4.3 Sugar Beets as a Source of Ethanol

Sugar beets are similar biologically and ergonomically with fodder beet. The only difference is the former contains high sugar in its tubers. The adaptability and agronomic requirements of fodder beets were studied at Holetta and Kulumsa (ARDU 1980). The fertilizer requirement study at Kulumsa in 1976 and 1977 showed that fodder beet gave the highest yield at the highest rate. The seed rate study at Kulumsa showed that a seed rate of 10 kg/ha at a spacing of 40 cm between rows and 30 cm between plants is optimum (Table 17). Studies at Kulumsa, Bekoji and Kofele have shown that the yield of fodder beets reaches 10 tons/ha (Tables 17 and 18). Both fodder beets and sugar beets are similar in their ecological and cultivation requirements and hence it can be assumed that sugar beets can provide similar yields in areas such as Holetta, Kulumsa, Bekoji and Kofele that are typical Ethiopian highlands with cool climate.

Table 17: Area of land under different suitability classes for Lowland dry land Sorghum by region (Demeke Nigussie 2014)

Seed rate kg/ha	Yield of dry matter kg/ha								
	Kulumsa			Bekoji			Kofele		
	top	root	total	top	root	total	top	root	total
5	0.35	4.14	6.49	1.58	7.20	8.78	1.46	11.49	12.95
10	0.39	8.60	8.99	1.35	7.69	8.96	1.49	10.64	12.13
15	0.41	6.97	7.38	1.30	7.80	9.10	1.71	12.62	14.33

Table 18: Biomass yield of three varieties of fodder beets grown at Bekoji and Kulumsa in 1977

Varieties	Kulumsa			Bekoji			
	top	root	total	Varieties	top	roots	Total
Sucropoly	0.37	11.54	11.97	Aring Barres	1.78	9.0	10.77
Zwaanss II	0.41	12.04	12.46	Meka	1.18	6.80	7.98
Zwaannnpoooly	0.37	11.81	12.17	Korsor	1.45	8.70	10.16
				Kyros	1.73	10.92	12.65

Sugar beets (Figure 9) grow in most temperate areas including Canada, USA, Russia, EU, Australia and Argentina. Sugar beets can grow in a wide variety of soil types, from sandy to rich topsoil to clay rich soil and climates. Beet sugar accounted for 58.8% of the sugar produced in the United States and 30 % globally in any single year (SKIL 2014).

Sugar beets require more net energy to produce sugar than sugarcane, because unlike sugarcane sugar beets do not have a byproduct like bagasse that can be burned for energy (SKIL 2014). However, sugar beets do have other byproducts that are used as animal feed. Both the tops of sugar beets and the pulp left after sugar is extracted from the beets are used as feed for cows and sheep. Molasses from sugar beets is also used as an additive to feed. Molasses from sugar beets does not have the same taste as molasses from sugarcane and is not generally consumed by humans. An average of 13 to 25 tons of sugar beets can be grown per acre of un-irrigated farmland. Irrigation increases yield by 15 to 30 percent.

Figure 9: Sugar beet tuber (left); TSB, India (Syngenta 2007)

It is relatively easy to extract sugar from sugar beets. The beets are chopped into thin chips called cossettes and washed in a counter-current flow with water in a diffuser. The washed cossettes are pressed to remove remaining water and sugar (SKIL 2014). The sucrose-rich water is then cleaned of impurities with lime and filtration and separated by drying and crystallization. If the sugar from beets is used to create bio-ethanol instead of sugar, the cleaned sucrose-rich water could be put through a fermentation step instead of drying and crystallization. The current sugar extraction process could be duplicated exactly to this point. The sucrose-water mixture might have to be diluted or concentrated to be a more ideal food for the yeast that would be used to ferment it. A separation step to recover ethanol, i.e. distillation, would finish the process of creating ethanol from sugar beets.

Ethanol production from beets can be done with the full beet plant or as a sugar co-product from the juices from the beet. From an economic point of view the best approach is an operating sugar factory with a bio-ethanol plant added using the raw and thick juices coming from the sugar process. Compared with a cereal-based plant, a sugar beet plant is generally a cheaper investment, requiring fewer workers (Jeanroy 2009).

A distillery or a sugar factory using sugar beets can also use sugarcane. In order to mitigate the risk of building a factory, sugarcane and sugar beet lend themselves to a multiple feedstock strategy. The agro-climatic conditions are such that both crops can be grown simultaneously and processed in the same plant. The factory must be adapted with upfront entry lines for feedstock reception and juice production, merging after the juice purification step (TIRET 2011).

Sugar beet offers competitive advantages as an energy crop because it requires less input, less water per unit area and has the best bio-ethanol yield per hectare, comparable to the yield of second generation cellulose ethanol. Sugar beet can also be used for biogas production from the pulp or vinasses or whole beet (Punda 2009).

Table 19: Compared ethanol yields and water needs (Jeanroy 2009)

	BEET	CANE	CORN	WHEAT
Ethanol Yield Hectoliter/ha	80-85	70-75	40	32
Average water need in mm	500-600	900-1,000	600-800	600-1,500

The biotechnology company Syngenta AG has developed Tropical Sugar Beet (TSB) varieties suitable for cultivation under tropical conditions. TSB has been introduced for trials in a number of East African countries, including Ethiopia. TSB cultivation trials began in India in 2007 in two locations, Ambad near Jalna, Maharashtra and Kalas, near Pune (Syngenta 2007). Two large sugar projects with sugar beets are proposed, one for Kenya and one for South Africa (Mumero 2012). In 2008, Saudi Star Agricultural Development PLC, a subsidiary of Derba MIDROC Cement PLC began studies with TSB at its Bir and Ayehu Farms as well as on individual farmers' plots surrounding the two farms. These trials were carried on for three successive seasons. The trials examined varieties, insect and diseases and planting schemes. These were the first trials with TSB in the country. The trials were reported to be successful, with the finding that TSB adapted well to the area where the trials were conducted and presumably would thus do well in areas with similar agro-climatic conditions.

Potential areas for the planting of TSB were identified in the Amhara, Benishangul Gumuz, Afar and Oromia regions, based on bio-physical (climate, soils and topography) similarities to the trial sites. Over 1 million hectares of land were identified in Amhara region alone to be suitable for cultivation of the crop (TIRET 2011).

In the Bir and Ayehu farm trials, the beets were ready for harvest between 5-6 months depending on the specific growing season. Average yield in the first two season trials ranged from 50 to 70 tones/ha while in the third season trial the yield increased to 70 to 120 tones/ha (TIRET 2011).

If the agronomic and quality traits of sugar beet under Ethiopian condition are found acceptable, then it could be an alternative source of bio-ethanol production. Sugar beet is easier to plant and harvest than sugarcane, and would reduce the cost of production either for sugar or ethanol. The lower water requirement of sugar beets as compared to sugarcane would be an added advantage. Sugar beet yields of bio-ethanol are comparable to the yields from sugarcane. Sugar beet can also be grown by small-scale farmers as a rain-fed crop with its leaves being used as feed. Sugar beets have a similar agronomy to beet root or table beets.

4.4 Sweet Potato

The sweet potato, *Ipomoea batatas* (Lam.) is a dicotyledonous plant belonging to the family Convolvulaceae. It is a tuberous root crop important for food security. It is grown widely throughout Sub Saharan Africa and is one of the most important food crops in Africa (FAOSTAT, 2013). It is grown in small plots by subsistence farmers. It is relied upon in the Southern, Eastern and South western parts of Ethiopia. It is produced annually on over 53 thousand hectares of land with total production of over 4,240 tons and average productivity of 8.0 tons per hectare (CSA, 2011—Table 1). Ethiopia is one of the largest sweet potato producing countries in East Africa and the Southern Nations Nationalities and Peoples' Region (SNNPR) is the major sweet potato producing region in the country. According to the CSA agricultural sample survey data, it is second to potato in area of production and productivity (Shonga 2013).

Sweet potato is an early and fast growing crop that contributes significantly to food security. The root is used as food and its leaf as animal feed.

Sweet potatoes are not to be confused with yams. Yam is the common name for plant species in the genus Dioscorea (family Dioscoreaceae) that form edible tubers. These are perennial herbaceous vines cultivated for the consumption of their starchy tubers throughout Africa. Yams are monocots, related to lilies and grasses. They are native to Africa and Asia while sweet potatoes are thought to have originated in South America. Sweet potatoes are moist and sweet while yams are dry and starchy (Schultheis 1993).

4.4.1 Ecology

Sweet potato is adapted in various climates and soil conditions but gives ideal yields when the temperature is > 24 ºC, with sunny days and cool nights. Sweet potato does not like shade and requires clear sunny days. Although sweet potato can be grown from sea level to 2,000 meters of elevation, its tuber yield is higher at lower altitudes. Sweet potato requires rainfall of 700-1,000 mm during the growing season.

Sweet potato gives high yield without fertilizer. Sweet potato is also a suitable crop for intercropping with sorghum, maize and common bean.

4.4.2 Pests

The productivity of the sweet potato crop in Ethiopia is extremely low compared to other African and Asian countries where it yields more than 18t/ha (Shonga 2013). The low productivity of sweet potato is due to the existence of insect pests and the diseases they transmit. Sweet potato weevil, Cylas puncticollis (Coleoptera: Curculionidae), is known as the most serious, followed by viral diseases transmitted by Aphis gossypii (Homoptera: Aphididae) and Bemisia tabaci (Homoptera: Aleyrodidae). In addition, sweet potato butterfly, Acraea acerata (Lepidoptera: Nymphalidae), is the most devastating pest in major sweet potato growing zones in the country but its occurrence is sporadic based on agro-ecological conditions (Shonga 2013).

Because sweet potato is grown in year around in southern Ethiopia and plots of different ages are found on the same farm or neighboring farms in close proximity, weevil-infested plots infest new plots of sweet potato. As a result, infested sweet potato fields and left over infested sweet potato tubers are the most important source of infestation for new plants. Careful timing in planting, good field sanitation and planting away from weevil infested fields are the practices expected to have noticeable effect on weevil management (Shonga 2013).

Sweet potato butterfly can be controlled by using clean planting material, crop rotation and covering or ridging the plants very well. Certain botanicals planted with the sweet potato help to repel the butterfly. Use of insecticides during infestation is necessary (Shonga 2013).

To avoid viruses, disease-free planting materials using tissue culture should be used.

Crop improvement research began on the sweet potato in the early 1970s and about 23 hardy and resistant varieties have been developed to withstand pests and diseases. While no plants may be immune to weevils, some varieties are able to withstand weevils more effectively.

4.4.3 Varieties

There are a number of varieties available for production (Table 20). Some of these varieties are yellow and are recommended for consumption as a good source of vitamin A.

Table 20: Yield and adaptability of sweet potato varieties in Ethiopia (EIAR 2011).

Variety	Length of growing period in days	Ecology	Average Yield q/ha
Kudadie	90-120	Dega, Wona Dega and Kolla	241
Dubo	90-120	Dega, Wona Dega and Kolla	217
Falaye	90-120	Dega, Wona Dega and Kolla	167
Funtete	90-120	Dega, Wona Dega and Kolla	354
Damota	120-150	Dega, Wona Dega and Kolla	307
Baraeda	120-150	Dega, Wona Dega and Kolla	296
Hawassa-83	120-150	Dega, Wona Dega and Kolla	366
Belela	150-180	Dega, Wona Dega and Kolla	176
Temesgen	90-120	Dega, Wona Dega and Kolla	183
Beletech	120-150	Dega, Wona Dega and Kolla	185
Ordolo	120-150	Dega, Wona Dega and Kolla	174
Koka-12	120-150	Dega, Wona Dega and Kolla	177
Koka-6	120-150	Dega, Wona Dega and Kolla	269
Kilfo	120-150	Dega, Wona Dega and Kolla	290
Tulla	120-150	Dega, Wona Dega and Kolla	285
Kero	120-150	Dega, Wona Dega and Kolla	354

4.4.4 Sweet Potato Production in Boleso Sore Woreda Wolita Zone

Boloso Sore Werda is found in Wolita zone of the Southern region. The Woreda is famous in root crops production (Table 21). The Woreda has a total of four Wona Dega and 25 Kola Woredas with a total population of 31,005 households and land area of 33,600 ha. Of the total area 556 ha is covered by perennial crops, 20,879 with annual crops, 1,234 ha with natural vegetation and 410 ha in plantation forest. The rainfall in the Woreda varies from 1,298 to 1,658 mm with a temperature of 14.4 to 25.9º C.

The household energy source in the Woreda is firewood, charcoal and crop residue.

Table 21 shows that sweet potato production increased in 2006 EC to 1,209,300 quintals over 4,031 hectares, up 215% from the previous year. Average yield over the 5-year period was 344.8 quintals/ha.

Table 21: Area, production in quintals of cereals, pulses and root crops in Boloso Soire Woreda of Wolita Zone during 2002-2006 EC

Crops	Year										Average productivity quintal/ha	Current Price Birr/quintal
	2002		2003		2004		2005		2006			
	Area ha	Production quintals	Area ha	Production quintals	Area ha	Production quintals	Area ha	Production quintals	Area ha	Production quintals		
Cereals												
Teff	4,450	84,995	7,419	80,345	4,157	73,165	4,125	57,730	4,025	57,388	14.6	1,300
Barley	379	8,932	315	8,820	265	7,419	303	6,700	57	1,269	25.1	1,000
Wheat	2,944	162,808	7,948	162,140	1,268	74,077	1,975	90,688	820	41,392	35.5	1,000
Maize	4,235	190,584	3,430	214,415	3,447	150,138	2,479	164,707	2,096	94,320	51.9	620
Pulses												
Common Bean	1,654	26,779	4,623	82,433	8,057	51,238	5,050	72,813	6,579	85,772	24.3	700
Field pea	284	4,828	268	5,095	247	5,415	320	5,103	485	9,955	9.5	1,000
Root Crops												
Taro	5,262	1,375,550	5,281	1,320,250	5,267	1,211,410	5,705	1,996,250	6,105	2,136,350	291.1	180
Sweet Potato	3,600	943,200	2,385	641,340	2,532	685,366	2,677	561,925	4,031	1,209,300	344.8	200
Potato	743	189,910	687	153,750	650	144,877	750	166,590	765	206,685	239.7	180
Cassava	134	41,240	138	40,570	80	24,000	79	23,943	261	78,300	300.7	-

4.4.5 Bio-ethanol production from Sweet Potato

Enzymatic processing technologies for industrial sweet potato conversion are studied. ► Up to 90% of starch in industrial sweet potatoes can be converted with current enzymes.

The sweet potato used is an attractive raw matter for fuel ethanol, since up to 4800 L ethanol per hectare can be obtained.(Lareo 2013).

7.5 Kg of sweet potato produces 1 liter of bio-ethanol
100 kg of sweet potato produces 13.3 liter of bio-ethanol
Based on the current price of 1 liter of bio-ethanol price of 13.5 Birr, one quintal of sweet potato produces 13.33 liters of bio-ethanol or 173.3 Birr per quintal as compared to 200 birr per quintal of raw sweet potato.

Although, the market price of sweet potato is 200 birr per quintal as compared to 173 birr of bio-ethanol that can be obtained from one quintal of sweet potato (Table 22).

Table 22: Total production, expected amount of bio-ethanol from the produce and revenue in birr from feedstocks in Boloso Sore Woreda.

Crop	Total production in 2006	Price at farm gate Birr per q	Total revenue at farm gate in million **Birr**	Amount of bio-ethanol expected in million liters	Expected revenue from bio-ethanol in million Birr
Taro	2136350	180	384.54	28.48	398.78
Sweet Potato	1209300	200	241.86	16.12	225.74
Cassava	78300			1.21	16.94

** 7.5 kg of Taro and sweet potato produces 1 liter of bio-ethanol*

4.5 Cassava

Cassava grows in warmer dry climates on poor soils within 30 º N and S of the equator. Cassava gives a high energy food, industrial starch and feed. In Ethiopia it grown in Southern Ethiopia for Dabo, Genfo, biscuit and injera mixed with teff.

4.5.1 Ecology and Propagation

Cassava grows well within altitudes of 0-2000 meters above sea level rain fall of 500-2000 mm distributed throughout the year. Cassava withstands high temperature and moisture stress. Cassava is very sensitive to moisture stress and does well within temperatures of 18-20º C. Although cassava grows on almost all soil types salty and poorly drained soils are not suitable for its growth. Cassava id propagated through cuttings. Cuttings should be taken from 12-18 month healthy mother plants. Cuttings should be 2-3 cm thick and 20-25 cm long taken from the middle of the mother plant.

4.5 2 Varieties

There are two varieties of cassava released from Hawassa Agricultural Research Center (Table 23).

Table 23: Agronomic characteristics of two cassava varieties grown in Southern Ethiopia.

Variety	Rainfall mm	Altitude meters	Yield q/ha		HCN (mg/kg)
			Research	Farmers	
Kello	980-1395	1200-1800	281	271	29.7
Qule	980-1395	1200-1800	272	241	20.3

HCN level of 10 mg/100 g on wet basis is considered safe for food. However the current varieties have very high content. On the other hand HCN evaporates and decreases at very low level above 28 C, hence cassava should be peeled, sliced and dries in the sun. In addition boiling or cooking can remove the HCN.

Cassava based foods can be seen in many cities, towns and villages of the southern region including Hawassa.

The major disease of cassava is virus. Hence mother plants used for obtaining cutting should be virus free.

The price of cassava and sweet potato price and production was surveyed in Boloso Sore Woreda of Wolita Zone. The description of the Woreda is indicated in section 3.4.6.

4.6 Fruits

4.6.2 Mango Fruits

Juice houses are common in many cities and towns of Ethiopia including the capital Addis Ababa. Fresh fruits can also be seen in the streets as well as shops. These fruits are grown in various regions of the country. Mostly Southern and Oromia regions are the major producers of fruits.

The kinds of fruits include mango, avocado, banana, papaya, guava and even cactus. Banana is consumed fresh while others are used for juice hence their seeds are wasted. It is known that the seeds of mango contain high grade starch that can be used for bio-ethanol production. Therefore seeds can be collected from juice houses as raw material for bio-ethanol. However collection of the seed from every juice house in major cities such as Addis Ababa, Adama and Hawassa may be a major cost.

A survey was made to estimate the amount of mango fruits that can be obtained from ten juice houses in Addis Ababa. All juice houses reported that mango fruits are wasted and collected daily by garbage collectors at a fee of 29% of their water bill. In almost all juice houses, mango fruits were dumped along with all other wastes. The amount of mango used as juice varied from 10 kg per day to 60 kg with an average of 37 kg. The juice houses reported that they utilize 70 to 420 kg of mango weekly with an average of 259 kg. Roughly the weight of the seed is half of the total weight. In addition eight kg of mango fruit makes up one liter of bio-ethanol.

The amount of mango fruit utilized in Addis Ababa is estimated 36 000 quintals of local varieties that have large seeds and 15 000 quintals of apple mango (Figure 10) produced by Horizon plantation or the former Upper Awash Agro Industry (Table 24). The local mango could result 18, 000 quintals of seed per year. However, collection of the mango fruits from each juice house is very difficult and expensive. At this point of time it is also inaccessible to estimate. Mango fruits as raw material for bio-ethanol can be visible if and only if large scale mango juice factories are established. In this case fruits can be obtained at one point as a single produce not mixed with any other wastes. Such a factory will be established very soon along with mango farms.

Table 24: Amount of mango supplied to Addis Ababa Atkilt Tera

Source of Mango	Months of Production	Annual Suppliers Production Season	Supplied Amount	Average ISUZU Capacity in Qtl	Total Supplied Qtl/day	Total Amount of Mango supplied per year
Assosa /Arba Minch	Nov-Mar	Feb-May	6 Isuzu trucks/Day	50	300	36 000* 18 000**
Horizon Plantation	May June		5 Isuzu trucks/Day	50	250	15 000 +

* Amount of mango fruit and ** approximate amount of mango seed.
+ Apple mango has a very small seed and cannot be determined.

Figure 10: Apple Mango at Melkassa Agriculture Research Center

In Adama, pig and poultry farmers are collecting mango fruits for feed. The farmers have provided a container for juice houses who collect seeds in a container and receive the seeds every evening at one birr per kg. The farmers collect the seed every afternoon or evening so that the seed is not spoiled. This experience can be used as an example.

4.6.2 Cactus Pear

Cactus pear production was surveyed in Erob Woreda of Eastern Zone of Tigay Region (Figure 12). The Woreda has total area of 93 345 ha varying in elevation from 1200 to 3000 meters.25 % Dega, 45% Wona Dega and 40% kola ecology and mean annual temperature of 11-36 C. The total population in the Woreda is 33 912 7 071 households. The livestock population in the Woreda is 18 284 cattle, 56 671 goats, 27079 sheep, 6238 equines and 1 196 bee hives.

The major source of house hold cooking is agricultural residues, fuel wood and charcoal. Two NGOs namely Erob Development association and Adigrat Diocesan Catholic Secretariat are very active in the Woreda. Barley, teff and maize are cultivated in the Woreda but cactus pear is by far important (Table 25). It appears that cactus pear can be a very good raw material for Bio-ethanol Micro Distilleries.

The brix value of cactus pear on average is about15 with sucrose content of 15% (Haileselassie et al. 2010). The yield of cactus pear land races at Mekelle varies 4-30 tones/ha (Table 26).

Table 25: Area, production and productivity of major crops in Erob Woreda of Eastern Tigray.

Crops	Crops			
	Barley	Maize	Wheat	Cactus pear
Total area	420	324	252	30 804
Productivity q/ha	4.45	6.15	7.35	68
Total Production in q	1869	1992.0	1852	2 094 672
Expected amount of bio-ethanol in liters				14 961 942

**1 liter of bio-ethanol is produced from 14 kg of cactus pear.*

Currently the production of cactus pear is in a serious threat by an insect called Cochineala (***Dactylopius coccus*** Figure 11)**.** This insect produces a red dye for fabrics that does not fed up on time. This insect feds on cactus leaf and protects itself from ants. Cochineala was introduced by Mekelle University as a technology shopping and fast dissemination. However the insect has become very serious threat to cactus in the region. Today the insect is found all over the region except Erob Woreda. It causes complete failure of cactus threatening the pear and leaf that is used as a food and fodder. Currently there is no control measure for the insect. Chemical control of the insect was found to be ineffective due to the terrain of the region and its complete abundance in all the areas including mountains, hills, gorges etc. in addition the chemicals needed to control the insect also affects honey bees threatening the honey production of the region. Biological control is also very difficult because of the insect protects/covers itself with shells (Mohammed 2013). Hence it is recommended that about 4-05 km of buffer zone be established between the infected Woredas and North East Tigray.

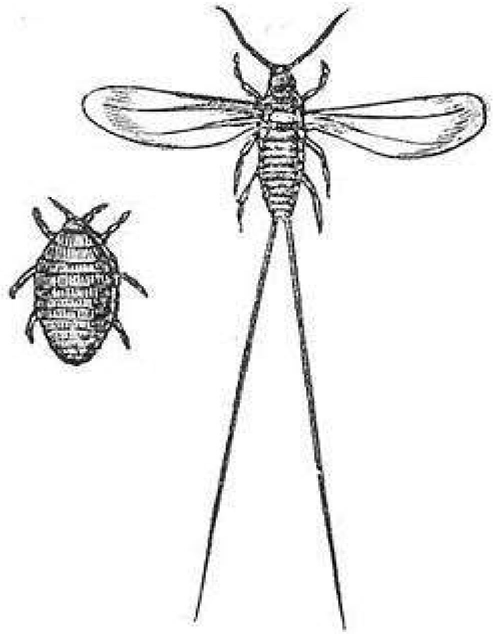

Figure 11: Female (left) and male (right) cochineals

Table 26: Average number of fruits per plant, fruit weight in g and estimated productivity tones/ha of 13 cactus land races (Tesfay Belay et al 2011).

Land race	Average number of fruits per plant	Average fruit weight g	Estimated production in tones/ha
Gerao	317.34	144.41	28.44
Naharisa	278.33	146.59	25.37
Kalamile	155.66	84.52	12.50
Adomuluhta	197.33	90.31	11.08
Geleweiti	82.30	60.02	4.69
Gerwanlayele	174.00	109.38	11.83
Suluhna	224.00	142.36	19.88
Hiraydaglyle	184.00	77.41	13.45
Neitsi	423.00	114.62	30.15
Orgufa	322.00	110.99	22.20
Ameudegaadobelesa	161.33	97.17	14.80
Hawawisa	101.33	119.92	11.54
Asakurkura	140	54.06	4.70

**Production tones/ha was estimated based number of fruits per plant, its weighty and number of plants/ha.*

4.6.3 Reject Common Bean

Common bean is produced on 133 372 hectares of land, by 1 247 557 growers with total yield of 1 987 777nquentals (14.9 q/ha) nationally. Common bean is an export commodity and during 2013 alone 400 000 quintals was exported abroad. Most of common bean seed cleaners and exporters are based in Adama. There are a number of seed cleaners that hand sort seed; hand picking plus machine cleaning using small machines and two companies have large seed cleaners. However ACOS Ethiopia PLC, established in 2005, is by far the largest. ACOS have modern seed processing machine with a capacity of 35,000 tons per year that combines sieve separation, gravity table and color sorters. The company has its own internal quality control and exports common bean in four classes (cream, small red, white and pinto) in three grades (Table 27 Figure 13).

Common bean has about 54-62% carbohydrate content by weight (Mulugeta et al 2003) and can be a good source of feedstock. However, grade 3 may not be valuable as a raw material for bio-ethanol. Currently ACOS has 1000 tons of reject.

Figure 12: Cactus Pear in Erob Woreda.

Table 27: Performance of ACOS Ethiopia PLC.

Parameter	Grades		
	1	2	3
Capacity of export tones/year	20 000	11 400	3 600
Amount of reject tones/year	2156	1078	1293
Estimated price Birr/tones	5000	3000	200

Figure 13: Hand Sorting of Red seeded common bean (top right) and processing by hand and machine, common bean varieties and seed color classes and white seeded common bean variety Awash-1.

5. Production and Productivity of Feedstocks by Regions

Table 28 shows production of feedstocks in million quintals and productivity in q/ha at a national level. It can be concluded that Oromia and SNNP grows all feedstocks followed by Amhara and Benighangul Gumz. Four regions namely Afar, Somali, Gambella and Tigray produce the least amount of feedstock variation.

Among feedstocks sorghum is cultivated in all regions while cactus pear is only grown economically in Erob Woreda in Eastern Tigray. In addition, sorghum production and the possibility of sweet sorghum production was passed in Tahtay Adeabo Woreda in Tigray. The Woreda is highly suitable for sorghum production and very likely for sweet sorghum cultivation Table 28 and 29). One entrepreneur has already shown interest for production of sweet sorghum as a feedstock for bio-ethanol. The National Sorghum Research project has also a testing site at Shire.

Table 28: Production and productivity of major feedstocks by region during 2006 EC nationwide.

(1= production in million quintals and 2, productivity in q/ha).

Crops	Regions															
	Tigray		Afar		Amhara		Oromia		Somali		Benishangul		Gambella		SNNP	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Maize	1.5	22.4	0.17	36.4	15.89	33.7	35.9	33.2	0.8	27.8	1.5	31.8	1.1	21.7	8.8	31.2
Sorghum	5.5	25.4			11.4	20.3	16.7	22.5	0.9	28.7	1.3	20.0	0.07	23.7	2.2	18.5
Taro							1.2	250.2					0.05	282.3	10.6	283.7
Sweet potato							10.6	502.7			0.1	135.6	0.01	114.1	7.0	228.9
Mango					0.3	35.1	0.3	69.1			0.5	67.2			0.3	93.0
Common bean					0.6	14.8	0.6	14.8			0.04	18.2			0.9	12.3
Sugarcane (smallholder)					1.1	391.9	1.1	15.7.							**9.6**	**539.9**

Table 29: Area in ha, total production and productivity of major crops in Tahtay Adeabo Woreda in Tigray, 2005-06 EC.

Crops	Area in ha	Production q	Productivity q/ha
Sorghum	23 336	851764	36.1
Maize	2267	102037	45.0
Millet	11653	256377	22.0
Sesame	20731	114020	5.5
Teff	329	3619	11.0
Field Pea	697	7318	11.0
Pepper	995	19402	19.5

6. Comparative and Competitive Advantages of Feedstocks

Bio-ethanol from sweet sorghum and sugarcane molasses does not compete with food security. This is because the stalk from sweet sorghum is utilized following grain harvest for food and its leaves for feed. In addition, there is wide resources and suitable ecologies to grow both sorghum and sugarcane. The production technologies for both crops is well established.

Starchy crops such as sweet potato and cassava are stress tolerant adapted in dry climates. Hence they are very good crops for food security. However industrial type of cassava which is cultivated exclusively for starch production than consumption can be used for bio-ethanol. At the present time these crops are suitable for food security than bio-ethanol production.

The potential of sugar beet looks good; however varieties suitable for Ethiopian condition should be tested. Each and every feedstock has its own ecological niche and competitive and comparative advantages (Table 30). Therefore, an entrepreneur should select his own best choice and comparative and competitive advantage.

Table 30: Comparison of feedstocks based on production technology, water use and competition with food.

Feedstock	Availability of production technology	Competitiveness with food	Water requirement	Ease of Availability of feedstock	Mass in kg required for 1 liter of bio-ethanol	Rank
Molasses	5	0	0	5	4	1
Sugarcane at smallholders	5	5	5		16.5	8
Sweet sorghum	4	0	2	5	18.2	3
Sugarcane with contract growing	5	1	5	4	16.5	3
Sweet Potato	5	4	2	5	7.5	3
Sugar Beets	2	0	3	1	8.5	9
Cassava	5	3?	2	4	6.5	3
Cactus	3	1	1	5	14.	1
Fruit Waste	4	0	0	1	8.0	7

* 0 = none and 5= very high

7. 0 Supply of Feedstocks

Feedstocks can be industrial byproducts such as molasses from sugar factories and malt left over. The EMD can purchase these by products for raw material to produce bio-ethanol. These industrial by products can be obtained through contract agreement with the factories.

Bio-ethanol processing and production requires constant supply of feedstock. This can be done through two channels. First, entrepreneurs can own EMD and produce their own feedstock. Ideally, the company (owners) should produce various feedstocks to keep the EMD running throughout the year.

In the second method, feedstock can be obtained through out growers based on contract agreement. Improved seed have been produced by Ethiopian Seed Enterprise without growers. The Enterprise signs contract agreement with Farmers Cooperatives to supply parent seed and receive the raw seed based on specified quality and at specific gate for preset price. The price is based on quality. Most of the hybrid maize and certified seed of wheat, barley, teff chick pea has been produced using contract agreement for many years now. Similarly malt barley has been produced using contract agreement between Assela Malt plant and farmers in Arsi zone. Dashin Breweries is also using the same method.

Contract agreements should be signed by the entrepreneur or EMD owner and PC or Unions to avoid breach of contract.

7.1 Recommended Feedstock for Small-Scale Bio-ethanol Production

Considering the availability of improved technology, productivity of feed stock and the bio-fuel strategy we propose that sugarcane, sweet sorghum among cereals and taro, sweet potato and cassava should be used for bio-fuel production. We further propose that these crops should be cultivated by an entrepreneur who owns EMD in his farm or contracts with an EMD owner/bio-ethanol processor. In many countries of Latin America and South East Asia, such model of business is working very well. Two cereal (sugarcane and sweet sorghum) and three toot crops (cassava, taro and Sweet potato) are selected because of their higher yield. Sugarcane and sweet sorghum are C4 plants with massive biomass productivity. In addition cassava, taro and Sweet Potato are the highest yielding crops among root crops. In addition cactus pear can be used as a feed stock but supplied by small scale farmers in Eastern Tigray.

There was 1.71 million ha under sorghum, 0.37 million ha under common bean, 0.04 million ha under taro, 0.05 ha under sweet potato, 0.022 million ha under sugarcane in 2005 EC nationwide (Annex 1). The productivity per hectare was 21.06 q for sorghum, 12.62 q for common bean, 270.4 q for taro, 284.64 q for sweet potato and 464 q/ha for sugar cane. The production and productivity of cassava is not indicated in statistics due to its limited distribution. It is newly introduced and expanding very fast. Cassava is a very high yielding and has established technology globally. We have no doubt it will be a major crop very soon as a source of starch.

In the case of sugarcane and sweet sorghum the juice can be directly used to produce bio-ethanol. In this case the productivity of bio-ethanol would be higher. In India the productivity of sweet sorghum varies from 1000 to 3000 litres of bio-ethanol per hectare depending on whether the variety is hybrid or open pollinated and degree of management. Melkassa Agricultural Research Centre is working to develop to develop sweet sorghum variety suitable for food, feed, fuel and syrup at the same time. The grain can be used as a food, the leaf as a feed, the stalk for bio-ethanol, syrup or feed as necessary. The high content of sucrose and glucose in the stalk is a value addition to the multi-purpose trait of a sorghum variety. Sweet sorghum can be cultivated in drier areas by small or large scale farmers. Small scale farmers can deliver their stalk to an EMD owner. However the scale of sweet sorghum production is right now n0on existent and can only increase as the industry develops.

Whereas sugarcane and sweet sorghum require milling, root crops take a one step to convert their starch in to fermentable sugar and then to bio-ethanol. This requires both energy, labour and time.

Although the suitable areas of sugarcane, sweet sorghum, sweet potato, taro, cassava and cactus is mentioned below, it is worth to compare the suitable areas for crop calendar.

Sugarcane: it is requires ample amount of water and warm temperature. The suitable areas are in the low lands and valleys along river banks. Sugarcane takes about one and half year for the first harvest and one year for the ratoons. However the crop can be harvested at any time throughout the year as required.

Sweet Sorghum: this crop is similar to grain sorghum except its high content of sugar in its stock. All grain sorghum growing areas such as East and Wrest Hararghe, Eastern Amhara, North Western low lands such as Gambella and Benishangul are highly suitable areas. Most Areas in Tigray particularly Shire and Humera are also suitable. Sorghum is normally harvested during November to December and the stock can be harvested during November. However if planted under irrigation it can be harvested at any time of the year.

Cactus: cactus is found in all water stress areas of Ethiopia but it is only considered economically important in Eastern Tigray particularly Erob Woreda. It is moisture stress tolerant and susceptible to the newly identified Cochineala pest. For some ecological reasons, Cactus results in a very high yield in Eastern Tigray particularly Erob Woreda. The estimated production in Erob Woreda is over two million tones.

Sweet Potato: Sweet potato is largely cultivated in North Shoa, Eastern and West Harraghe, Wolita, Sidama and Gamgofa Zones This crop is highly productive and its tubers can stay in the ground for up to three months. In addition it can be planted at different times of the year so that it can be harvested for a longer period.

Taro: Taro has a similar ecology with sweet potato however, it is only widely cultivated in Southern Ethiopia particularly Wolita and Gamo Gofa zones.

Cassava: Cassava is a worm season and drought tolerant crop. It is highly suitable in the Gam Gofa Zone. It is newly introduced crop which is getting very popular within the Southern and Oromia region. It is highly productive and more research is required to identify the highly suitable areas. It is being introduced in moisture stress areas of the North Shoa and South Wello.

The productivity, production and area coverage of feedstock nationally is shown on Annex 5. The data is summarized from 2005 and 2006 EC CSA statistical hand book. It appears that sorghum and sweet potato are distributed throughout the regions. Feedstock statistical data is not available from Afar region. It appears that Oromia, SNNP, Amhara, Gambella and Benishangul Gumz have significant amount of feedstock in that the order.

Table 31 shows the feedstock volume and land required for cultivation for different sizes of EMD capacities. The land requirement and yield per unit area of sugarcane and sweet sorghum is similar. Both crops are cereals with similar brix value. However sweet sorghum takes less water and it is can be harvested within five months. It appears that large area is required for sugarcane and sweet sorghum because of their sugar content in their stock. About 60 Kg of sugarcane and 54 kg of sweet sorghum stalk is required to produce one liter of bio-ethanol as compared to 14 kg of cactus and 7.5 kg of root crops. Root crops are very productive and high yielders per unit area o as compared to cereals. These crops are very attractive for entrepreneurs because of their response to inputs and modern cultivation. These crops could yield further more if managed by an entrepreneur. An additional note to these crops of root crops and sweet sorghum as well as cactus is they are moisture stress tolerant. Sweet sorghum, sweet potato and taro can be cultivated in rotation as well as border plots because of their similarity in ecological requirements. In addition, the size of EMDs matter. If an entrepreneur is involved in such a business, it is advisable that he/she may have to choose the largest size.

It will be difficult to assume one feedstock to run an EMD year round (Table 2). Therefore a combination of cereals namely sugarcane or sweet sorghum along with root crop complementary can be an alternative. In this study four models of feed stock production are discussed below.

The first is choice is **sugarcane based** where the feedstock is totally cultivated under irrigation. The best example is the Wonji Sugarcane Growers Association Union which supplies 30% of the feed stock to the factory. The Union is now planning to be the supplier of feed stock of 70% to the factory in a very short time. The Union has now included farmers around Wolenchiti and Dera which increases the volume of feed stock significantly. Similar models can be considered for the EMDs. Sugarcane is a well proven choice that has established cultivation and processing technology and provides adequate biomass yield. The only limiting factor is its high requirement of irrigation water.

The second enterprise can be **Cactus based**. There is a huge production of cactus in Eastern Tigray particularly Erob Woreda. Hence the cactus production can support an EMD of any size. However, the feedstock is only available for five months in any year. Supplementary cultivation of sweet sorghum and root crops is hampered by the shallow soil depth and very poor fertility of the soil in Erob Woreda. Currently there is very low production of teff, sorghum, maize or any other cereal crop. Hence, the Cactus pear should be transported to some other place where year round processing is feasible. In other words cactus pear can be considered as supplementary feedstock where other feed stocks such as sugarcane, root crops as a feedstock is a major business. The major disadvantage of cactus pear as a feed stock is its harvest is not spread throughout the year and does not support the EMDs busy year round.

The third enterprise is **Root Crop and Sweet Sorghum based.** Root crops in combination with sweet sorghum can be good feed stock. The root crops namely taro and sweet potato as well as cassava have similar ecology with sorghum they can be utilized in combination with rain fed or irrigated sweet sorghum. This enterprise can obtain feedstock throughout the year. Although sweet sorghum varieties are available locally, there remains quite significant amount of research to be done. The most important being the effect of planting dates and harvesting stage on the sugar content of the stock.

The fourth is **root crop based** where different root crops can be grown in aggregation. The root crops namely sweet potato, taro and cassava are productive and require less land as well as water. The major advantage of this enterprise is the yields of feedstocks can be increased further than the current level using modern cultivation. In addition root crops are very responsive to inputs and improved cultivation. Therefore, the chances of harvesting high yield per unit area are greatest with minimum amount of water as compared to other feedstock such as sugarcane.

Table 31: Feedstock and land requirement of various feed stocks.

Factor	Capacity of EMDs per Day in Liters						
	150	800	1000	1600	2400	3200	5000
Working Days	330	330	330	330	330	330	330
Annual production of Bio-ethanol in Liters	49 500	264 000	330 000	528 000	792 000	1 056 000	1 650 000
Feed stock required annually Tones							
Sugarcane	2 970	15 840	19 800	31 680	47 520	63 360	99 000
Cactus	693	3696	4620	7392	11 088	14784	23 100
Sweet Potato	371	1980	2 475	4 065	5 940	7 920	12 375
Taro	371	1 980	2 475	4 065	5 940	7 920	12 375
Sweet Sorghum	2673	14 256	17820	28 512	42 768	57 024	89 100
Area required in hectares							
Sugarcane	62.80	334.88	418.60	669.76	1004.65	1339.53	2093.02
Cactus	10.1	54.35	67.94	108.70	163.05	217.41	339.70
Sweet Potato	12.0	64.08	80.09	131.55	192.23	256.32	400.48
Taro	13.49	72.00	90.00	147.82	216.00	288.00	450.00
Sweet Sorghum	49.5	264.0	330	529.0	792.0	1 056.0	1 650.0

60 kg of sugarcane, 14 kg of cactus, 7.5 kg of sweet potato and taro produces 1 liter of bio-ethanol. Local data for sweet sorghum is lacking but in literature (Almodares and Hadi 2009) reviewed that sweet sorghum yields on average 1000- 3000 lit/ha of bio-ethanol and the stock yield is 54-69 tones/ha. In this study the lowest value of stalk yield 54 tones and 1000 lit/ha is adopted. Based on this calculation 54 kg of sweet sorghum stock yields one liter of bio-ethanol. Based on 2005 and 2006 EC CSA data the average yield of sugarcane is 47.3 t/ha, 27.5 t/ha for taro and 30.9 t/ha for sweet potato. Although data is not available for sweet sorghum similar calculation is made as sugarcane. Statistical data for feed stock from Afar is not available.

Table 32 shows cropping calendar of selected feedstocks. Cropping calendar is very important to plan for activities of EMDs annual operations and budgeting such as for labor and etc. Feedstock should be available at the right time, with the right quantity and quality. Hence the cropping calendar is important to the owner of the EMDs and operators. In other words, the cropping calendar should be included in the business plan of the EMD owner and operator. Timely availability of feedstock determines the availability of bio-ethanol to consumers.

Sugarcane and sweet sorghum can be available in any time of the year if grown under irrigation. The sugar estates in Ethiopia are operating throughout the year because of the cultivation of sugarcane is under irrigation. However care should be taken when using irrigation. In many cases, surface irrigation such as furrow or flood increases salinity of the soil therefore, sprinkler irrigation like the sugar estates is recommended. Water wastage is very high when using surface irrigation.

Rain fed grown sweet sorghum will only be available as feed stock from October to December for a maximum of two months with aggregate planting. This is because the crop growth stage allows only for a short time. Sweet sorghum cultivated under rain fed can only be used as supplementary to other feedstocks due to its short duration. No matter one can plant his/her crop in aggregation, sweet sorghum crop cannot support EMDs for a significant length of period. The high sugar content in the stock of sweet sorghum is only value addition to the grain sorghum as a feedstock of EMDs or even as a high energy feed to live stock. Hence rain fed sweet sorghum should be considered as supplementary to other feedstocks such as root crops and sugarcane. In countries where sweet sorghum is used as a feed stock such as in Brazil and the Philippines, it has been used as supplementary to sugarcane. However, sweet sorghum cultivated under irrigation can support EMDs throughout the year. But irrigation facilities are additional investment for an entrepreneur.

On the other hand sweet potato, taro and cassava will be available for much longer time because their tuber can stay in the soil even after maturity. Sweet potato and taro can be available for eight months in a year and aggregate planting can used to maximize availability of feed stock. The possibility of using irrigation for taro and sweet potato has never been tried as these crops are normally cultivated in moisture stress areas by resource poor farmers. The yield of sweet potato in Ethiopia is one of the highest in the World and can be increased substantially if grown under improved management by an entrepreneur. These crops are very productive and their yield can be increased substantially under improved cultivation practice. Furthermore root crops as feedstock are very advantageous to an entrepreneur due to their productivity and longevity. The leaves of sweet potato can be feed to livestock as supplementary to its value. The ecology of sweet potato and sorghum is similar and both can be cultivated alongside or intercropped. Sweet potato and taro can be a dependable feedstock particularly if grown by an entrepreneur.

Cactus cultivation in Eastern Tigray is a very special issue. First the crop bears fruits of economic value only in Eastern Tigray. Second although the plant grows in many parts of Ethiopia, substantial yield is only known from Eastern Tigray. Therefore it deserves the attention of both modern cultivation and utilization. The volume of production in Erob Woreda can support several EMDs of 5000 lit capacity. However, the EMDs would not have any other alternative feedstock for the rest of the seven months in a year. The cultivation of any other feedstock alongside with the cactus pear is hampered by the very shallow soil in Erob Woreda. Therefore, an EMD owners or processors in some other locations either nearby or far away can obtain a cactus pear feedstock as a supplementary to his/her other feed stock. Unfortunately storage of the cactus pear for a substantial period is not possible. In conclusion an entrepreneur should consider alternatives based on the availability of land, water, ecology and planting materials. Of all feed stocks sugarcane under irrigation can stand by itself as a source of feedstock. All other feedstocks can be used in combination although enterprises can have their major choice. Table 2 shows clearly that cactus pear can be supplementary to sweet potato and taro during June to October where these crops are under cultivation.

Table 32: Cropping Calendar

Feed Stock	Harvesting Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Sugarcane	----- -	----- -	------ -	-----	----- -	----	---	-----	-- -	----- -	---- -	---- -
Sweet sorghum-Irrigated	----- -	----- -	------ -	----- -	----- -	----	----	-----	-- -	----	----	---
Sweet sorghum-rain fed										----- -	---- -	---- -
Sweet Potato	----	-----	----	----	-----					----	---	----
Taro	----	-----	----	----	-----					-----	---	----
Cactus						----	----	-----	-- -	----- -		

8. Cellulose Bio-ethanol

Bio-ethanol can be obtained from cellulose materials through hydrolysis (Figure 14). The cellulose feedstocks include forest residue, crop residue or any material that contains cellulose. The first step in the processing of cellulose material to bio-ethanol is chipping, milling and grinding the material to enlarge the surface area and remove the protection of epidermal tissue of the plant such as the cuticle epicuticle waxes. Pyrolysis or heating the material about 300oC and then cooling and condensing it, has also been tested, because cellulose rapidly degrades at high temperatures. To which extent the material is treated depends on the material itself weather it is forest hard wood or litter.

To break down the cellulose, the primary source of sugar, hemicelluloses and lignin that surround the cellulose material must be removed. This process is known as pre-treatment. Moderately high temperature, high pressure dilute acid pretreatment process to break down (hydrolyzing) hemicelluloses and disrupt or dissolve lignin. Research is still continuing to develop cheaper and more efficient pretreatment methods.

8.1 Acid Hydrolysis

There are two types of acid processes, dilute and concentrated acid hydrolysis, each with variations. Dilute acid hydrolysis is conducted under high temperature and pressure, and has a reaction time within a range of seconds or minutes, which facilitates continuous processing (Badger 2002). Most dilute acid hydrolysis is limited to a sugar recovery efficiency of around 50%. The reaction for this is that at least two reactions are part of this process. The first reaction converts the cellulose materials to sugar and the second reaction converts the sugar to other chemicals. The advantage of dilute acid reaction is the fast rate of the reaction, which facilitates continuous processing. The biggest disadvantage is the low sugar yield.

The concentrated acid process uses relatively mild temperature and the only pressure involved is usually only that which is created by pumping materials from vessel to vessel. The solid residue from the first stage is then developed and is soaked in a 20% to 40% concentrated sulfuric acid for one to four hours as a pre-cellulose hydrolysis step. This material is then dewatered and dried with the effect that the acid concentration in the material is increased to 70%. After reaction to another vessel for one to four hours at 100 ^{o}C, the reactor contents are filtered to remove solids and recover the sugar and acid. The sugar/acid solution from the second stage is recycled to the first stage to provide the acid for the first stage hydrolysis. The sugars from the second stage hydrolysis are thus recovered in the liquid form. The primary advantage of the concentrated acid hydrolysis is the high sugar recovery efficiency, which can be in the order of over 90% of both cellulose and hemicelluloses sugars.

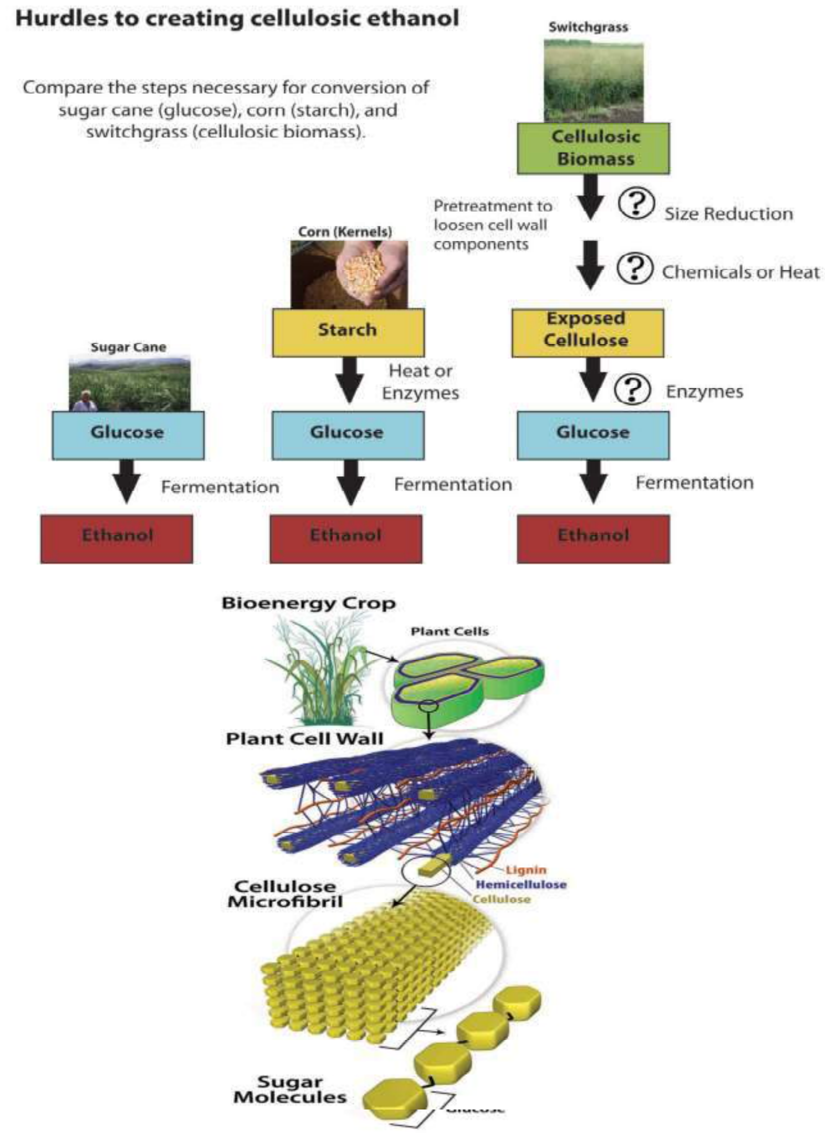

Figure 14: Biochemical processes of cellulose bio-ethanol (Great Lakes Bioenergy Research Center www.glbc.org/education).

www.glbc.org/education).

8.2 Enzyme Hydrolysis

The purpose of enzyme hydrolysis is to maximize the conversion of cellulose to sugar, accelerate the rate of conversion and use fewer and cheaper enzymes (Badger 2002). Cellulose acts very slowly as the decaying wood or tree takes its time. For enzyme hydrolysis, some kind of physical pre-treatment is required. Physical methods may use high temperature and pressure, milling, radiation or freezing, all of which require high energy consumption. The chemical method uses a solvent to break apart and dissolve the crystalline material. Due to the crystalline structure, the enzymes available today require several days to achieve good results. Since long process times tie up reactor vessels for long periods of time, these vessels have to be either quite large or many of them have to be used. Either option is expensive. Currently, the cost of enzymes is too high and research is continuing to bring down the cost of the enzymes. The advantage of enzyme hydrolysis is 1/ their efficiency is quite high and their by product can be controlled 2/ their mild processing conditions do not require expensive construction materials and 3/ their process energy requirement is relatively low.

8.3 Gasification

There are two bio-ethanol processes that involve gasification. The first system is a hybrid of gasification and biological (Badger 2002). Biological materials are gasified and the synthesis gas bubbled through specially designed fermenters. Microorganisms capable of converting the synthesis gas are introduced into fermenters under specific process conditions to cause fermentation to bio-ethanol.

The second gasification process does not use any microorganisms. In this process, biomass materials are first gasified and the synthesis gas passes through a reactor containing catalysts which cause the gas to be converted to ethanol. The recovery efficiency varies from 50-80%. Unfortunately, the cost of gasification is very high.

8.4 Selected Feedstocks for Cellulose Bio-ethanol in Ethiopia

There are several resource feedstocks of bio-ethanol in Ethiopia. These include forest residues, crop residues, alien invasive weed species and homestead residues such as paper wastes etc. Crop residues are used as animal feed and for soil enrichment. In addition to crop residues, animal wastes are used to improve the fertility of the soil and consequently supplement food security. Also, forest residues are used for construction and other homestead purposes.

Within crop residues some, particularly cotton residues, can be used as a source of cellulose and hemicelluloses for bio-ethanol processing. Of the bush and weed species, alien invasive weeds can be used as source of cellulose and hemicelluloses because they cannot be used for food, feed, fiber or any other purpose. These species are threatening the Ethiopian environment including crops, animals and forest production. The most prevalent and threatening species are described below.

8.4.1 Cotton Crop Residue

Ethiopia is expanding cotton production for its growing garment industry. Currently the demand and supply of cotton are far apart; therefore it is likely that the size of cotton farms will be increasing. A modest estimation of cotton crop residue estimates a potential yield of 400 301 tons per year (Dawit 2012). Cotton is cultivated in the lowlands where population density and demand for firewood is low. Hence there is a potential of using cotton stalk as raw material for cellulose bio-ethanol in and around cotton farms. Approximately 2-3 kg of grounded or powdered wood will produce one liter of ethanol (John Loke personal communication 2014).

8.4.2 Invasive Alien Species

Invasive alien species are plant species introduced to new regions of both arable and non-arable land and detected as noxious potential terrestrial and aquatic habitats (Taye et al 2009, Rezene 2010). A plant is noxious when the interaction threatens human activities and the native flora and fauna. Invasive species may have a substantial effect on the environment particularly biodiversity.

Currently there are a number of invasive alien species but those of the greatest concern are *Prosopis juliflora*, *Parthenium hysterophorus*, *Lantana camara*, *Xanthium strumarium Senna didymobtrya* and *Eichhornia crassipes*. These species have threatened, biodiversity, habitat composition, human well-being and ecosystem functions.

8.4.2.1 Prosopis juliflora

Initially *Prosopis juliflora* was introduced to Ethiopia for erosion control and forest tree some 46 years ago in the Awash Valley. But the species have invaded the fertile agricultural lands in Middle and Lower Awash and dominated some of the forests in the Amhara region. Now it is threatening the protected area of Awash National Park as well as pastoral and irrigated farmland in Middle and Lower Awash valley, Eastern Harerge, the Wabi Shebele, basin, several locations in Ray and Kobo plain, and north Wello (Taye et al 2009, Rezene 2010). It has also started invading the grazing lands around Arba Minch, threatening the Nech Sar National Park. The land invaded by *Proposphis* is estimated at 700,000 hectare of prime fertile potentially irrigable in Afar region alone (Figure 11). The alien weed is spreading at the rate of 50,000 ha annually. If this weed is not controlled, Southern Wello, Nech Sar National Park and Upper and Lower Omo may be lost very soon. The species has numerous harmful effects including

1. It makes under growth natural regeneration of native species impossible.
2. It over dominates the native species particularly *Acacia* Spp.
3. It affects the water level negatively
4. Due to its thick stands communities are unable to access water ways and grazing lands and threaten health.
5. Palatable forage and pasture species are eliminated.
6. It invades and may completely force the abandon of national parks.
7. Destroys farmland. e.g. in 1986, the land invaded by *Prosophis* was 700 ha at Amibara and as of 2007, it had increased to 11, 579 hectares.

Prosophis can be controlled in private lands and managed in pastoral and agro pastoral areas with communal land holding. Some of the management options include charcoal and briquette production for household purposes.

One of the management options is using *Prosophis* as a source of cellulose and hemicelluloses for bio-ethanol production. The whole plant part can be mulled and processed to bio-ethanol. In fact this has been proposed by entrepreneurs for the same purpose, however the investment capital turns out to be high.

8.4.2.2 Parthennium hysterophorus

Parthennium hysterophorus is an obnoxious alien weed species has spread throughout Ethiopia after its noticeable occurrence in Dire Dawa in 1980. It is found along roadsides, railway lines, farmlands, and residential areas of both rural and urban areas (Taye et al 2009, Rezene 2010). There are different opinions as to how it was introduced in Ethiopia. Some suggest that it was introduced either from Djibouti through the railroad or Dire Dawa Airport. Some strongly suggest that the alien invasive weed was introduced by Somalia soldiers who invaded Ethiopia in 1976. The soldiers used the weed to cover their tanks and armored vehicles. Now it can be found all over Ethiopia affecting farm and grazing lands.

On grazing lands, *Parthennium* reduces forage and pasture yield by at least 90%. It is a serious problem on poorly managed fields, plantations and widely spaced crops. The problem is serious on non-cultivated fields, neglected fields, near fences, irrigation and drainage ditches and wastelands. *Parthennium* is rarely found in well-managed and cultivated land.

8.4.2.3 Lantana camara

Lantana camara is native of South America. It is invasive and noxious and competes with other species. In some cases this shrub has been deliberately distributed by people for ornamental purposes. Hot spots of Lanatan are eastern Hararage and the neighboring Somalia region. In addition Debre Zeit, Adama, Shoia Robit, Harar and Dre Dawa are heavily infested with Lantana.

Lantana produces massive biomass and can be a good candidate for cellulose ethanol production.

9. The Significance of Scaling up Bio-ethanol Stoves and Micro Distilleries for Environmental and Food Security Concerns

In Ethiopia a total of 990 billion tons of woody, crop residue and animal waste biomass is utilized as energy. This depletes the forests and bush lands, aggravating soil depletion and erosion. Deforestation also destroys the wildlife habitat and under growth casing ecological imbalance and environmental degradation. Soil depletion and erosion removes organic matter, organic carbon, nitrogen and other nutrients of the soil that do not support a good harvest. On the other hand if the biomass is added to the soil then;

1. The fertility of the soil will be maintained or improved. This supports good crop harvest, particularly of backyard crops such as coffee, enset, potato and cabbage.
2. Soil erosion will be minimal, which in turn improves soil fertility and crop production.
3. Deforestation will decrease substantially and creates a good environment for indigenous forest, shrub and under growth species regeneration.
4. Forests are home to wildlife and sources of livelihood for local people. With forest regeneration the livelihood of local/indigenous people improves.
5. Increases availability of construction materials.

These ecological and economic benefits can only be realized through the provision of cook stoves that do not use biomass. In this case the bio-ethanol stoves come first.

10. The Role of Private and Public Sector in Scaling up of Bio-ethanol Stoves and Micro Distilleries

10.1 Public Institutions

Research

The bio-fuel/bio-ethanol program in Ethiopia requires an intensive and concerted research effort in agronomy, production and distribution. Under the current Ethiopian conditions, bio-fuel research should be handled by a single institute. Bio-fuel research is multidisciplinary and requires specializations that are far apart. The research involves

1. Feedstocks (Breeding, agronomy, soil science, protection and extension)
2. Chemical engineering on bio-ethanol and biodiesel
3. Microbiology and genetic engineering
4. Economics and marketing
5. Extension and scaling up

These subject areas must be handled by a single institute. Scientists working in the institute could utilize graduate students from various universities to carry out basic research in agronomy, science, genetics, microbiology and genetic engineering.

Since a national bio-fuel research institute that deals with research and extension is required.

Regulatory

The quality of bio-ethanol produced by public and private institutions as well as stoves produced locally or imported from abroad should be certified for its standard and safety based on physical specifications.

10.2 Private

The private sector can be efficiently involved in import substitution of stoves and micro distilleries. It is very important that the price of stoves should be reduced substantially through import substitution that can only be done by the private sector, including cooperatives (if any). The private sector that can own micro distilleries can be involved in bio-ethanol production. In addition large private sugar estates and factories will be involved in bio-ethanol production and supply chain. The cooperatives that are private themselves can be part of the value chain. The private banks can provide loans for bio-ethanol businesses. The loan from government banks can create public private partnership.

11. The Significance of Scaling up of Bio-ethanol Stoves and Micro Distilleries for Employment

The Ethiopian bio-ethanol industry value chain involves research, production, processing distribution and retail in the transport sector. In the household energy sector, in addition to the above, the value chain includes stove importers, manufacturers and distributors.

A very large work force is involved from production to utilization including permanent and casual workers in sugarcane estates, sugar factories, blending plants, distribution of bio-ethanol and retail.

A recent study, conducted in United States, examined the impact of the U.S ethanol industry in 2013 on job creation, the economy, household income, and foreign oil displacement. It found that the 50.4 billion liters of ethanol produced in 2013 created 86,503 jobs and sustained an additional 300,277 indirect and induced jobs while contributing $44 billion to the United States' gross domestic product and added $30.7 billion to household incomes.

12. The Food and Fuel Debate

Unlike the USA and EU, both of which produce bio-ethanol from corn, raw sugar and sugar beet, bio-ethanol in Ethiopia is produced from sugarcane molasses and probably from sweet sorghum in the future. In the long run, bio-ethanol can be produced from cellulose and hemicelluloses materials and from invasive weed species. Both molasses and sweet sorghum are byproducts of sugar and grain sorghum.

The Ethiopian befouls Development and utilization strategy aims for sustainable utilization of natural resources and to support food self-sufficiency. Bio-ethanol produced from byproducts of sugar processing and grain sorghum production can be used to save the environment through the adoption of ethanol cook stoves and water pumps to irrigate the land.

The use of invasive alien species for bio-ethanol production is actually saving farm and grazing lands from destruction. Fertile and potentially irrigable large lands and grazing fields have been taken over by the invasive weeds. If *Prosophis juliflora* is reduced in Awash Valley, large tracts of fertile and potentially irrigable land shall be available for cotton, rice, sugarcane and grain . well as sweet sorghum production.

In short, whereas the bio-ethanol industry in EU and USA is using food crops, the Ethiopian bio-ethanol industry utilizes sugarcane and grain sorghum residues as raw material. Hence the food versus fuel debate is out of context in Ethiopian condition.

There is a good potential of using root crops particularly sweet potato and taro using as feedstock for EMDs. These crops are very productive and their yield per unit area can be increased using improved cultivation techniques particularly if grown by an entrepreneur. Root crops are a good alternative for an entrepreneur who owns EMD or contracts an EMD owner to supply raw material due to their productivity per unit area than any other feedstock. However, these crops are also food security crops particularly at time of cereal shortage. Therefore a win compromise between a bio-ethanol and food security should be considered. It is recommended that these crops must be grown by an entrepreneur rather than by small scale farmers. The price of feedstock cultivated by small scale farmers would be expensive and may compete with food security. In addition both crops particularly sweet potato is cultivated by small scale farmers in either densely populated or moisture stress areas. Sweet potato is also easily propagated by cuttings and fast to produce tubers in bad times. In short sweet potato, taro and yam are good crops for farmers who owns less land plot and tend to be unfortunate.

The food versus fuel debate is also stronger with cactus pear. Cactus pear is used as a food in Eastern Tigray. There is a huge production and wastage and using cactus pear as raw material for EMDs could transform cactus pear to a commercial level and may avoid wastage. We believe that the amount waster is far more than consumed.

Similarly, reject common bean from warehouses and cleaning plants in Adama can be used as raw material for EMDs. The use of reject common bean as raw material for EMDs will not compete with food production in any means but rather may be a solution for wastage. However the price of the grade 1 is expensive and grade 2 and 3 are very inferior and had too many stones and chaffs.

13. Conclusions and Recommendation

The following recommendations are drawn from the report.

1 Bio-ethanol cooking stoves can contribute significantly to the food security, natural resource conservation and climate change mitigation of the nation, hence scaling up of these technologies should be a priority.

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 an alternative 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 should be given top priority. Collaborative research between EIAR and ICRISAT can be initiated.

4. Feedstocks can be best cultivated by entrepreneurs themselves or on contractual basis. The contract growing of sugarcane by unions in Wonji is best example.

5. Among the regional states Oromia and SNNP grows all feedstocks assed in this study followed by Amhara and Benishangul Gumz. Tigray Afar, Gambella and Somali cultivate the least. Among feedstocks sweet potato, taro and sugarcane are the highest yields per unit area.

6. Among feedstocks sorghum is cultivated in all regions indicating the potential of sweet sorghum.

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