fuel Development and Utilization Strategy is governed by a national forum of stakeholders that convenes every two months. The forum consists of:

- Ministry of Water, Irrigation and Energy
- Ministry of Agriculture
- Ministry of Industry and Trade
- Ministry of Environment and Forest
- Ethiopian Customs and Revenue Authority
- Ethiopian Standards Agency
- Ministry of Finance and Economy
- Addis Ababa University
- Ethiopian Institute of Agricultural Research
- Ethiopian Sugar Corporation
- Ministry of Science and Technology
- Ethiopian Small and Medium Enterprise Agency
- Ethiopian Petroleum Supply Enterprise
- Ethiopian Transport Authority
- Ethiopian Investment Agency
- Investors
- Local Non-Government Organizations

The forum discusses and plans activities on bio-ethanol and biodiesel development at a national level. The day-to-day activity and management is handled by the Bio-fuel Development Coordination Directorate and chaired by the State Minister of the Ministry of Water, Irrigation and Energy.

The forum plans research and extension activities, obtaining funds from donors and organizing workshops. Each member of the forum reports on activities in his sector.

Food vs. Fuel

Sugarcane and sweet sorghum are perhaps the only two crops that can be used as feed, food and fuel at the same time, at least in relatively low technology settings. Bio-ethanol from sugarcane is obtained from molasses after raw sugar is taken off. The bagasse is used as feed, composted as soil amendment, or burned for steam to produce heat or power. The primary product of sugarcane is usually the raw sugar. The ethanol and the feed are co-products. In the case of sweet sorghum, the primary product may be the grain produced for food or the ethanol produced from the sugar in the stalk. The leaves and stems are fed to animals. Thus, unlike bio-ethanol from corn and wheat, bio-ethanol from sugarcane and sweet sorghum do not tend to provoke controversy in the food vs. fuel debate.

It should be noted, however, that many feedstocks processed for ethanol also produce valuable food, feed and other co-products. The corn ethanol industry in the United States now produces another extremely valuable product, DDGS or Dried Distillers Grains and Soluble, which in some cases is more valuable than the ethanol produced and which is shipped around the world as a premium animal feed additive. Corn ethanol distilleries also produce corn oil for the biodiesel industry and in some instances separate specific constituents of the corn kernel or the ethanol for use in green chemicals. The processing of wheat and other grains also produces valuable animal feed. Generally, a starchy crop will leave a protein and solids residue in the fermenters that is recycled in particular for its protein value. In a modern ethanol distillery or bio-refinery, nothing is wasted. The food vs. fuel debate tends to be a bit overwrought or simplified. An examination of the merits of each micro distillery has to be examined on a case by case basis to be sure that the farmer is being strengthened and his and her ability to provide food as well as fuel to the community is likewise being strengthened. Metrics can standards have been developed to evaluate this. The smaller, farm-scale distilleries tend to raise fewer issues and create greater synergies than large operations. Cellulosic and so-called second generation ethanol crops may offer additional advantages, as some of these crops will thrive on land not suited for conventional agriculture. Second generation ethanol feedstock may actually contribute to making more land available for agriculture if it can capitalize on invasive species and pest plants that need to be cleared or managed to restore lands to human use.

Education and Capacity Building:

The education and training policy of Ethiopia states that “higher education at diploma, first degree and graduate levels will be research oriented, enabling students to become problem-solving professional leaders in their fields of study and in overall societal needs” and promotes “technical and vocational training in agriculture, industrial arts, construction, commerce and home science.” Therefore, bio-fuel processing and feedstock production can be included in the curriculum. In addition, graduate students can be involved in all aspects of bio-ethanol production in their thesis work. Already some universities have included sugar technology in their stream of graduation. The basic technology of the bio-ethanol stoves and the use of bio-ethanol as fuel should be studied in the vocational training.

Pioneering cellulosic and second generation bio-ethanol in Ethiopia will require much research in chemical engineering and microbiology. Graduate students will need to be involved in the selection of the right yeasts for fermentation and chemicals and enzymes that can degrade the cellulose material to release the glucose molecules. Chemical engineers will be required to maximize the bio-ethanol yield per unit of cellulose feedstock. This kind of technical expertise is already being created in the Ethiopian university system. One of the leading researchers at the U.S. Department of Energy Lawrence Berkeley National Laboratory for advanced ethanol research is an Ethiopian, educated at the Addis Ababa University Science and Technology Faculty, who began her career with the ethanol stoves in Addis Ababa and who went on to do advanced work in her field at the Department of Energy, where she is currently engaged. Her work at DOE will eventually be able to be applied in Ethiopia.

Stove Safety:

The bio-ethanol stoves do not produce smoke and are free of hazardous emissions such as those produced by kerosene wick stoves and solid fuels. Among these hazardous compounds that are produced by kerosene and wood burning are benzene, toluene and xylene. These compounds travel on very tiny soot particles deep into the lungs and have multiple and complex effects on the body. There is a long list of illnesses associated with habitual exposure to these compounds. In contrast, when ethanol burns it produces CO2 and water vapor. If the plant material has been sustainably harvested, the CO2 is offset by the growing of new plant material. Unlike charcoal stoves, ethanol stoves do not produce much carbon monoxide (CO), as ethanol is a low-carbon fuel, which, moreover, carries an oxygen atom in its molecule that helps it to burn. The better the ethanol stove, the less CO it produces. Normally, almost any ethanol stove will test below the World Health Organization's recommended maximum for CO production.

The "CleanCook" branded bio-ethanol stove now available in Addis Ababa is to some extent child resistant because its flame is less exposed than that of an open fire, a charcoal stove or a kerosene stove. The flame is protected by a ring or guard. The fuel is contained in a spill proof canister that has adsorbed the ethanol onto a fiber so it will not spill out (but only evaporates out). The fuel canister is open and cannot pressurize and explode, yet it can be closed by the stove regulator to prevent the fuel from evaporating. The stove regulator is on a spring steel arm. If suddenly the ethanol were to expand, because of heat, the regulator would lift on the spring steel arm to release the pressure. Perhaps most importantly, the ethanol fire can be put out with water because alcohol is miscible in water. This also means that ethanol readily biodegrades if spilled and does not present a contamination risk in the environment.

The stoves are convenient to light, easy to turn on or off and to regulate to high, medium or low settings. They only require refilling once per day or every other day. They are not overpowered and use their fuel efficiently.

The “Green Economy”

Among the objectives included in Ethiopia’s energy policy is the goal of providing alternative and renewable energy sources for the household, industry, agriculture, transport and other sectors and “to ensure the compatibility of energy resources development and utilization with ecologically and environmentally sound practices” (Melis Teka 2008). In addition, the general policy of the country toward a “green economy,” hence, replacing kerosene and non-renewed biomass with renewably produced bio-ethanol fuel helps to achieve the green economy that has been called for.

Investment Support

The investment policy of Ethiopia encourages investment in befouls. The regional states have identified large areas of land available for befouls production. Land has already been provided to entrepreneurs like Al Habesha and Hiber Sugar for sugarcane production. The Government of Ethiopia has been supporting investors in castor bean for biodiesel production in Wolita Zone, Eastern Harrarghe and Shenele Zones. Financial incentives given to other investors have also been given to investors in Ethiopian befouls production.

3. Review and Assessments of Reports

Among the reports reviewed for this study, two are mentioned here. They are: "Feasibility Assessment for Ethanol Micro Distillery (EMD) in Ethiopia" (Ethio Resources Group 2011) and "Rapid Assessment of Bio-fuels Development Status in Ethiopia (Hilawe Lakew and Yohanes Sheferaw 2008"). The proceedings of a workshop on the environmental impact assessment of befouls development were also considered. The following is a short assessment of these studies and the workshop.

"Feasibility Assessment for Ethanol Micro Distillery (EMD) in Ethiopia" by Hilawe Lakew of the Ethio Resources Group is professionally prepared and executed. The document deals with the economic feasibility of using micro distilleries in rural Ethiopia. It was prepared as a planning document for a program sponsored by the World Bank and the Nordic Climate Fund to construct and operate a micro distillery demonstration plant close to Addis Ababa, which plant is nearing completion as of the writing of this report.

The causes, significance and need of using bio-ethanol for household cooking are well documented in this report. The feedstock resources highlighted in the document, namely sweet sorghum, sugarcane and molasses, are the correct choices, supported by the findings of this report. However, much detail about their suitability and potential yield is not provided. Two other sources of feedstock, excess production of fruits and vegetables, do not seem to be realistic. First, there are many fruits, for example avocado, mango, orange and banana. Each of them has different characteristics. For example, avocado is free from sugars and citrus has a very high level of citric acid. In addition, there may not be very much excess commercial fruit in Ethiopia. As far as the availability of unsold fruit the market, or the spoilage of fruits and vegetables that could have been diverted for use as feedstock, this may be more of a management problem than an opportunity for ethanol fuel feedstock. Management practices in Ethiopia are improving. Thus these sources of feedstock remain unproven.

The second study was "Rapid Assessment of Bio-fuels Development Status in Ethiopia" (Hilawe Lakew and Yohanes Sheferaw 2008). The strength of the study is its concern for the environment but this concern should be based on facts and figures. The document fails in three important ways:

1. The report does not distinguish between bio-ethanol and biodiesel. The Ethiopian bio-fuel industry is entirely based on sugarcane and biodiesel is only an emerging fuel. Sugarcane is cultivated mainly for sugar production and the bio-ethanol is processed from the byproduct molasses. Much of this molasses historically has been discarded, because it could not be used in the quantities produced. The bagasse is burned to generate electricity. The document did not discuss the success stories of the Ethiopian Bio-ethanol Industry. The household energy program at Gaia Association is based on bio-ethanol and has enormous environmental, economic and cultural benefits.

The report does not identify feedstocks appropriately. The biodiesel industry is just emerging and research is being conducted in order to identify the most economical and appropriate feedstocks and method of cultivation. Of paramount importance is the cultivation of physic nut (*Jatropha curcas* L.) on dry areas and degraded lands. Physic nut tolerates moisture stress but requires moisture to set seed. It bears seeds containing oil content of about 35% highly suitable for biodiesel. The government of Ethiopia is promoting physic nut to be cultivated on degraded and stressed areas for biodiesel. However, high yielding provenances along with optimum cultivation techniques are still to be identified. The second species identified by the bio-fuel development and utilization strategy as a feedstock is castor (*Ricinnu*s *Communis* L.) Castor has a similar ecology to sorghum and the Rift Valley, specifically Melkassa, Arsi Negelle and Arba Mich, are the most suitable areas of production. Castor seed contains oil up to 55%, under the Rift Valley conditions, with about 90% ricinoleic acid, an important raw material for the chemical industry. Castor and physic nut oils are not used for feed and food and hence have been selected by the Ethiopian Bio-fuel Development and Utilization Strategy as biodiesel feedstock.

Among vegetable oil sources, oil palm is the highest yielder on the average of 8 tons of refined oil per hectare. Oil palm is a big tree and its canopy covers the ground quite well. Currently, of all of the vegetable oil production globally, 50% is palm oil. Ethiopia imports from abroad 89% of the national vegetable oil demand, which mainly consists of palm oil. It is widely believed by its policymakers that Ethiopia needs to substitute imported palm oil with local production. Oil palm is adapted in areas with high rainfall throughout the year and at least 100 mm of rain every month, warm temperatures and no strong wind. In all countries, oil palm is best adapted to tropical rain forest and, in Ethiopia, Kefa Sheka Zone and Gambella region are the most suitable areas. In all countries oil palm has been established by clearing tropical rain forests and there is no exception in Ethiopia.

2. The report has not mentioned the success stories of the Brazilian and U.S. befouls industry. The U.S. is the global leader in bio-ethanol production while Brazil is the largest exporter of bio-ethanol. The International Food Policy Research Institute urges all developing countries to learn from Brazil. Ethiopia should also learn from Brazil, rather than the EU, as indicated in the study. This is because the EU is interested largely on Biodiesel rather than bio-ethanol and there are numerous environmental and policy regulations that are not relevant to Ethiopia.

3. Almost all of the bio-fuels companies mentioned in the report do not exist today. The British company Sun Bio-fuels was involved in developing physic nut plantation in degraded areas of Wolita Zone; however, it abandoned its business after three years of testing.

The “Proceedings of the National Workshop on Environmental Impact Assessment of Bio-fuel Development” (Kirubel Teshome 2008) were also reviewed. The proceedings are varied in approach and quality. Two presentations are mentioned here as example. One is a review of the National Bio-fuel Development and Utilization Strategy. This paper discusses the strategy and seeks to create interest in it.

The second is a presentation designed to discredit befouls. It provides an historical background for the Oil Crisis of the 1970’s and presents an argument against befouls based on a series of generalizations, incorrect assertions, disputed data and fallacies about befouls (…………). Despite an abundance of evidence on the economic, environmental and social benefits of befouls both in Ethiopia and abroad, the presenter fails to address this and instead assembles a litany of fallacies about befouls. One example is the author’s warning that a “genetically modified tree” would be introduced into the country to produce befouls. While the paper is of no substantive merit, it does provide an example of the fears about befouls that have to be acknowledged and addressed.

4. Bio-ethanol Feedstocks

Feedstocks for bio-ethanol production can be divided into four different groups. The first are the sugary crops, particularly sugarcane and sweet sorghum. The use of sugarcane molasses or sweet sorghum stalk for ethanol production does not, practically, affect food or feed supply. Only a relatively small amount of the molasses produced in the sugar industry can find its way into cattle feed. Small scale farmers produce sugarcane as a cash crop and this is sold for chewing, but this is a very small amount of the sugarcane produced.

The second group of feedstocks are grain crops such as maize and wheat. These crops are staple crops and should not necessarily be promoted for bio-ethanol production in the near future, except in very specific instances where gains in food production are to be achieved. There was a time when there was surplus production of maize in major growing areas. During such times the price of maize went down too low and some of that crop could have been used for bio-ethanol production to stabilize the market. When corn is used for ethanol production, it leaves a high-protein mash that can be used for animal feed and possibly for human food. In the U.S., distillers grains are produced in the corn-ethanol industry as a high-value feed that is shipped around the world. These distillers grains are similar in texture, taste and cooking to corn porridge. Dried distillers grains could be used as a protein supplement in certain staple foods.

The third group of feedstocks are roots and tubers, particularly potato, sweet potato, taro, cassava, etc. There are many indigenous root and tuber crops that can be used for bio-ethanol feedstocks. These crops are staple crops both in the highlands and lowlands. However these crops can also be used by entrepreneurs as ethanol feedstocks because they are prolifically grown.

The fourth group of feedstocks are fruits such as mango, banana, cactus, melons, etc. There are many fruits that have sugar and starch in them. Mango seeds have high content of starch that can be used for bio-ethanol and banana peels are a good source of starch. Cactus fruits offer a promising ethanol feedstock. Tree fruits provide an agro-forestry crop that may withstand the impact of drought and thus offer a climate adaptation strategy for farmers. Examples of tree fruits in addition to the mango include guava and jackfruit, just to name a few. Addis Ababa University Science and Technology student researchers have conducted trials on fermenting *Prosopis juliflora* seed pods from a nuisance invasive brushy tree. These seed pods are high in sugar and also have nutritional value.

4.1 Sugarcane

Sugarcane belongs to the family of Gramineae, a perennial tall grass native of warm tropical and Asian Zones. The above ground part of the plant is essentially formed by stalks, containing saccharose, and by tips and leaves, which make the sugarcane straw. These components all together total around 35 tons of dry matter per hectare (BNDES 2008).

Sugarcane is one of the most important commercial crops all over the world. It occupies more than 20 million hectares of land. Brazil stands out as the leading sugarcane producer, accounting for 42% of the total production (BNDES 2008).

The typical sugarcane cycle varies depending on the local weather, variety and practices. In Brazil, the cycle typically requires six years and comprises five cuts. The first cut is made 12 months or 18 months after planting when the cane crop is harvested. The ratoon crop is harvested once each year for four or five years in a row. After that it is cost effective to replace the old crop with a new one.

In Ethiopia, it takes 18 months to harvest the first crop and every one year consecutively for three years to harvest the ratoon crop (Sugar Corporation 2006).

Sugarcane harvest periods vary depending on the location and period of rainfall to allow for cutting and transport and for the crop to reach the best maturation point and sugar accumulation. The traditional harvest system relies on the manual cutting of the whole sugarcane plant. However, in many countries, including Brazil, the manual harvest is progressively being replaced by mechanized harvesting. After it is cut, sugarcane is transported to the mill within four to five hours to avoid loss of sugars.

The initial processing stage of bio-ethanol is basically the same as that of sugar production. Once in the mill, sugarcane is washed and sent to the preparation and extraction phases. Extraction is done by roller mills arranged in sets of from four to seven successive three-roller mills that separate the sugarcane juice containing saccharose from the bagasse, which is sent to the mill's power plant to be used as fuel. The bagasse is pressed through a drying roller or pulverized and then fed into the boilers. Extracted in the mill or in a diffuser, the juice containing sugar is used in sugar or in bio-ethanol production.

The sugarcane bio-ethanol production may be based on fermentation of sugarcane juice, molasses or a mix of both. Normally the juice is mixed with water to produce the sugarcane mash, a sugary solution that is ready for fermentation.

4.1.1 Varieties

The Ethiopian Sugar Corporation Research and Training Directorate carries out research on crop protection, cultivation methods, soil fertility and irrigation as well as processing. Unfortunately, the variety development program is not very advanced. It is thus important that the country initiates a sugarcane breeding program. So far all the varieties are introductions from abroad and future imports could be hampered by royalty issues. A total of 285 varieties have been introduced from abroad but only 15 are under production at this time. There are ten recent introductions of Cuban sugarcane varieties available at testing level (Shemelis et al. 2013). Currently, most of the production of sugar comes from four varieties, namely B52298, NCo 334, NCo 376 and N 14.

4.1.2 Ecology

Sugarcane requires warm temperatures with an ample amount of irrigation water. All the sugarcane estates are located in lowland irrigated areas or planes (Shemelis et al. 2013). Sugarcane grows very well on loam Luvisols or Verisols. There are a total of 500,000 ha of land suitable for sugarcane cultivation in the country and of this 342,000 ha is already committed for production (Table 1). Within Ethiopia, sugarcane grows from about 400 meters elevation at Tendaho and Kuraz to 1600 meters elevation at Wonji. The temperatures at Tendaho and Kuraz reach up to 37^{o} C and 30^{o} C at Wonji.

Table 1: Existing, expansion and new sugar development planned (Shemelis et al. 2013).

Sugar Estates	Area to be developed (ha)	TCD*	Region	Zone	Wereda	Irrigation from River
Wonji-Shoa	18,129	6,250	Oromia	East Shoa	Adama, Boset	Awash
Metahara	10,280	5,000	Oromia	East Shoa	Fentale	Awash
Finchaa	21,000	12,000	Oromia	East Wellega	Huro Gudro	Finchaa
Tendaho	50,000	26,000	Afar	Zone 1	Dubti, Asaita, Afambo	Awash
Kesem	20,000	10,000	Afar	Zone 3	Dulecha	Kesem r
Kuraz	150,000	10,000 (6 factories)	SNNP	Lower Omo	Selamago and Egnangatom	Omo
Tana-Beles	50,000	10,000 (2 factories)	Amhara	Awi	Jawi	Beles River
Wolkait	25,000	10,000	Tigray	Western	Welkait and Tselemti	Dukuko and Zarema Rivers
Total	342,000	269,253				

* TCD= *Refers to crushing capacity of the factory in tons of cane per day*

The land suitable for sugarcane production is totally in lowlands and arid and semi-arid areas with sufficient availability of irrigation water. The approximately 150,000 ha of land suitable for expansion is located in lower and upper Beles, Baro, Humera, Anger Valley, Genale Dawa and Baro Gilo basins.

4.1.3 Diseases and Insects

Ratoon stunting and smut are the most important diseases of sugarcane that inflict yield losses of 19 to 43% for stunting and 12 to 28% for smut. Using disease free planting material and resistant varieties are the best methods of controlling these diseases. Among 17 insects identified on sugarcane, stem borer is the most damaging.

4.1.4 Projections of Bio-ethanol from Sugarcane in Ethiopia

Ethiopia initiated production of bio-ethanol at Finchaa factory and reached a volume of 209,444 liters in 2001, 6.8 million liters in 2005 and 20 million in 2013 (Sugar Corporation 2013, Table 2). Ethiopia started the blending of ethanol with gasoline in 2009. Initially, it started with 5% blending. E5 increased to E10, which is being sold at all filling stations within Addis Ababa and surrounding areas. When the program started in 2009, the country produced 6 to 7 million liters of ethanol per year at Finchaa Sugar Factory. In 2010/2011, the annual production capacity of Finchaa increased to 8 million liters, while Metahara Sugar Factory started producing 12.5 million liters per annum. This increased the annual total national production of ethanol to 20.5 million liters. By 2015, the blend is to be increased to E20-E25 and distribution is to be expanded outside of Addis Ababa. When the new factories at Tendaho, Kuraz, Wolkait, Beles and Kesem commence production, the production will increase to 200 million liters (Table 3).

Table 2: Current production and productivity statistics of cane, sugar, molasses and ethanol during 2001/02 to 2010/11 cropping seasons from the three sugar factories [Finchaa, Metahara and Wonji] (Shemelis et al. 2013).

Year	Cane (t/ha)	Sugar (t)	Sugar (t/ha)	Sugar recovery (%)	Ethanol (lit)	Molasses (t)
2001/02	146.8	261,041	16.4	11.5	209,444	26,775
2002/03	143.6	267,998	17.4	11.5	894,624	16,221
2003/04	154.3	273,300	16.9	11.5	911,431	17,408
2004/05	154.8	281,435	17.6	11.1	1,636,047	11,000
2005/06	153.5	292,011	18.0	11.3	6,847,816	11,578
2006/07	145.6	283,918	17.6	11.2	6,066,860	24,629
2007/08	135.6	276,009	16.5	11.3	5,330,337	37,943
2008/09	142.0	302,480	15.7	11.1	5,878,513	18,304.
2009/10	138.3	291,649	16.3	11.1	7,116,585	-
2010/11	146.3	276,836	15.5	11.3	13,501,670	-
Mean	146.1	280667.7	16.8	11.3	4,839,332.7	16,386

The amount of bio-ethanol produced in Ethiopia during 2013 is estimated to be 20 million liters.

Bio-ethanol can be used for household fuel purposes, mainly cooking and lightening. Its production has multiple applications and benefits. One of the objectives of the Ethiopian Sugar Corporation is to substitute up to 137,464 m3 or 137.46 million liters of kerosene used for household cooking with ethanol. In addition the corporation's objectives include the production of 44,340 m3 or 44.34 million liters of bio-ethanol for blending purposes. Hence the bio-ethanol production for cooking could far exceed the bio-ethanol production for fuel blending.

Bio-ethanol production by 2015 is expected to reach 181 million liters. Table 3 shows that when full capacity is attained, at something approaching 317 million liters, the country could meet a stove fuel demand of almost a million stoves. It might be concluded that the country has enough potential capacity to produce bio-ethanol from sugarcane alone to meet its needs for fuel. Table 4 shows the current and realized production of bio-ethanol at Metehara and Finchaa Sugar Factories and the amount used for blending.

Table 3: Projected sugar in tones and bio-ethanol in M3 of seven sugarcane estates and factories (Ethiopian Sugar Corporation 2014).

Factory/Estate	Capacity per annum	
	Sugar in tones	Bio-ethanol
Metehara	136,692	12,500 m^3
Finchaa	270,000	20,000 m^3
Wonji-Shoa	222,700	12,800 m^3
Tendaho	619,000	55,400 m^3
Kesem	153,000	12,500 m^3
Kuraz	1,946,000	183,134 m^3
Wolkait	-	-
Beles	242,000	20,827 m^3
Al Habesha	-	-

Table 4: Actual amount of Bio-ethanol produced at Finchaa and Metehara and used for blending. (Note that in some years the amount blended exceeds the amount produced because the blending included carry-over stock.)

Year	Amount produced in millions of liters	Amount used for blending	Amount in millions of USD saved due to blending
2008	5.8	6.7	5.5
2009	7.1	3.4	1.6
2010	7.1	9.8	7.0
2011	13.8	10.6	9.2
2012	6.5	8.6	7.6
2013	9.8	7.5	7.6
Total	50.8	46.8	38.7

4.1.5 Seed Cane Production

The lack of multiplication procedures has been a serious problem in the sugarcane breeding program (Singh et al. 2001, Shang et al. 1987, Jeffery et al. 2003). Usually after 15 years of breeding work to complete a selection cycle, an improved variety can be planted commercially only several years later when enough sugarcane can be produced.

The time spent for this multiplication is a serious economic problem mainly in view of the higher yields that would be obtained by planting that new variety earlier in a large commercial scale. Under Ethiopian conditions, it takes one hectare of cane crop to plant ten hectares. Hence it takes a substantial effort and economic burden to cover a large farm using clonal propagation.

Sugarcane is a clonally propagated crop from which multiple annual cuttings of stalks are typically obtained from each planting. The clonal propagation of sugarcane is prone to the spread of systemic bacterial diseases, such as ratoon stunting disease. To minimize losses due to diseases, growers should obtain disease-free planting material. Traditionally this has been done by using hot water treatment. However, if it is already established in the cane, hot water treatment will not provide complete control of ratoon stunting disease.

Nowadays the most appropriate procedure to obtain disease free large stock planting material is through tissue culture. In this procedure, sugarcane is propagated from disease free foundation plants. The plant part used for tissue culture is termed the explant. The procedure to obtain meristem or shoot tips are cultured in appropriate media for regeneration, transferred to rooting media and grown into disease free plant. In this case several million seedlings can be produced from a single laboratory.

The Ethiopian sugar industry is expanding in size and locations and planting material has always been a problem. Hence, tissue culture protocols using meristem culture has been developed at Melkassa Agricultural Research Center (Figure 4). The protocols for different varieties are now supplied to Wonji and Metehara Sugar Estates and can be used everywhere. It is important that the Research and Training Directorate of the Ethiopian Sugar Corporation builds capacities such as greenhouses, growth rooms and develops human resources for tissue culture techniques.

A private tissue culture laboratory known as Dejena Endowment has also the capacity to supply tissue culture derived from sugarcane planting material. Sugar estates, particularly Wolkait, Beles and Hiber can benefit from this lab.

4.1.6 Cost of Production of Bio-ethanol from Sugarcane

The sugar industry's production costs would include land preparation, planting, cultivation, crop protection, irrigation, harvesting, and transportation of cane, plus factory costs. Bio-ethanol is obtained from a byproduct of sugar production known as molasses. Micro distilleries can use molasses from sugar factories to produce bio-ethanol for cook stoves. Hence the price of bio-ethanol would include molasses cost, transportation cost and processing costs at the micro distilleries.

4.1.7 Molasses Production at Wonji

Molasses production at Wonji is only for nine months per year from October to June at a capacity of 70% or 1,561.87 quintals per day or 46,856.1 quintals per month, or 421,704.9 quintals year. This is approximately 4,217,000 kg or 5,334,500 liters of bio-ethanol per year assuming a conversion rate of 1 to 10. However, the amount of ethanol produced could certainly increase with the increase in production of molasses. When the capacity of the factory is increased to 85%, molasses production would be 1,896.56 quintals per day and at full capacity production would be 2,231.25 quintals per day.

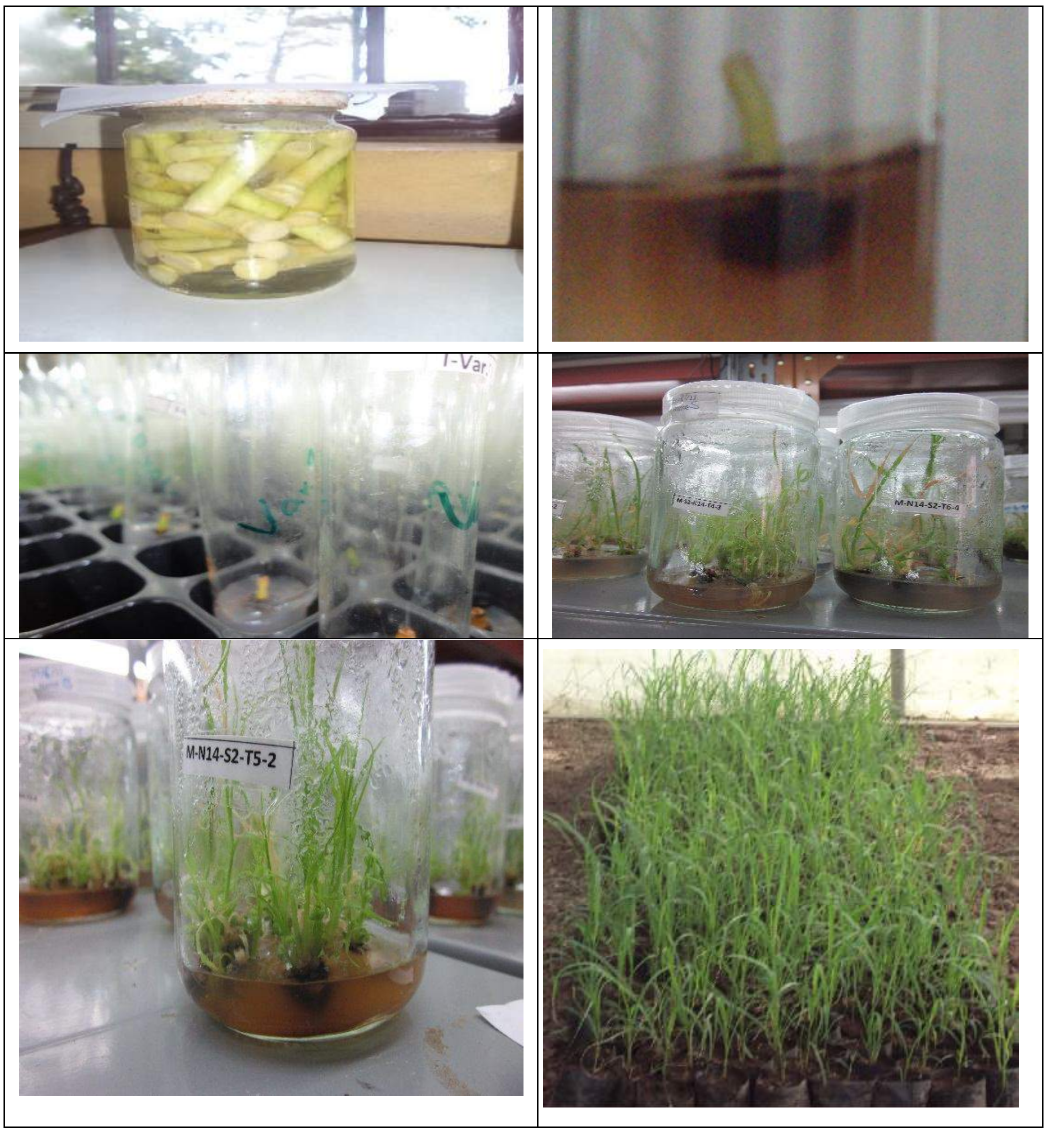

Figure 4: Steps of micro propagation of sugarcane (Courtesy of Melkassa Agricultural Research Center)

The cost of molasses currently is about 70 ETB/quintal or $35 per ton. This would yield an approximate feedstock cost of 7 ETB or $0.35 per kg, or slightly less per liter. Hence utilization of molasses as a raw material in micro distilleries would appear to be economically feasible.

4.1.8 Sugarcane Production under Smallholders

Sugarcane is produced by small scale farmers in mid altitude areas that have fertile soil with year round irrigation water. It is normally grown in backyard plots for chewing as well as a source of cash. It is abundantly found in North Wello around Sirinka and Mersa, Sidama Zone particularly Wondo Genet Woreda, Jimma Zone, Gamo Gofa Zone and West Gojam. The area of small scale sugarcane was 22,119 ha in 2011/12 and 22,388 ha in 2012/13 with production of 10,335,863 quintals and 10, 398,657 quintals respectively (CSA 2013).

The sugarcane genotypes cultivated by small scale farmers are local or even unknown genotypes. The sugarcane crop cultivated by small scale growers are normally tall, thick stemmed and variable in stem color. Almost all the sugarcane produced by small scale farmers is used for chewing, indicating that they are soft and have high water content.

Thus, sugarcane production by small scale farmers is usually for cash, sold for chewing as a source of energy. Three Woredas, namely Wondo Genet, Shoa Robit and Dawa Chefa were surveyed for this study for their production, productivity and price.

Wondo Genet is found east of the City of Hawassa, 280 km from Addis Ababa. The altitude of the Woreda varies from 1500-2500 meters above sea level. It has 13 peasant associations and two town Kebeles. The Woreda is densely populated, with 666 person per square kilometer. The Woreda has 64% Wona Dega (temperate) and 36% Dega (cold) climate or growing zones. The total amount of rainfall in the Woreda is about 1,200 mm distributed from April to December. The population living in the Dega Kebeles cultivates annual food crops while those in the Wona Dega Kebeles grow perennial crops, particularly chat, sweet potato and sugarcane. The most famous Wondo Beleche Chat brand is cultivated in Wondo Woreda. The major household energy in the Woreda is firewood, charcoal and crop residue for household cooking and electricity for lightning. Table 5 shows the area, crop and production of crops cultivated under irrigation during 2006 EC, or 2014.

Table 5: Cultivated area, crop and production under irrigation in Wondo Genet Woreda.

Crop	Area in ha	Production in quintals (q)	Value at farm gate in Birr/q	Value of raw material at farm gate in million Birr	Amount of bio-ethanol in million liters	Value of Bio-ethanol in million Birr
Maize	34	-				
Cabbage	57	17,100				
Head Cabbage	275	18,600				
Tomato	304	76,000				
Carrot	55	11,000				
Garlic	14	2,760				
Green Pepper	79	15,800				
Onion	19	4,250				
Sweet Potato	462	138,660	200	27.73	1.85	25.90
Sugarcane	940	233,750		19.58	1.42	26.30
Chat	3,186	810,000				
Total	5,426	1,327,920				

The Woreda has a very low livestock population due to land shortage. Table 5 shows that Wondo Beleche Chat, Sugarcane and Sweet potato are the major irrigated crops in the Woreda. Sugarcane is harvest throughout the year. Farmers in the area reported that they can harvest two FSR Isuzu truckloads of sugarcane from a 1,000 m^2 plot and one truck can carry from 2,500 (long) to 2,800 (short) piece of sugarcane piece/steams. One short cane is usually sold at 3.50 birr and the long one at 4.50 birr. One FSR Isuzu truck carries about 100 quintal or 10,000 kg of cane. One long piece of cane is about 4 kg and one short piece about 3.57 kg. One liter of bio-ethanol is obtained from 10 to 16 kg of cane. To compare the chewing market with cane as a feedstock for ethanol, 4 pieces of cane that would be worth 18 birr could produce one liter of ethanol. Therefore, the cost of raw material destined for the chewing market is much higher than the market price of bio-ethanol, which is currently 14 birr per liter.

The second Woreda surveyed is Kewot in North Shoa. Altitude in the Woreda varies from 1,200 to 1,700 meters with even distribution of Wona Dega and Dega climates. The size of the population is about 93,000 with 15,084 households. The mean annual rainfall is 650 mm with bimodal distribution, the small rainy season in March and April and the main rainy season in June and July. Hence the Woreda cultivates crops in the Belg and Kiremt seasons. Only 8 Kebeles have access to transportation and ten have no accessibility to transportation. Nine Kebeles are connected to the national electricity grid. The major source of household energy is firewood, charcoal and agricultural residues. Some communities are using improved charcoal and biomass stoves.

The farming system is mixed a cropping and livestock system and there are 23,471 oxen, 11,771 cows, 5,699 caves, 33,781 sheep and 41,739 goats. Table 6 shows the area cultivated and productivity of major crops in Kewot Woreda.

Farmers in the Woreda harvest sugarcane throughout the year and sweet potato in October.

Table 6: Cultivated area, productivity and major bio-ethanol feedstocks in Kewot Woreda.

Crops	Area in ha	Productivity q/ha	Production q	Production cost per ha	Farm gate price Birr per q	Revenue in Birr	Approximate amount of bio-ethanol that can be obtained	Value of Bio-ethanol at retail Price (ETB)
Mung bean	11,050	13	144,391					
Teff	9,278	22	211,027					
Wheat	2,072	28	58,138					
Barley	2,105	24	50,792					
Sugarcane	15	120	1,800	22,578	94.07	169,326	10,800	151,200
Sorghum	5,683	35	195,905	16,288	219.97		* (note below)	
Sweet potato	20	65	1,300	14,378	110.60	143,780	17,333	242,666
Mango	196	120	23,250	470,028	623.00			
Orange	39	63	2,437					

*One tone of sugarcane produces 60 to 80 liters of bio-ethanol and 1 tone of sweet potato produces 136 liters of bio-ethanol (Shchs 1980). One ha of sugarcane produces 4,000 to 6,000 liters of ethanol and 1 ha of sweet potato produces a similar amount.

Major crops in the Woreda are mung beans, teff and sorghum, suggesting that the Woreda has a moisture stress problem (Table 6). Mung beans are a short season crop and mature at about 60 days. The current production of sugarcane and sweet potato is small but could grow.

The third Woreda surveyed is Dawa Chefa in Oromia Zone of the Amhara region. The Woreda covers 115,638 ha of land with an elevation range of 1,400 to 2,500 meters and distribution of 1% Dega, 10% Wona Dega growing zones and 89% Kola zone ecology with mean annual temperature of 25° C. The population in the Woreda is 127,150 with 22,887 households. The Woreda receives bimodal distribution of rainfall with the small rain falling in March and April and main rain in June to August. Farmers harvest sugarcane throughout the year while sweet potato in October.

During the survey period, the livestock population in the Dawa Chefa Woreda was 32,934 oxen, 109,072 cows, 7,809 caves, 16,529 sheep, 26,759 goats, 6,383 donkeys, 122 horses, 87 mules, 1,404 camels and 66,495 poultry. The major source of household energy is firewood, charcoal and agricultural residue. Improved charcoal and biomass stoves are in use.

Among 21 Kebeles in the Woreda, 5 are along the main highway, 10 have gravel roads and 6 are inaccessible by road. Half of the population has access to clean water with an average distance of 1.2 km to the water source. There is 1 petrol station in the Woreda and 6 Kebeles are connected with the national electricity grid.

Table 7: Cultivated area, production, productivity and major bio-ethanol feedstocks in Dawa Chefat Woreda.

Crops	Area in ha	Productivity q/ha	Production q	Production cost per ha	Farm gate price Birr per q	Revenue in birr	Approximate amount of bio-ethanol	Value of Bio-ethanol at retail Price
Teff	143,958	20	79,160					
Maize	1,354	35	47,390					
Pea	264	17	4,488					
Sugarcane	18	140	2,520	10,989	77.40	195,048	15,120	211,680
Sorghum	9,544	44	419,936	7,699	219.97			
Sweet potato	14	70	980	6,989	110.60	108,388	13,066	182,933

The major crops in the Woreda are teff, maize, and sorghum (Table 7). It appears that there is no high production of bio-ethanol feedstocks in Dawa Chefa Woreda currently, however the potential for sweet sorghum seem great.

4.1.9 Sugarcane Production under Contract without growers by Wonji Shoa Sugar Estate in Adama Zuria Woreda

Wonji Sugarcane Growers Union was established in 1993 EC (2001) with 5 Peasant Associations (PA). Currently the Union consists of 13 PAs with 1,713 male and 791 female members. The union covers 25-30% of the cane requirement for the Wonji Shoa Sugar Factory (Table 8).

The production capacity of the union has reached 3.7 million quintals of sugarcane per year (Table 9). The crop is harvested from October to June. The cost of one quintal of sugarcane is 50 birr with a production cost of 36.75 birr and a profit margin of 13.25 birr.

There are flower and feed processing plants close to the union. The Union is fully accessible to transportation and electric power. The main source of household cooking is firewood, charcoal and agricultural residues.

The purpose of assessing the activities of the union were to estimate the benefits and losses of contract growing of sugarcane as feedstock for EMD. In this case the sugarcane juice can be used directly for bio-ethanol.

Table 8: Production, Productivity and Pricing of Sugarcane by Wonji Shoa Sugarcane Growers Peasant Association Union

Year (EC)	Production in tones	Cost of production in Million Birr	Price of produce in million Birr	Productivity tones/ha	Amount of bio-ethanol that can be produced at 60 liters/tone	Expected revenue in millions (13.99 ETB/liter)
1994/95	79,831.0	4.87	6.89	55.27	4,789,860	67.0
1995/96	110,156.1	6.56	10.27	73.92	6,609,366	92.5
1996/97	110,492.7	8.18	11.89	76.85	6,629,562	92.7
1997/98	98,743.8	5.85	10.76	66.01	5,924,628	82.9
1998/99	91,940.1	5.96	9.91	64.38	5,516,406	77.1
1999/00	99,009.4	9.4	15.68	70.77	5,940,564	83.1
2000/01	87,268.8	9.79	13.96	62.67	5,236,128	73.2
2001/02	69,436.5	10.28	11.21	62.84	4,166,190	58.3
2002/03	162232.1	30.42	56.78	96.12	9,733,926	136.1
2003/04	142297.9	20.68	34.78	87.12	8,537,874	119.4

We are estimating 1 tons of sugarcane producing 60 lit of bio-ethanol and one liter of bio-ethanol being sold retail for 13.99 ETB.

Table 9: Area production and productivity of Sugarcane by Wonji Sugarcane Growers Union

Year	Area in ha	Productivity q/hq	Total production in q
2003	1,167.51	1,747.82	2,040,597.33
2004	1,541.11	1,666.83	2,568,768 38
2005	2,343.94	2,343.94	3,712,894.71

In all the Woredas surveyed (Wondo Genet, Kewot, Adama Zuria and Dawa Chefa), the major source of household energy is firewood, charcoal and agricultural residue. Some improved charcoal and biomass stoves are in use in these locations. Of the bio-ethanol feedstock produced, sugarcane produced by the Cooperative Unions of Adama Zuria is by far the best priced for ethanol production. The factory obtains 30% of its raw material from the Sugarcane Growers' Union. The union cannot breach its contract and can only sell to the Wonji Sugar Factory.

Sweet potato and sugarcane grown by small scale farmers in Dawa Chefa and Kewot Woredas could be marginally profitable as a raw material for bio-ethanol. Sugarcane produced by farmers in Wondo Genet Woreda would be too expensive.

4.2 Sweet Sorghum (*Sorghum bicolor (L.)* Moench)

Sorghum is found in the grass (Gramineae) family and is the most important cereal in the dry areas. In Ethiopia, sorghum is the third most important cereal after Teff and Maize (Table 10). It covers about 1.2 million hectares of land with total grain yields of 0.7 to 1.2 million tones and average yield of 12 quintal/ha in five months (Seme et al. 2013). However, yields of 30-60 quintal/ha can be obtained with improved varieties and cultivation methods. Sorghum is a C4 plant like maize and sugarcane, meaning it is a prolific producer of biomass.

Table 10: Area (ha), Production (q) and yield of sorghum as compared to other cereal crops at country level 2008/09-2010/11.

	Area (000 ha)			Production (000 q)			Yield (q/ha)		
Crop type	**2008/09**	**2009/10**	**2010/11**	**2008/09**	**2009/10**	**2010/11**	**2008/09**	**2009/10**	**2010/11***
Teff	2,481,333	2,588,661	2,761,190	30,280,181	31,793,743	34,839,826	12.20	12.28	12.61
Barley	977,757	1,291,112	1,046,555	15,194,042	17,504,436	17,033,465	15.54	15.50	15.20
Wheat	1,453,817	1,683,565	1,533,240	25,376,398	30,756,436	28,556,817	17.46	18.27	17.11
Aja (Emmer) wheat	30,605	24,018	30,859	427,729	330,191	475,651	13.98	13.75	11.72
Rice	35,088	47,739	29,886	713,937	1,031,277	904,120	20.35	21.60	30.25*
Sub-total	**4,978,600**	**5,635,095**	**5,401,730**	**71,992,287**	**81,416,083**	**81,809,879**	_	_	_
Maize	1,768,122	1,772,253	1,963,180	39,325,217	38,971,655	49,861,255	22.24	21.99	22.89
Sorghum	1,615,297	1,618,677	1,897,734	28,043,510	29,712,625	39,598,974	17.36	18.36	19.80
Finger Millet	408,099	368,999	408,110	5,603,045	5,241,911	6,348,258	13.73	14.21	16.07
Sub-total	**3,791,518**	**3,759,929**	**4,269,024**	**72,971,772**	**73,926,191**	**95,808,487**	_	_	_
Total	**8,770,118**	**9,395,024**	**9,670,754**	**144,964,059**	**155,342,274**	**177,618,366**	**-**	**-**	**-**

4.2.1 Sweet and Grain Sorghum

Cultivation practices of sweet and grain sorghum are similar. The only dissimilarity between the two is the accumulation of sugars in the stock of sweet sorghum, which can be crushed to produce juice for processing into ethanol (Michael et al. 2006). Apart from stocks harvested for juice content to produce ethanol, sweet sorghum provides additional benefits in the form of grain as food and bagasse (left after extraction of juice) as an excellent feed for livestock. The potential food versus fuel conflict from diversion of cropland for sorghum cultivation is allayed as it meets the multiple requirements of food, fuel and fodder.

4.2.2 Genetic Resources

Sorghum is believed to have originated in Africa and its culture is deeply rooted with Africans (Berhane 1979). In Ethiopia it is a major cereal crop from the highlands to the lowlands and throughout the country. There are a number of landraces known by various local names. A landrace is defined as a domesticated regional ecotype or a locally adapted traditional variety of a domesticated species that has developed over time through adaptation to its natural and cultivated environment in isolation from other plants of its variety. *Zengada* is the red seeded landrace adapted in the highlands while *Tinkish* is the sweetest variety.

Sorghum germplasm for Ethiopia is held by the Institute of Biodiversity Conservation (IBC 2001). The Institute holds 8,021 accessions within its gene bank in Addis Ababa. The research institutes have also released a total of 35 improved varieties and two hybrids adapted in various ecologies. The hybrids are short in plant height and are very high yielders (Figure 5). In addition there are 42 sweet sorghum accessions with acceptable brix value. However their stock yield and bio-ethanol yield per hectare has not been determined.

Sweet sorghum has been a low priority of the National Sorghum Research Project and hence little effort has been made to study its quality and production. In 2007, ICRISAT initiated a sweet sorghum tests at Melkassa and 21 genotypes were planted in July. However, the rain came late and stopped early and hence entries did not reach to full maturity. Table 11 shows the days to flowering and brix value of the 21 genotypes.

Figure 5: Hybrid seed production of sorghum at Melkassa Agriculture Research Center

In addition, some genotypes from the national variety test were found to have sweet stalks. Hence three randomly selected plants were evaluated for their brix value from their upper, middle and lower part of their stalks. The brix value ranged from 7.6 to19% and 12.78 to 19% for ICRISAT materials and for local materials respectively. It is known that the sucrose content of sweet sorghum juice increases with the maturity of the plant until the seeds are ripe. Therefore the low brix value in the ICRISAT sweet sorghum genotypes may be due to immaturity or they were evaluated before full maturity. Table 11 shows that sweet sorghum genotypes that can be used as raw material for micro distilleries are available. In addition, similar genotypes were tested at Meiso, Wolenchiti, Melkassa and Kobo for two years. Data on stalk yield is available but the brix percentage was not read.

Table 11: Refract meter brix percent of the genotypes introduced from ICRISAT and available materials from the national yield trials tested in 2007 main season at Melkassa (Asfaw 2008)

Genotype	Days to Flowering	Brix % at 21 C			
		L	M	U	±
89 MW 5073	85	10.7	9.7	9.3	9.9
ICSV 700	96	15.7	14.7	14.0	14.8
ICSV 93046	99	15.0	18.0	15.0	16.0
IESV 92008 DL	89	19.3	19.0	12.7	17.0
IS 8193	82	19.3	-	-	19.3
KARI MTAMA 1	85	18.3	18.7	14.0	17.0
IESV 91104 DL	87	11.3	7.0	11.0	9.8
IESV92021 DL	97	7.3	7.7	7.7y	7.6
IESV 92089 DL	87	12.0	10.0	8.3	10.1
IESV 92162 DL	99	14.0	14.7	14.3	14.3
IESV 92165 DL	95	10.3	10.0	9.7	10.0
KIBOKO LOCAL MR# 22 X IS	91	17.3	16.7	11.3	15.1
8613/1/2/55-2-1	91	15.0	14.3	-	14.7
NTJ2	97	13.7	13.3	8.0	11.7
2005 MI 5071	92	14.7	19.0	15.0	16.96
2005 MI 5075	85	19.3	18.33	13.00	17.00
2005 MI 5077	82	20.0	18.0	19.0	19.0
2005 MI 5082	90	12.6	13.0	12.67	12.78
2005 MI 5089	90	22.3	9.33	16.33	16.00
2005 MI 5093	78	19.0	16.67	7.67	14.44
ICSV 2492	80	19.0	19.67	14.67	17.78
Mean		15.6	13.7	11.1	14.3

4.2.3 Ecology

Sorghum is adapted in various ecologies but it is found mostly in lower altitude dry areas. This is because it gives relatively higher seed and biomass yield in drier areas. Sorghum grows also on various soil types and prefers a soil with pH of 5.5-8.5. It grows well in 12 of the 18 major agro-ecologies (EIAR 2011).

Sorghum grows in four major agro-ecological zones. These are dry lowlands, wet lowlands, mid altitudes and highlands. The dry lowlands are with altitudes of less than 1,600 meters above sea level, low rainfall and humidity and high temperature. These areas include Kobo Alemata lowlands, most of the Rift Valley and western, southern and eastern lowlands bordering Sudan and Somalia. The varieties adapted in these areas should mature within 90-120 days after planting. Wet lowlands include areas such as Gambella that has sufficient rainfall, high humidity and temperature. Varieties adapted in these areas mature 15-20 days later than those adapted in dry lowlands.

Mid altitude or Woina Dega areas are those with altitudes of 1,600-1,900 meters with intermediate temperature and sufficient rainfall and high humidity. Such areas include East Wollega, West Shoa around Bako and Jimma. Varieties adapted to these areas mature 150-190 days after planting.

Dega sorghum growing areas are those above 1,900-2,700 meters with cool temperature and varieties adapted to these areas take 180-270 days.

Sorghum is believed to have originated in Ethiopia hence there exists huge variability within the germplasm. Traditionally there are landraces known as *Tinkish* in Amharic. The stalk of *Tinkish* contains a very high level of sugar and has been consumed as food traditionally. In addition, the International Crops Research Institute for the Semi-Arid Tropics in India has developed varieties of sorghum known as sweet sorghum that can be used for food, feed or fuel. The grain can be used for food, the stock for high value feed or ethanol production through fermentation and leaves for feed. Sweet sorghum has several advantages as compared to sugarcane and sugar beets. These include:

1. It can be grown in dry areas such as the northeast lowlands where other cereals or pulses fail to grow. Sweet sorghum has much lower water requirement than sugarcane and sugar beet.
2. Yield of sweet sorghum is comparable to sugarcane and higher than cassava. It takes less time to mature than both sugarcane and cassava. In the Philippines sweet sorghum yields 43-65 tons of stalk with 3.28-4.40 tons of grain per hectare per year. Both grain and stalk can be used for bio-ethanol conversation. The stalk can be used for syrup, vinegar, and basi, a fermented drink. Farmers can benefit from both the stalk and grain (Table 12).
3. Economic analysis in the Philippines and India indicated that the price of cane from sweet sorghum is lower than cassava, sugarcane and corn. Financial measures indicate the profitability of bio-ethanol production from sweet sorghum (Dar 2007).
4. Being a short cycle crop, sweet sorghum is cheaper than other feedstocks.
5. With availability of irrigation two or more harvests can be made per year.
6. Sweet sorghum can be cultivated in various ecologies such as Kolla, Wina Dega and Dega

Table 12: Comparison of sweet sorghum, sugarcane and sugar beet production (Almoders and Hadi 2009)

Factor	Sugarcane	Sugar Beet	Sweet Sorghum
Crop duration	18 months	5-6	4-6
Growing season	3	1	1
Soil requirement	Grows well in drained soils	Sandy loam and tolerates salinity	All types of soils
Water requirement	36,000 m^3/ha	18,000 m^3/ha	12,000 m^3/ha
Crop management	Requires good level of management	Greater fertilizer requirement & medium management level	Lower fertilizer requirement and management
Yield per hectare	70-80 tones cane	30-40 tones tuber	54-69 tones stalk
Sugar content on weight basis	10-12%	15-18%	7-12%
Sugar Yield	7-8 tones/ha	5-6 tones/ha	6-8 tones/ha
Bio-ethanol production directly from juice	3,000-5,000 l/ha	5,000-6,000 l/ha	3,000 l/ha
Harvesting	Mechanical and manual	Very simple manual	Very simple both manual & mechanical

4.2.4 Insects and Diseases

Sorghum can be afflicted with several diseases and negatively impacted by insects. Among diseases smut (loose and covered smut) is the most damaging and has the potential to reduce seed yield substantially. There are several diseases that reduce both seed and stalk yield. Stalk borer is a major insect pest that affects stalk yield of both sugarcane and sweet sorghum. Stock borer can be controlled by insecticides as well as cultural methods. Pacnoda is also becoming very damaging to the head.

The parasitic weed Striga (witchweed), family Orobanchaceaecauses, causes serious yield reductions on sorghum. Control of this parasitic weed is expensive and requires a high degree of management (Mbwika et al 2011).

4.2.5 Suitability Mapping

Cropland suitability analysis is a pre-requisite to achieve optimum utilization of the available land resources for sustainable agricultural development. Land suitability is defined as the fitness of a given type of land for a specified kind of land use. Proper identification of the property, potential and limitations of the land resources facilitates development and extension as well as the scaling up of sustainable agricultural crops and technologies**.**

Sorghum suitability maps were developed using soils (soil type, property, such as PH effective depth, texture and drainage) and climate layers (rainfall and temperature during the growing period and length of the growing period) (Demeke 2014).

There is highly suitable land of 3.52 million ha in the highland, 5.1 million ha in mid altitude and 7.29 million ha in lowlands (Tables 13, 14, 15 and Figures 6, 7 and 8).

Figure 6: Land suitability map for highland sorghum (Demeke Nigussie 2014)

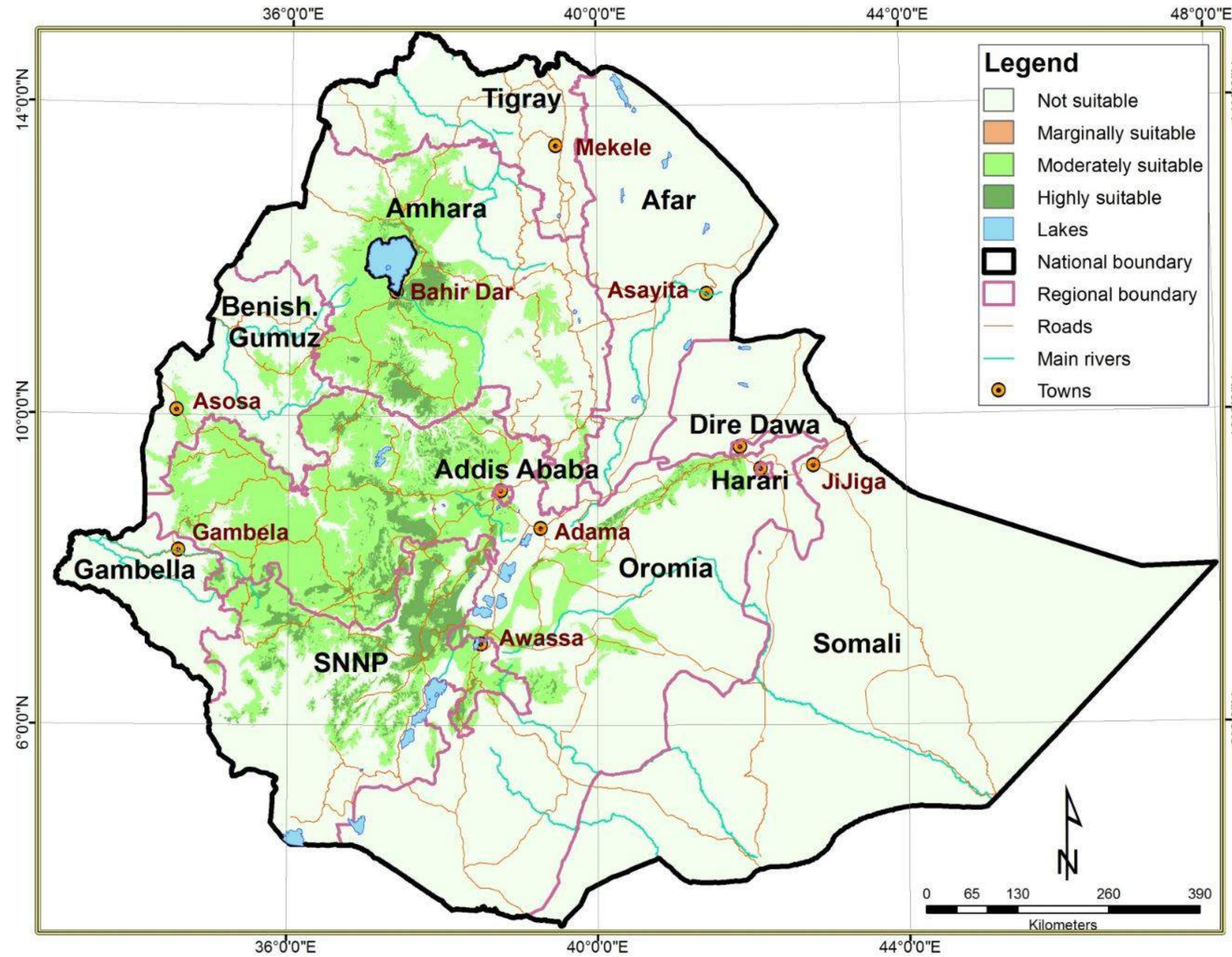

Table 13: Area of land under different suitability classes for highland sorghum by region (Demeke Nigussie 2014)

Region	Suitability								Total area (ha)
	Not suitable		Marginally suitable		Moderately suitable		Highly suitable		
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	
Addis Ababa	12,472	23.14	0	0.00	40,888	75.85	508	0.94	53,905
Afar	9,378,104	99.15	8	0.00	12,724	0.13	84	0.00	9,458,647
Amhara	9,386,652	61.65	56,076	0.37	5,084,992	33.40	687,532	4.52	15,226,388
Benishangul Gumuz	4,352,084	86.13	2,136	0.04	660,124	13.06	2,160	0.04	5,053,107
Dire Dawa	105,504	99.95	48	0.05	64	0.06	0	0.00	105,556
Gambella	2,936,836	95.17	16	0.00	101,192	3.28	10,716	0.35	3,085,850
Hariri	37,140	99.93	0	0.00	0	0.00	0	0.00	37,165
Oromia	21,129,084	65.38	10,348	0.03	9,810,300	30.36	1,323,620	4.10	32,315,167
SNNP	6,365,224	58.41	1,996	0.02	2,932,872	26.91	1,492,232	13.69	10,898,331
Somali	31,233,268	99.43	96	0.00	1,136	0.00	0	0.00	31,411,883
Tigray	5,012,228	91.69	148	0.00	189,972	3.48	6,828	0.12	5,466,505
Total	89,948,596	80	70,872	0.1	18,834,264	17	3,523,680	3	113,112,504

Figure 7: Land suitability map for mid land sorghum (Demeke Nigussie 2014)

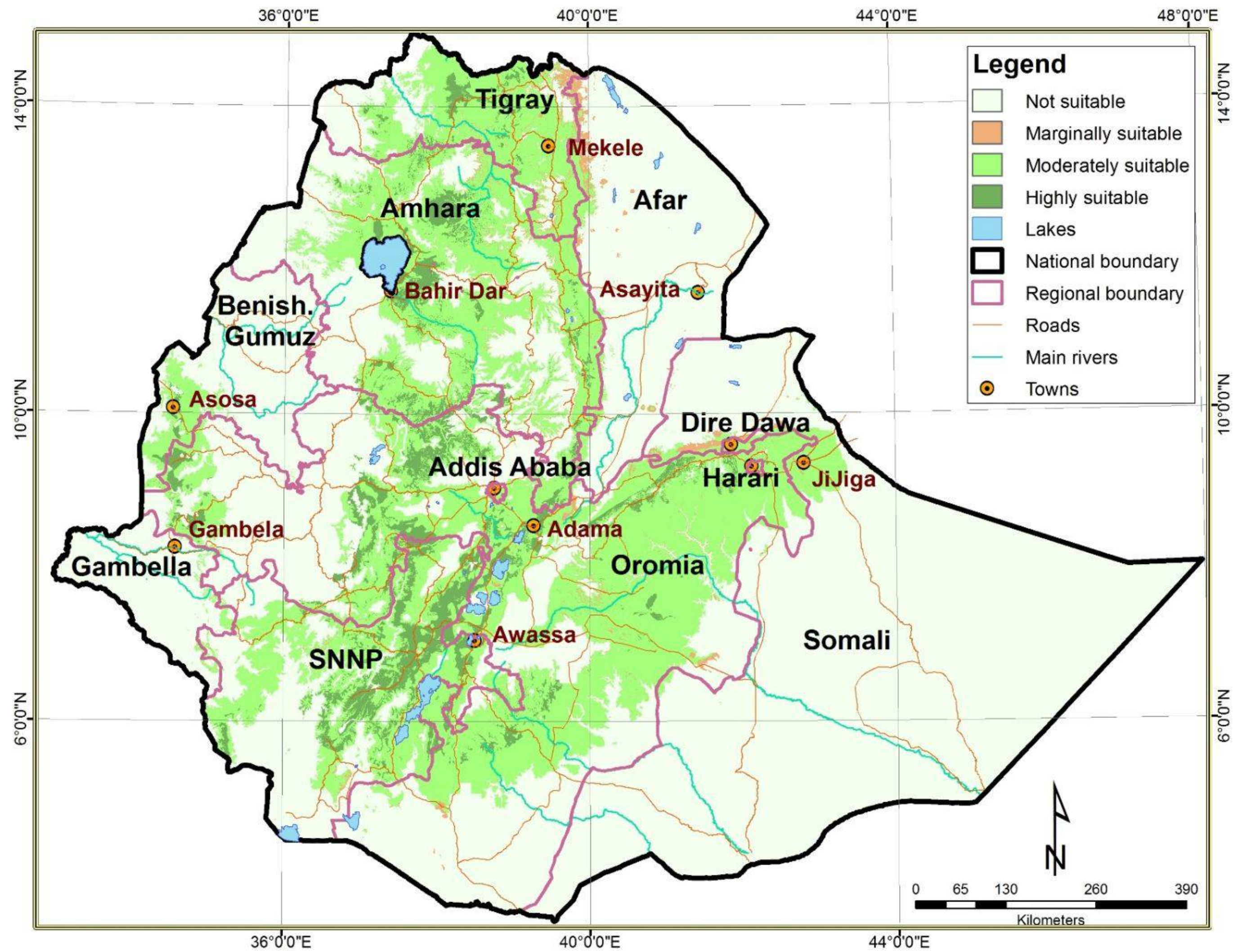

Table 14: Area of land under different suitability classes for Mid-land Sorghum by region (Demeke Nigussie 2014)

Region	**Suitability**								**Total area (Ha)**
	Not suitable		**Marginally suitable**		**Moderately suitable**		**Highly suitable**		
	Area (ha)	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	
Addis Ababa	12,728	23.61	0	0.00	41,140	76.32	0	0.00	53,905
Afar	8,761,020	92.62	230,236	2.43	396,196	4.19	3,932	0.04	9,458,647
Amhara	6,591,016	43.29	150,044	0.99	7,305,120	47.98	1,146,096	7.53	15,226,388
Benishangul Gumuz	4,248,904	84.08	0	0.00	682,480	13.51	63,828	1.26	5,053,107
Dire Dawa	10,192	9.66	27,952	26.48	67,472	63.92	0	0.00	105,556
Gambella	2,892,364	93.73	3,164	0.10	134,520	4.36	0	0.00	3,085,850
Hariri	0	0.00	0	0.00	36,380	97.89	760	2.04	37,165
Oromia	15,931,872	49.30	240,104	0.74	14,119,284	43.69	1,980,400	6.13	32,315,167
SNNP	4,649,816	42.67	37,376	0.34	4,464,836	40.97	1,633,044	14.98	10,898,331
Somali	30,243,828	96.28	125,156	0.40	864,976	2.75	0	0.00	31,411,883
Tigray	1,436,220	26.27	192,232	3.52	3,260,192	59.64	271,036	4.96	5,466,505
Total	74,777,960	66	1,006,264	0.9	31,372,596	28	5,099,096	5	113,112,504

Figure 8: Land suitability map lowland dry land sorghum (Demeke Nigussie 2014)

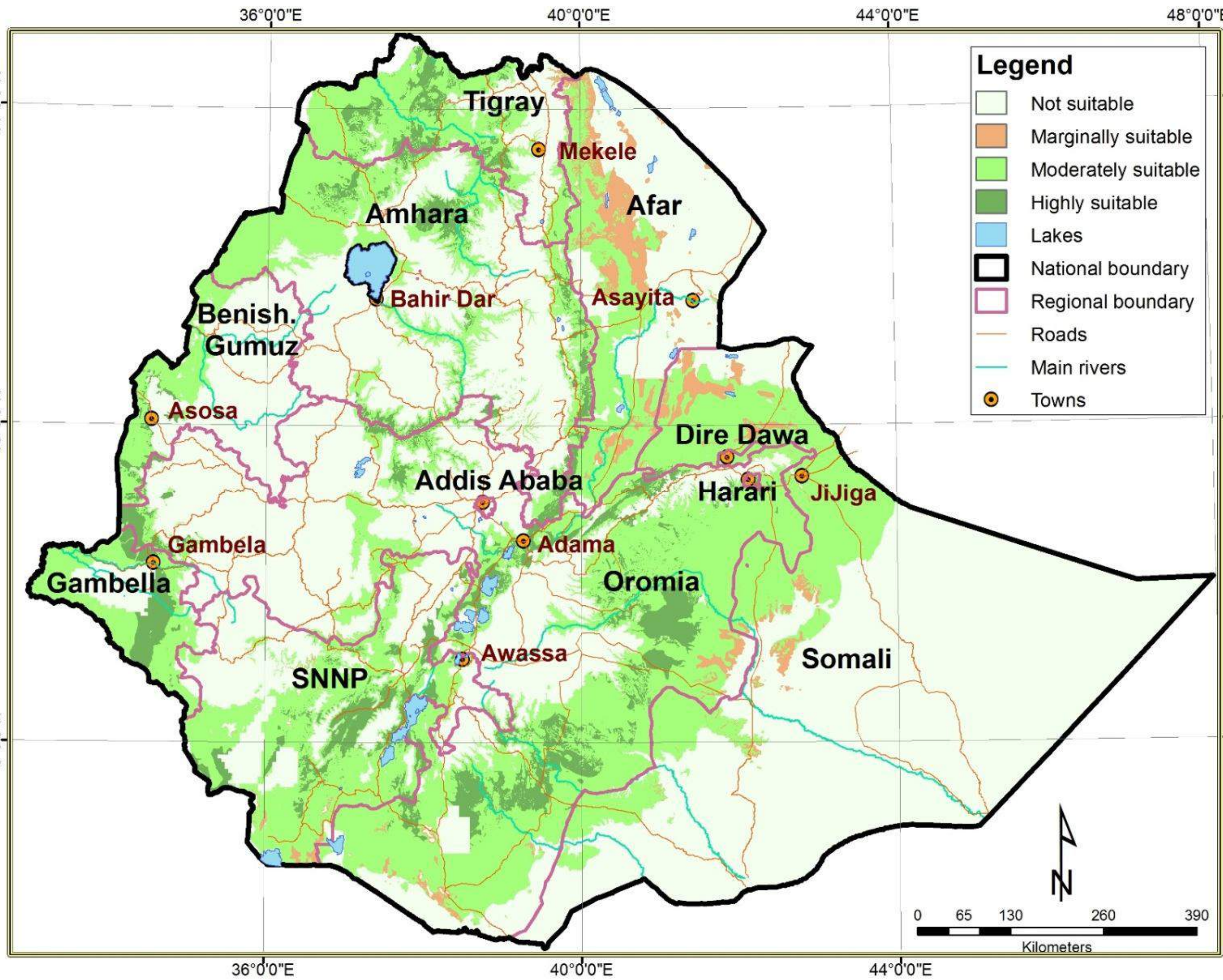

Table 15: Area of land under different suitability classes for Lowland dry land Sorghum by region (Demeke Nigussie 2014)

Region	Suitability								Total area (Ha)
	Not suitable		Marginally suitable		Moderately suitable		Highly suitable		
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	
Addis Ababa	28,596	53.05	0	0.00	25,272	46.88	0	0.00	53,905
Afar	6,304,388	66.65	997,876	10.55	2,058,896	21.77	0	0.00	9,458,647
Amhara	5,879,284	38.61	1,353,812	8.89	6,898,888	45.31	1,064,152	6.99	15,226,388
Benishangul Gumuz	324,740	6.43	0	0.00	1,989,932	39.38	2,678,740	53.01	5,053,107
Dire Dawa	0	0.00	75,752	71.76	29,864	28.29	0	0.00	105,556
Gambella	618,564	20.05	6,172	0.20	1,463,744	47.43	937,692	30.39	3,085,850
Hariri	0	0.00	1,760	4.74	35,380	95.20	0	0.00	37,165
Oromia	11,567,348	35.80	1,170,368	3.62	17,701,252	54.78	1,811,600	5.61	32,315,167
SNNP	2,889,424	26.51	200,584	1.84	7,022,348	64.44	672,368	6.17	10,898,331
Somali	28,185,952	89.73	587,584	1.87	2,349,600	7.48	0	0.00	31,411,883
Tigray	1,160,948	21.24	578,056	10.57	3,295,700	60.29	129,668	2.37	5,466,505
Total	56,959,244	50	4,971,964	4.4	42,870,876	38	7,294,220	6	113,112,504

4.2.6 Estimation of Bio-ethanol from Sweet Sorghum

The current area coverage of sorghum in Ethiopia is about 1.2 million ha per year. In some areas of Ethiopia such as North West, sorghum is cultivated in rotation with sesame and cotton. Sesame is an export commodity that is worth up to 210 USD per quintal while cotton has an increasing demand for the garment industry that shows rapid growth and high demand for raw material. Therefore it is wise not to assume area expansion.

The amount of bio-ethanol that can be obtained from sweet sorghum can be calculated using an average yield of bio-ethanol per hectare multiplied by the area. Brix value of the sweet sorghum genotypes available at the Ethiopian Sorghum Research Project reaches up to 24.0. The data on stalk yield and ethanol yield per hectare of sweet sorghum genotypes under local conditions is not available. Table 16 shows the amount of bio-ethanol that can be obtained at various intensities of area coverage.

Table 16: Area of land under different suitability classes for Lowland dry land Sorghum by region (Demeke Nigussie 2014)

Percentage expansion as percent of the current area 1.2 million hectares	Area in Hectare	Amount of bio-ethanol expected in million liters	Approximate number of households to be involved in production*
1	12,000	12	24, 000
2	24,000	24	48,000
5	60,000	60	120,000
10	120,000	120	240,000
15	180,000	180	360,000
20	240,000	240	480,000

* *One household is assumed to have approximately one half hectare of land. Assumption is made that one 1,000 liter/ha of bio-ethanol can be obtained (Lau et al 2006).*

Bio-ethanol yields of sweet sorghum per hectare vary from 1,000 liters to 3,000 liters per hectare depending on the variety and cultivation intensity. The yield of 1,000 liters/ha is for the poor management using open pollinated varieties while 3,000 liters/ha is for the best management with hybrid varieties. Therefore the average yield of 1,000 liters per hectare and land area of 1.2 million hectares is considered to calculate the figures in Table 16.

4.2.7 Cost of Production of Sweet Sorghum

In Ethiopia, sorghum is cultivated mainly in moisture stress areas, labor based and family owned. So far there is no study within Ethiopia on cost of production and economic analysis of sorghum. However the cost of grain production from sorghum around Kobo areas is about 21,000 ETB/ha. However, stalk of sweet sorghum is a byproduct of grain production but framers will not waste the stalk because they use it either for feed or fuel. Therefore a farmer around Kobo and Moheni makes about 9,000 birr per hectare from sale of sorghum stalk.