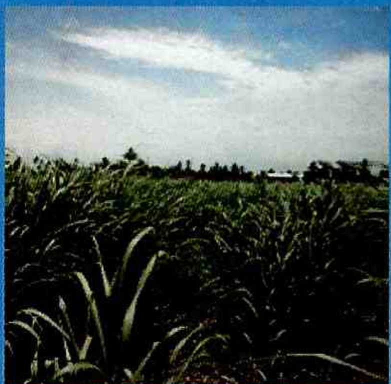
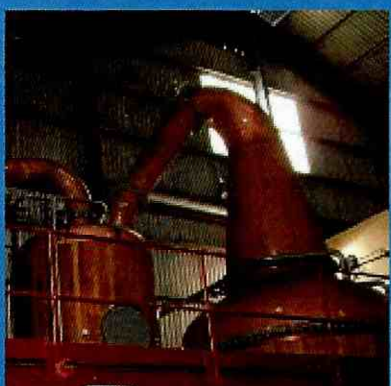
Assistance for Biofuels Development and Policy Support in Jamaica

Final Report

May 24, 2011





Organization of American States

WINROCK INTERNATIONAL

ACKNOWLEDGMENTS

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Executive Summary

This report covers the initial phase of a project, sponsored by the Organization of American States, to lend technical assistance and policy support for the development of a biofuels industry in Jamaica. The findings presented here, in conjunction with policy analysis conducted separately for the government's Biofuels Task Force, will form the basis of additional activities to be carried out in the future, including public education and awareness, pilot project development, and ultimately implementation in the form of investments in biofuels production capability.

Based on its research, the project team reached several conclusions regarding the prospects for a Jamaican biofuels industry:

- With 47,000 hectares of suitable land available for sugar cane, Jamaica has the capability to produce all the sugar and molasses the nation needs for its domestic consumption and rum production plus enough ethanol for 10 percent blending in gasoline (E10) throughout the island. Increasing yields per hectare could expand production significantly above this level, as well as reducing cost.

- Ethanol production from cane can be cost-effective but will require year-round operation for efficient utilization of the distillery and a market for surplus energy in the form of reliable electric power. All-season operation will require economically increasing available feedstock to the distillery and providing supplemental fuel for the cogeneration power plant.

- Various ways to increase distillery feedstock should be considered, including: extending the cane harvesting season by introducing varieties of sugar cane or perhaps sweet sorghum that are suited to early/late harvesting, using partially processed and stored cassava, and storing concentrated whole sugarcane juice and/or molasses,

- Concerning supplemental fuel, Jamaica has plenty of land to grow biomass crops, including bamboo, for off-season sugar mill operation or other uses. Sorghum and cane varieties selected for energy value are other possibilities. Field trials, such as the Petroleum Corporation of Jamaica's fuelwood demonstration project at Font Hill Farm, are necessary to evaluate energy crop species, perfect cultivation and harvesting techniques, and refine cost estimates. The aim has to be to ensure that the average cost of supplemental fuel remains below the average proceeds from sale of electricity to the grid when supplemental fuel is being used.

- In general terms, the cost of processing vegetable oils into biodiesel are in approximately the same range as refining petroleum (US $ 0.50 per gallon), so the oil feedstock has to cost less than crude oil to be profitable without subsidies in some form.

All countries with commercial biodiesel subsidize it one way or another, e.g., through lower excise taxes or mandatory use. Based on Brazilian experience, the cost of small-scale production of castor beans, for example, containing 48% oil, is US $0.50 per Kilo ($1.00 per Kilo of oil), which amounts to $3.40 per gallon, or roughly twice the cost of crude oil.

- Large-scale mechanized production of castor or jatropha could be less costly, but it might also displace sugarcane. As a large-scale field crop, soy might be a better alternative, since it has food as well as energy value, although it too could compete with cane for land. Another solution would be higher oil-yielding palm trees, which would not compete with cane for land and could possibly provide solid fuel for off-season sugar mill operation.

- Adequacy of land for biodiesel depends on the crops involved. Ongoing field trials will determine the conditions under which castor and jatropha can be cultivated, but other crops should also be considered as well, including oil palm, provided disease resistant cultivars can be identified.

- While B5 blending has been discussed as a biodiesel market outlet, Jamaica's diesel fuel consumption is much greater in stationary engines than in automotive engines, and biodiesel could be introduced with fewer institutional and technical complexities for electric generation than for vehicles. Truck and bus fleets represent another application that would not require an island-wide blending program.

- Although E10 has been established as the national fuel formulation, public communication efforts will still be needed as Jamaica builds production capacity, especially in rural communities likely to be affected by new farming practices, construction activities, and changing labor markets. Education and awareness campaigns can serve both to elicit stakeholder concerns early enough to accommodate them, and to lessen resistance to implementation when it occurs.

- Biofuels production is capital intensive, so the Ministry of Finance has an important role to play in creating a positive financial framework for investments to occur. This framework should reflect the economic merits of supporting domestic production, including job creation, rural development, etc. compared to welfare costs and spending foreign currency to import liquid fuels.

1. Introduction

In early 2010, the Organization of American States contracted Winrock International to conduct a project designed to help the Government of Jamaica in its efforts to take advantage of biofuel technology and the island's agricultural resources to offset the cost of imported petroleum and reduce its impact on the local economy. After extensive fact-finding, including background research, meetings with government agencies, interviews with experts and decision makers, and visits to sugar estates, the Winrock team undertook a broad prefeasibility study, reported in the pages that follow, covering the following topics:

- Biomass Resource Assessment, including a discussion of available land, alternative uses, topographic and rainfall considerations, and suitability for biofuel feedstocks (Section 2.)
- Human and Institutional Resources and Roles, including industrial and research organizations, as well as technically skilled personnel (Section 3.)
- Economic Analysis, including product markets, pricing and financial considerations (Section 4.)
- Processing and Distribution, including ethanol and biodiesel conversion options (Section 5.)
- Technology Assessment, including emerging technologies (Section 6.)
- Risk Assessment, including potential hazards for investors and approaches to mitigating them (Section 7.)

The team also worked closely with the government's Biofuels Task Force and performed research and policy analysis that contributed to the government's draft *National Biofuels Policy 2010-2030* released in October 2010. In addition to formulating a public education and awareness program for advancing biofuels (Annex I), the team presented material on biofuels technology at a summer course at the University of the West Indies and also presented preliminary findings from the prefeasibility analysis to a broad audience at a workshop in Kingston, organized by the Task Force, in November 2010. In addition to obtaining valuable reactions to the analysis from participants, Winrock's team also took advantage of breakout sessions and informal discussions at the workshop to identify pilot projects (Annex II) and formulate an implementation plan (Annex III). The pages that follow contain the results of initial background research, drawing on published sources and extensive meetings and interviews in Jamaica.

2. Biomass Resource Identification

2.1 General Overview

As illustrated in Figure 1 and Table 1, Jamaica appears to have ample land for food crops and biofuel/bioenergy crops.

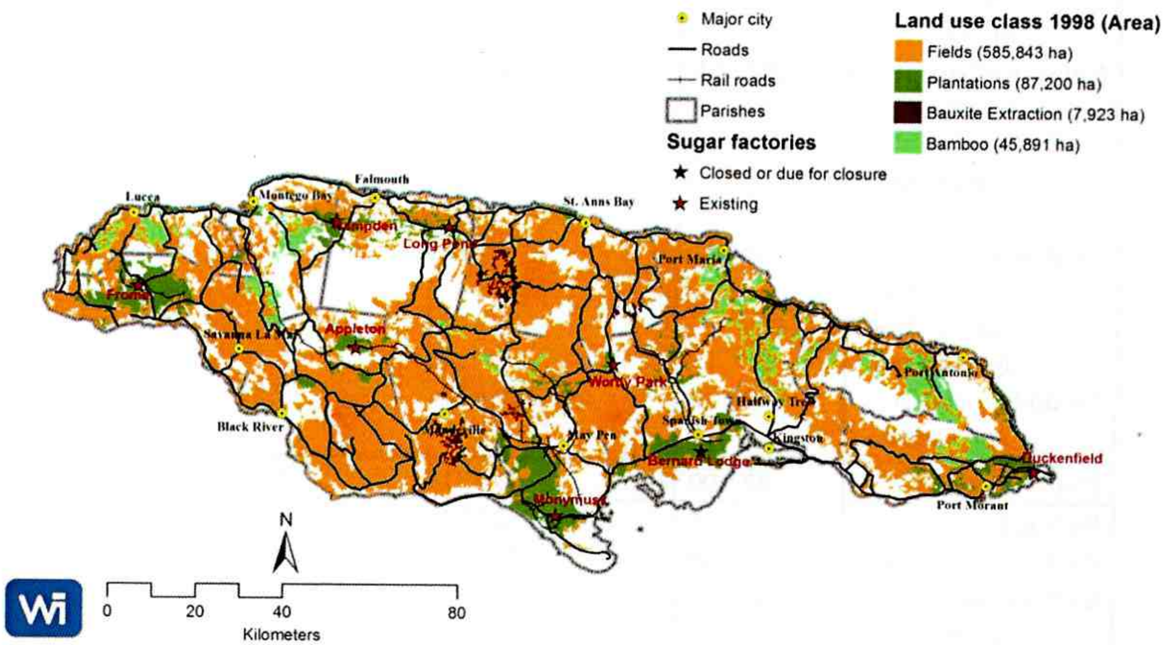

Figure 1: Location of plantations, fields, bamboo and bauxite extraction areas and area (ha) according to the Forestry Department 1998 land use map (Annex IV)

According to the Forestry Department of the Ministry of Agriculture and Fisheries, plantation areas, which will be discussed in the next sub-section, amount to 87,200 ha. The Department classifies an additional 585,800 ha under four other categories that are either wholly of partly fields, so the total area that could be suited to food and bioenergy crops amounts to 673,000 ha. In addition, there are more than 45,000 ha of bamboo, which can be a particularly good source of biomass fuel.

Table 1: Decrease of area classified as "field" categories after applying sustainability and slope criteria

Land use category	Extent in 1998	Extent after exclusion of protected areas	Extent after exclusion of slope >12%	Percent of area remaining to original area
	ha	*ha*	*ha*	*%*
Fields and Secondary forest	120,539	115,690	60,052	50%
Fields: Herbaceous crops, fallow, cultivated vegetables	292,681	282,468	195,259	67%
Fields and Secondary Forest/ Pine Plantations	4,287	1,783	58	1%
Secondary Forest and Fields	168,336	159,654	79,515	47%
Plantations[1]	87,200	85,171	79,610	91%
Bamboo	2,980	2,671	852	29%
Bamboo and Fields	29,430	26,979	8,699	30%
Bamboo and Secondary Forest	13,481	12,783	5,902	44%

Table 1 provides the quantities of various land types derived from the Forestry Department data. Even when protected areas and land with slopes exceeding 12%, above which degree of incline agriculture becomes difficult, are excluded from consideration, the area of land remaining is relatively large. The total area for plantation crops including sugar cane is just less than 80,000 hectares. Areas that are fields with some secondary forest exceed 330,000 hectares, and the area of bamboo exceeds 14,000 hectares. The areas are shown graphically in Figure 2.

In addition to a good supply of land, Jamaica also had a rainfall pattern that while it varies from one part of the island to another offers generally good prospects for crop yields. The patterns shown in terms of the severity of the dry season are indicated in Figure 3.

[1] Area of 9,780 ha from the plantation located southeastern from Monymusk sugar mill is overlapping with Portland Bight Protected Area established by UNESCO in 1999. This area was not excluded from the analysis since currently most of the area is under sugar cane cultivation.

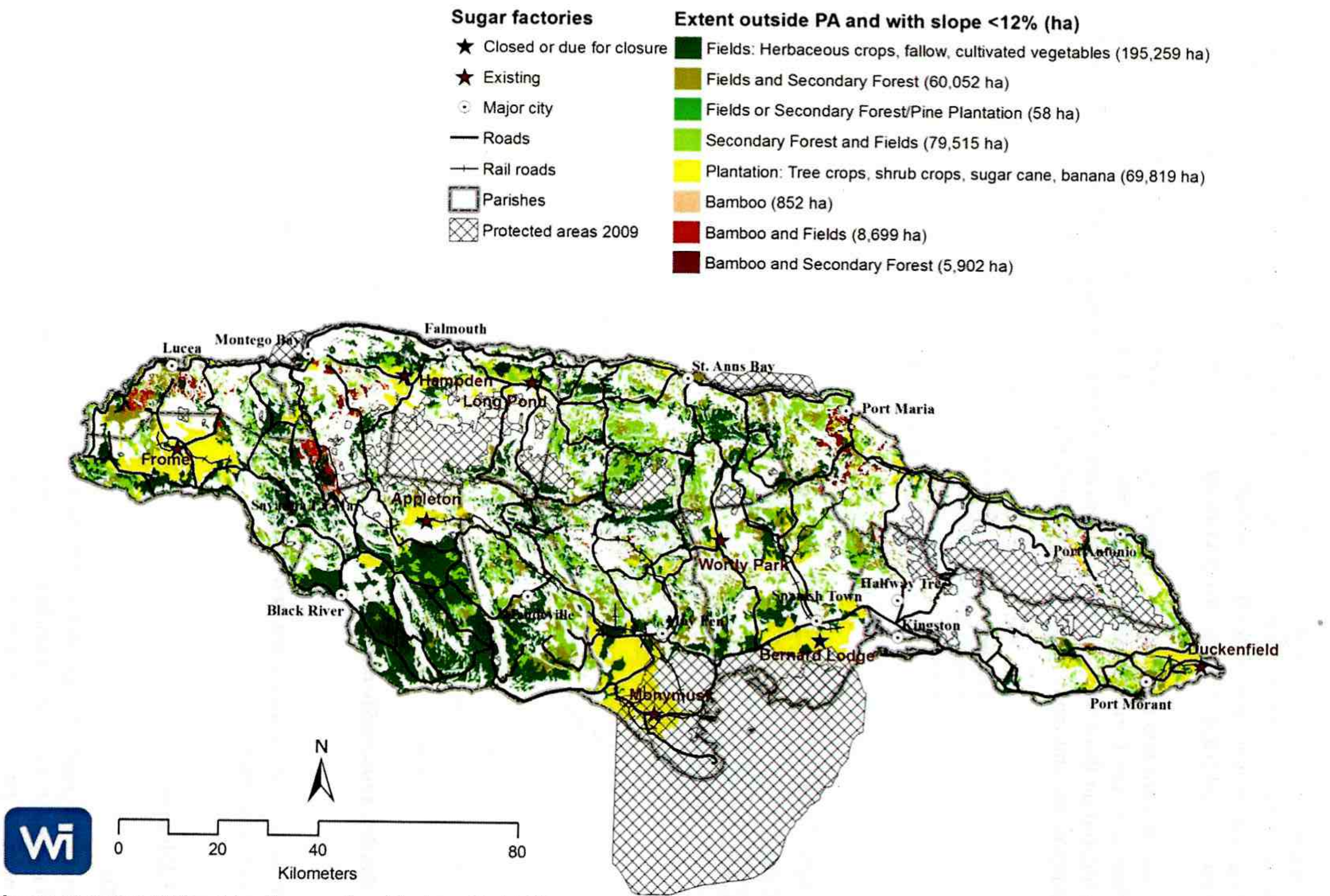

Figure 2: Areas of land in classes classified as 'fields' (some with secondary forests), 'plantation' and 'bamboo' from the Ministry of Forestry data and quantities of each classification after exclusion of areas under protection as of 2009 [2] and areas with slopes greater than 12%

[2] An area of 9,780 ha of "plantation" land covering the Monymusk sugar mill and some of the cane estate areas is within the Portland Bight Protected Area established by UNESCO in 1999. This area was not excluded since most of the area is believed to be under sugar cane cultivation.

Regarding rainfall, areas with a continuously wet season will cause ripening problems for cane and also for bamboo, the latter of which will be with too green to be stored for later burning. Cane ripening can be managed, and other cultivation schemes, like soybean with sorghum in rotation or two annual crops of castor, are promising theoretically and worth testing.

Severe dry seasons are less desirable for biofuel crops, but sorghum is a possibility, as is cane with irrigation perhaps enriched with vinasse. However, since the areas with a severe dry season are located on the north side of the island, are relatively small and largely coincide with tourist developments, this land is of little use for biofuel purposes in the long term.

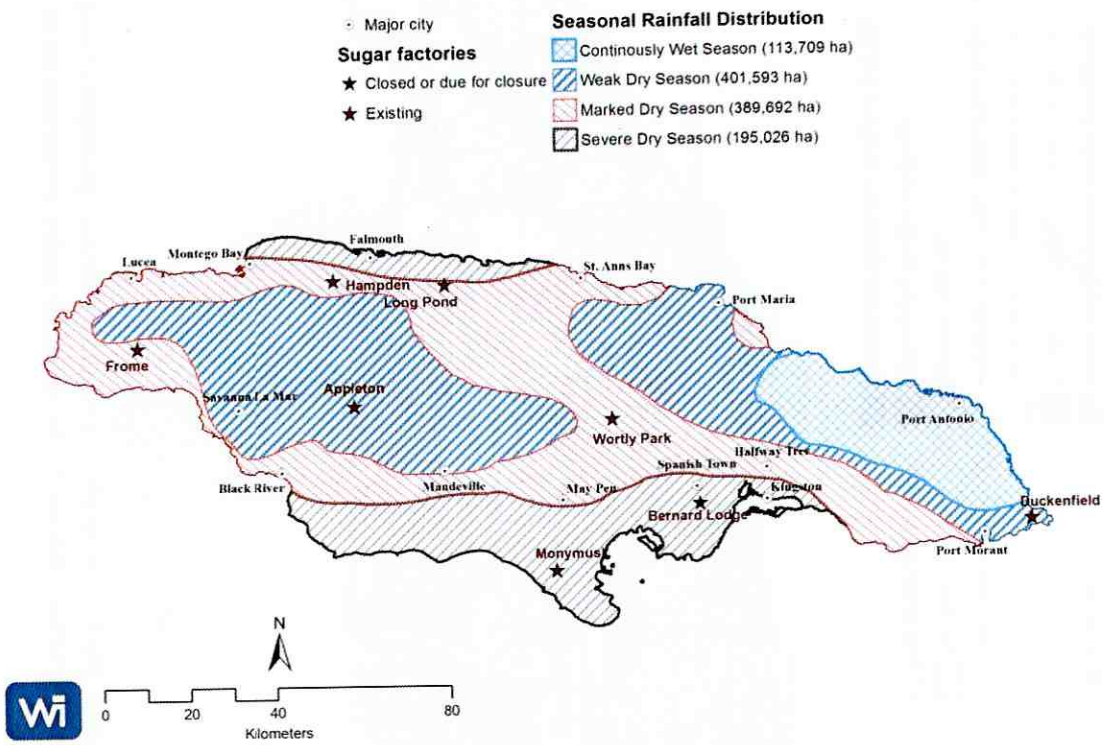

Figure 3: Rainfall Seasonality and locations of sugar mills in Jamaica

Areas with weaker dry seasons are generally best for all crops and should be the preferred, other things being equal.

2.2 Ethanol

<u>Sugar Cane</u>

Sugar cane, a C4 plant, is regarded as the most efficient crop in converting solar energy into chemical energy through photosynthesis, and this is the main reason to use it as a mainstream for any biofuels policy. It is a crop well adapted to tropical weather and under optimal conditions accumulates dry mass under and above the ground, with an exuberant vegetation and vigorous root system. When a stress period occurs, drought and/or cold weather, it accumulates sugar in the stalks.

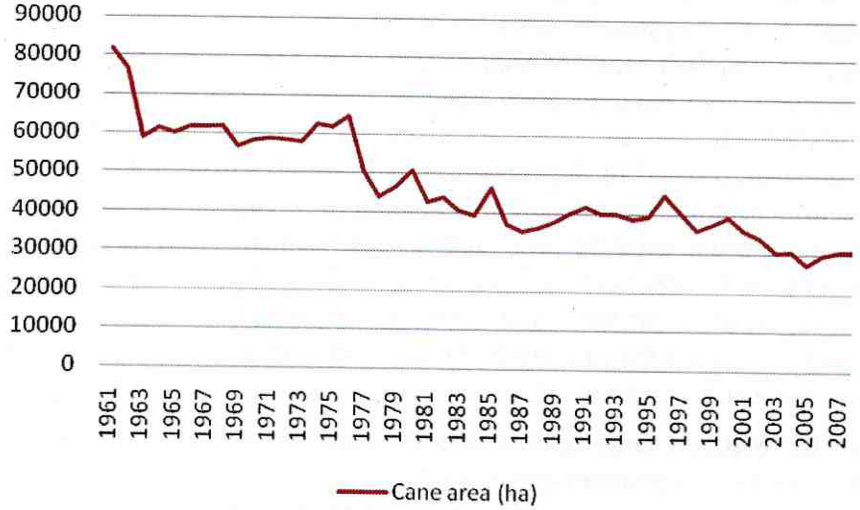

Figure 4: Total sugar cane area from 1961 to 2008 on an annual basis (FAO data)

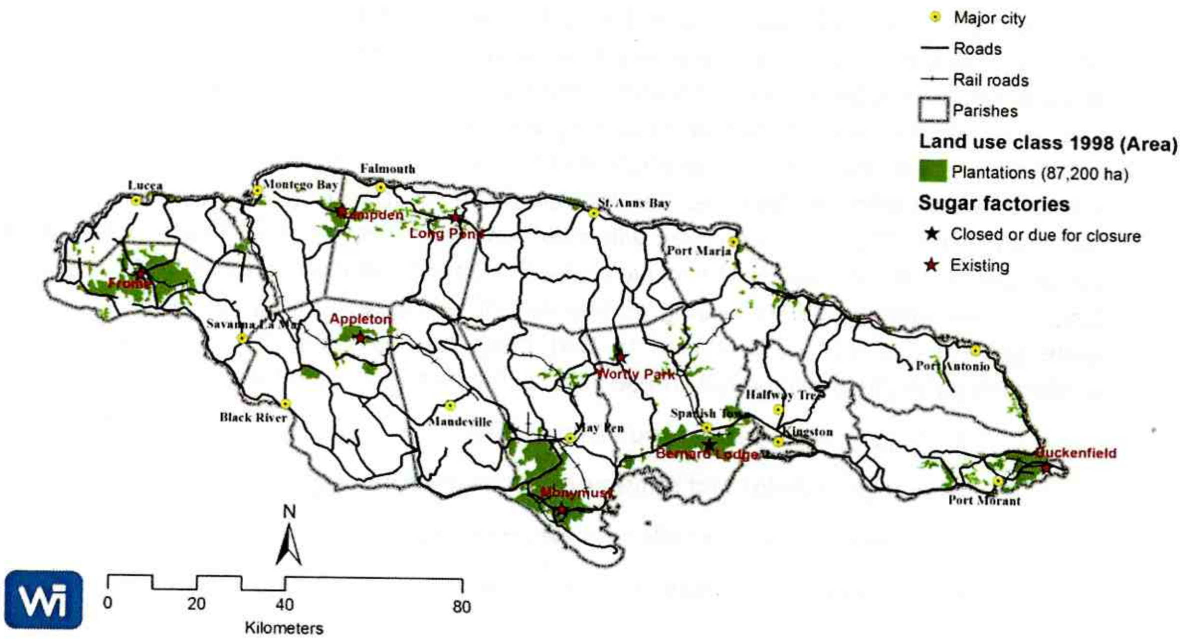

Figure 5: Plantation Area and Mill Locations

Historically, sugar cane has been produced in Jamaica and other countries of Central America for centuries, and is highly suited to these tropical regions. Jamaica's production has in the past been significantly higher than it is currently, as can be seen in Figure 4. The last comprehensive land use data for Jamaica shows that the cumulative area of plantation crops in 1998 was 87,200 hectares[3]. FAO data for 1998 indicates that 36,000 ha of sugarcane were grown and more might have been possible because the amount of idle cane land is unknown. Indeed, only two years previously, in 1996, FAO reported that 45,000 ha of cane were grown. Earlier FAO data indicates a maximum area used to grow cane of 81,800 hectares in 1961. The area remained at about 60,000 hectares through the 1970's before falling to about 40,000 until 2000, after which a downward trend to the current 30,000 hectares occurred. Although some land has been lost to urbanization, a combination of ground observations and satellite imagery indicates that much of the areas used 50 years ago for cane remain available today. Jamaica would require an estimated 47,000 hectares[4] (including 4,000 ha for intervals, irrigation and drainage infrastructure plus plots for trials and breeding) to produce all its current domestic needs for granular sugar, molasses for rum production and ethanol to reach E10, so availability of adequate land does not appear to be an issue.

Sugar cane is grown by relatively larger plantations that are owned or leased long term by individual sugar mills, and by independent growers whose sizes of operation range from a few hectares to several thousand. Due to its long history, local growers are quite familiar with this crop and given appropriate conditions should be able collectively to reach previous production which cannot be said about alternative biofuel crops without trials and further studies.

While a number of factors have lead to the decline of sugar cane, the most important in recent years is the removal of price support for Jamaican sugar by the EU. This means that for the sector to expand, it needs to find a way to achieve economic sustainability by cost saving and revenue enhancing measures. Optimising revenue from sales of granular sugar, molasses for rum, ethanol and sales of surplus electricity will require new approaches by all stakeholders including the cane farmers. An examination of the current Jamaican production system for cane and comparison with Brazilian practices by a cane specialist from that country has revealed that many improvements can be achieved with relatively low investment. The specialist also felt that the production of cane does not receive as much attention as it should and that the fields often appear quite abandoned or lacking application of latest technology applied. To correct this some general policies are proposed to that focus on increasing the probability that future production goals can be achieved. These policies fall into four main categories:

1. Sugar cane varieties and observations
2. Range of yields and ranges of sucrose and total sugars
3. Varieties suited to soils with elevated salinity
4. Work being undertaken by SIRI [based on visit to trial plots May 20]

[3] Forestry Department, Land Use Data 1998 – includes sugar cane, bananas, coconuts and fruit trees/bushes.
[4] The basis for the 43,000 ha is discussed later in this report

1. Sugar cane varieties and observations

The general conditions of Jamaica suggest that varieties specially adapted to high photosynthesis efficiency are desirable because they convert solar energy to accumulate total carbon as sugars and fiber. More specifically, Jamaica should trial varieties with characteristics of the following types:

a) High total sugar varieties rather than high sucrose, since rum and ethanol do not require sucrose as granular sugar does

b) High fiber varieties where more bagasse is needed to allow a modern cogeneration plant to run year round, including varieties with high sucrose content and salinity tolerance

c) Varieties that mature early or late to allow an ethanol plant to receive feedstock over a longer period annually

d) Varieties of sweet sorghum as a supplement to sugar cane where it can help increase overall profitability or require less water and grow in dryer areas

To develop suitable varieties, the current cane-breeding program should be expanded in order to select those that match the changes to the products and not just to focus on good varieties for granular sugar, as has been the past need.

The ripening period seems to be quite challenging due to the absence of low temperatures or severe drought throughout the year. The yields found in the visited mills show that there is a lot of room to increase cane yield and sucrose content, especially through the introduction of new varieties.

The SIRI plots visited are a testimonial that there is a huge potential to increase production with new varieties, but the numbers are still relatively small for future sector growth plans. The breeding program receives material from the West Indies Central Sugar Cane Breeding Station (WICSBS), Barbados, but this source should not be relied upon solely. Cooperation with other breeding programs must be initiated with priority to programs with similar weather conditions as Jamaica. Many breeding programs around the world are willing to have agreements with other places and countries in order to develop new varieties. We recommend that Jamaica considers contacting the following breeding centers with a view to establishing a working relationship with at least two in addition to the current relationship with WICSBS:

(1) Sugar Breeding Institute (Indian Council of Agricultural Research), Combitore, Tamil Nadu, India [www.sugarcane-breeding.tn.nic.in]

(2) Philippines Sugar Research Institute (PHILSURIN), Victorias City, Negros Occidental, Philippines. [www.philsurin.org.ph]

(3) Indonesian Sugar Research Institute (P3GI), Jalan Pahlawan No 2S, Pasuruan 67126, Indonesia [www.sugarresearch.org]

(4) Centro de Technologia Canavieira (CTC), Piracicaba, Sao Paulo, Brazil [www.ctcanavieira.com.br]

(5) Others similar to the above in Australia, Thailand and South Africa.

Nursery practice is already familiar to Jamaican growers, and all new varieties go through this process of multiplication. Before planting, the cane should be heat-treated or propagated by meristem tip culture to prevent diseases. Since the process is applied on a small scale, the material is multiplied under good care. Usually the rate of 1:8 is achieved, so enough cane is treated in the first year to plant one hectare, which will provide seed cane to plant 8 hectares the following year, and so on. Techniques like irrigation, larger row distance, high fertilization, etc. can improve the rate.

While we recommend trials of sweet sorghum as a potential adjunct to sugar cane, we should stress the need to undertake extensive trials covering local conditions for those areas in Jamaica where it may be grown. These trials need to be completed before any significant reliance is placed on sweet sorghum as a biofuel or bioenergy feedstock, since only limited experience exists for such applications even on a worldwide basis.

2. Range of yields and ranges of sucrose and total sugars

The yields currently achieved for sugarcane in Jamaica are low, suggesting that some limiting factors that are not being corrected. The yield of sugar cane achievable under ideal conditions is approximately 200 tonne/ha, and the sucrose content can reach values greater than 15% pol. By comparison, the average yield in Jamaica is currently 63 tonne/ha compared to a peak of 80 tonne/ha in 1966. In addition to the introduction of new varieties, improved agricultural practices and technology are required. These include but are not limited to the following:

- biological control of pests;
- weed control;
- soil preparation with systematization of lands, minimum tillage, deep and combined row furrowing;
- soil correction, fertilization and soil recovering through addiction of organic matter and recycling of nutrients with mill`s residues;
- ripeners in some cases;
- better planning and scheduling of harvest suited to each variety;
- harvest without burning cane in order to increase organic matter content of the soil;
- use of nursery practices to propagate and test new cane varieties prior to field trials
- efficient irrigation;
- increased mechanization; and
- improved management techniques.

3. Varieties suited to soils with elevated salinity

Sugar cane is naturally tolerant to salinity, using sodium in some metabolic functions where other plants use potassium. This does not mean that excess sodium will not cause harm. Where soil sodium is higher than normal, varieties with higher tolerance to these salinity conditions need to be developed through the breeding program. Additionally, soils with high sodium require greater care in the application of vinasse as fertilizer, due to reduced margin for error before the plants are harmed.

4. Work being undertaken by the Sugar Industry Research Institute (based on visit to trial plots May 20, 2010)

The Sugar Industry Research Institute (SIRI) is doing a very good job in selecting new varieties and using good agricultural practices showing, in the field, that it is possible to achieve higher yields than currently being realized. Without resort to revolutionary techniques, SIRI is showing that significantly higher productivity is possible. However, there are limitations due to the limited number of sites where trials are conducted and dependence on the current limitation of breeding stocks from a single source (Barbados). The selection of the breeding program works with about 30 thousand seedlings/year, and considering the great variability of sugar cane breeding, it can be characterized as a relatively small program. However, it is well conducted.

It is strongly recommended that this program be expanded to cover all existing conditions in the island and through the introduction of breeding stock from other sources. The program can be used to adapt and develop other agricultural practices and be a testimonial of how to grow the crop for local farmers. Based on this, SIRI can play an important role in extension services to achieve the improved production goals, because they have knowledge that can be disseminated to the farmers.

Among the different plots visited at the SIRI Experimental Station, two varieties shown great potential: BJ 75-04 and BJ 74-52. The plots were prepared with good soil to a depth of approximately 40 cm to ensure good root system development and vigorous aerial parts. The plots received a fertilization program based on 250 kg/ha of 14-28-14 (N-P_2O_5-K_2O) and 250 kg/ha of 17-00-20 in ratoon crop. Overall the trial shows that these simple practices alone are adequate to increase the productivity of sugar cane in Jamaica, in the short term, by approximately 50% in some areas.

5 Options for Jamaica

Since there is a need for biomass to produce energy as well as granular sugar, molasses and ethanol, the sugar cane crop seems to be the most reliable crop to fulfill these combined goals in Jamaica. Other crops (e.g., sweet sorghum) that could supplement sugar cane for one or more of these products may be possible over time but not in the short term and not without experimentation and slow introduction. Additionally, in Jamaica there is already a strong demand for molasses by the rum industry. So in order to achieve the overall needs, it is necessary to increase production both in area planted and in yields (total recoverable sugars/area). The total tonnage must be increased over a larger area and within current areas.

Besides this, the cane quality also must increase, with higher sucrose content that is dependent on varieties fully adapted to its conditions, good management to harvest each one in its right time and proper practices during its growth and ripening period in order to use the weather conditions in favor of production.

Sucrose content seems to be little bit over 10% in sugar cane grown in Jamaica. This can be improved, but it is a long process that goes through breeding and adoption of good practices. For molasses and ethanol production high total sugars (sucrose plus invert sugars) may be required as opposed to highest possible sucrose. The final product mix (granular sugar, molasses, ethanol, electricity) will influence the aims for variety improvements. Regarding fiber content, while higher fiber content may increase the bagasse available for cogeneration, high bagasse quantity tends to reduce the sugar recovery efficiency of the milling process. The actual industrial equipment of the Jamaican sugar mills are quite old and out dated with low extraction and energy efficiency, so without investment in improving the mill's equipment, probably no profits will come from increasing quality in the fields.

To increase the sucrose content in some cases it may be useful to apply ripeners. This should only be introduced commercially after field trials that will need to take into consideration the range of local conditions across the island. As well as having relevance in terms of increasing sucrose, it is also something that should be considered as a means to increase the length of the harvesting period.

As granular sugar becomes less the primary product and mill owners begin to optimize for the combined revenues from sugar, molasses, ethanol and electricity combinations, the total sugars, as opposed to just sucrose content, and even fiber content will become significant indicators for raw material both in the field by growers and in the factory by processors. A payment method or methods should be quickly introduced in order to incentivize the farmers to produce cane with the characteristics most suited to the changing needs of their buyers. There are many methods around the world that could be utilized quite easily.

For sugar mills where granular sugar is the main objective and no ethanol is being produced at the same plant, the system should incentivize the sucrose content more than any other parameter, and the simplest model is to pay for kg of sucrose in each load based on standardized methods of sampling and analysis. One approach is to sample sugar deliveries and measure the "Pol"[5] of each delivery. Applying the measured Pol to the delivered mass of cane in each load allows the mass of sucrose to be calculated and paid for.

For sugar mills where either ethanol or molasses production is important, an alternative approach, applied in Brazil, involves measuring the total recoverable sugars that are fermentable to ethanol. The measurement is based on a combination of both Pol and "Brix"[6], which latter includes all soluble solids, including salts, sucrose and other sugars. The total

[5] "Pol" is a commonly used term in sugar technology defined as: the apparent sucrose content of any substance (normally sugar cane) expressed as a percentage by mass (of the sugar cane as delivered to a sugar mill) and determined by the single or direct polarization method"

[6] The term used when a refractometer equipped with a scale, based on the relationship between refractive indices at 20°C and the percentage by mass of total soluble solids of a pure aqueous sucrose solution, is used instead of a hydrometer to test the solids concentration of a sucrose containing solution.

fermentable sugars are calculated for each delivered load of cane using the measured Brix and a formula to account for the proportion of reducing sugars (e.g. glucose and fructose), salt content, and other factors. The final Brazilian cane price formula also reflects industrial processing productivity and the mix of final products and their corresponding prices in a given year.

A Brazilian-style formula may be premature in Jamaica, depending as it does on knowledge of the operation of existing mills and ethanol product markets, and developing a scheme for independent producers in Jamaica will require negotiation among the interested parties within the specific context of an emerging industry. That said, the system, when it comes into being, should be designed to reward producers who deliver their cane in short periods and with higher quality, because it will reduce industrial costs. At the same time, it should not unduly penalize harvesting at the beginning and end of the season, when Pol may be lower, but raw material is still needed to keep the mill operating. Remuneration of the fiber for energy processes can be accomplished through a separate system, especially during the off season, when the mill would be able to accept other materials like bamboo, grasses, wood, etc. for cogeneration or distillation

At the Moneymusk Estate, payments are based on Pol and Brix, and the formula has a byproduct component, which is not currently utilized. Moneymusk sells Grade C molasses to the rum factory next door, along with steam. Quality based payment seems to be the best way to go, since sugar is produced in the fields and only recovered in the factory. Under an effective quality-based payment system, some practices like burning will naturally stop, because burning begins the inversion of sucrose, resulting in an inferior material detrimental to both sides of the transaction. Besides that, the fiber content can be increased without harming the extraction efficiency, since the cane cleaning system will have to be dry, and a surplus of fiber with lower water content will be available for the boilers. This component of the raw material can be rewarded for both sides, industrial and agronomical.

Sorghum

Varieties suited for ethanol are available but with far less long term experience than with sugar cane. If sorghum proves to be adapted to Jamaica in the future, it can theoretically be grown in rotation with soybeans. It would be possible to have two harvests of sorghum (plant and ratoon), one for each 3-4 months, and before replanting it, a soybean crop.

To make this possible, as it is already in use in other Caribbean countries, it must begin with field trials to find a suitable variety to present conditions. The use of sorghum may have some advantages like being planted by seeds produced by the own farmers, and the excess production can be sold to cattle growers.

- Method of cultivation – grown from seed, 5-6 months to maturity, two crops per year with second crop from ratoon. Requires less water than sugar cane.
- Sorghum properly conducted may produce two harvests in one year, plant and first ratoon should be economically liable. The crop is more efficient in water use and this

can make it to become a good option if a deficit of water in soil is registered. It can be grown even with a deficit over 200 mm

- Peak total sugar lasts for a shorter time than sugar cane so needs to be cut within a tighter window of time
- If this crop is use for ethanol production, it must be very well planned to ensure that the sugar content in the stalks can be recovered. Otherwise, it only will produce seeds and fiber.
- Produces a bagasse which cattle can digest more easily than sugar cane otherwise similar in terms of fuel use. The fiber of sorghum has better qualities for burning in boilers or for cattle feed than sugar cane fiber.
- Some varieties produce seeds that may be of value to smaller farmers as an animal feed.
- Experience in similar conditions to Jamaica cannot be found extensively, but it is being introduced in Dominican Republic after two years of field trials and selection of cultivars. So sorghum, though promising, entails some risk.

Cassava

Cassava is a tropical starch crop that forms rhizomes. It is grown primarily as a source of food in many part of the developing world but has become a feedstock for ethanol mainly in Thailand, Vietnam and China. Although a potentially interesting crop for Jamaica, harvesting costs are relatively high, due to a typical need for manual techniques. Table 2 provides comparative yield and cost information for cassava in relation to sugar cane based on experience from Brazil.

Table 2: Comparison between Cassava and Sugar Cane as Feedstock for Ethanol Production (Cabello, 2005)

PARAMETER	CASSAVA	SUGAR CANE
Annual agronomic yield - t/ha.	30.0	80.0
Total sugars	35.0%	14.5%
Annual yield in sugars - t/ha.	10.5	11.6
Theoretical conversion - m^3/t sugars	0.718	0.681
Annual ethanol yield - m^3/ha.	7.54	7.90
Price of feedstock - US$*/t	$64.70	$22.76
Cost of ethanol - US$*/m3	$257.45	$230.53

*US$ 1.00 = 1.70 Brazilian Real

Note that total sugars in cassava refer to starch, not simple sugars, so processing costs are not strictly comparable, and theoretical conversion rates are not achieved in practice. In addition, the cassava does not provide residual biomass to fuel boilers, so process energy must be purchased in some form from elsewhere. Because of these and other factors, as the table indicates, the cost of ethanol from cassava is generally higher than from sugar cane. However, it does offer a possible way to extend the operational use of a distillery to full year.

Petrobras invested in a cassava mill during the period of 1978 to 1983, but Brazilian experience with ethanol from cassava since then is limited. Although there is room, in all likelihood, for increased productivity, as has occurred with cane in the past, the average yield of cassava in Brazil is only 20 t/ha. Also, according to Felipe and Alves (2007), it is very difficult to average more than 20% starch in cassava over a season. At those rates, about 100 L of ethanol could be produced annually per hectare under pilot and laboratory conditions.

New varieties of cassava are being developed, and while it is worth more as food, some processing residues could be used economically to produce ethanol. Before cassava can be considered for commercial application in Jamaica a number of challenging issues need to be evaluated by local field trials and a number of other factors taken into account:

- Cassava can be produced in a wide range of soil types and conditions, but like any other crop, it responds positively to better practices. Sandy soils are better than loam soils because of the development of the rhizomes with less soil resistance. It is a robust crop capable to produce even in quite low technology conditions.
- Experience growing cassava in similar conditions to Jamaica involves food production on a small scale, so it has to be tested under local conditions.
- Preprocessing requirements, such as enzymatic or acid hydrolysis to break down the starch into fermentable sugars before it can be fermented and fed to a distillery designed primarily for sugar cane, with some process adjustments
- Supplemental fuel requirements for processing. While above ground parts of the plant could theoretically supply some fuel, these are likely to be needed to provide natural humus for the restoration of the soil.
- Storage requirements and seasonal factors for year-round continuous processing. Cassava may have an application in Jamaica as a crop that can be stored in piles or as dried chips to provide feedstock when sugar cane is out of season.

2.3 Biodiesel

Castor

- **Characteristics**

Castor is a perennial plant that grows wild in many locations and is well adapted to poor soils, so it commonly appears as a weed among other crops. As such, the economical growth of this crop often needs more care than most farmers are willing to provide for the attainable return. For success, it needs a suitable fertilization program, proper soil preparation, weed control and other good practices.

If properly cultivated and with adequate rainfall and/or irrigation, it can produce two crops per year, since it takes somewhat less than 6 months to complete its cycle. The germination process is very dependent on water availability. Approximately two to three months after germination, flowering begins, a process that also requires adequate water. Harvesting, either manually or with coffee harvesting machinery, will be completed three to four months after flowering. Provided adequate water is available, under ideal conditions with appropriate equipment and technology, the oil content of the fruits can reach 60% and productivity 2,200 kilograms of oil per hectare. Due to the varying impacts tied to local conditions, field trials in the local area where castor is planned for commercial use are necessary in order to determine the best time for planting and the possibility of having two crops per year. The total required precipitation over the fruiting cycle is approximately 650 mm. Variations will influence the oil content.

- **Experience in similar conditions to Jamaica**

Brazilian experience with castor is under quite different conditions from those found in Jamaica, but some lessons can be learned. In Brazil, castor is grown in areas with very pronounced dry and wet seasons, where it is planted immediately before the rainy season to ensure germination and high oil content of the beans. The actual average yield is about 600 kg/ha of beans with a 45% content of oil, but the potential with existing technologies is over 1.5 t/ha, the yield considered as the "break even point" for economic analysis in Northeast Brazilian conditions. The oil content can also reach 48%. The average castor productivity in Brazil is 600 kg/ha, but it can reach 1.8 t/ha without irrigation using proper fertilization and cultivation practices. The potential yield in the field, projected by EMBRAPA for the next 15 years, reaches 5 tonnes of beans per ha. Productivities above 1.5 t/ha are now achieved in big biodiesel enterprises, but lower values remain typical for smaller scales of production. The costs of production are between US$ 200 and US$ 300 /ha with limestone and fertilizer application and weed control.

- **Use by smallholders**

The small farmers have many incentives to grow castor in Brazil. These include: special loans and *"bolsa familia,"* an income support program for families with incomes under $2,000/yr., which make the Brazilian biodiesel costs appear lower than they would under conditions where similar incentives are not available. Hence, Brazilian biodiesel economics are not directly comparable to the Jamaican situation and may be misleading.

As a crop that can be totally cultivated manually, it also can grow in areas with steeper slopes, where higher fertility soils may prevail. As an annual crop, unless irrigated, it will not employ manual labor year round. In Brazil, small farmers apply practically no consumable inputs and essentially leave the crop to grow wild.

- **How it might be used as the basis for gradual development of biodiesel production in Jamaica**

This crop can be used theoretically by small and big farmers, with different production systems, different yields and incomes. Subsidized castor cultivation can be an effective tool for social welfare, but sustainable production will need modern production technology and higher investments.

Coconut Palm

- **Characteristics**

Coconut palm is a perennial plant that produces a fruit with the highest oil content of any terrestrial plant. The oil content in coconuts can easily reach 80%. Generally, the coconut fruit and its oil have too high value to be used as a biofuel, but coconut shells can also be used to produce energy,

- **Experience in similar conditions to Jamaica as a feedstock for biodiesel**

The oil and other products of this crop have high market prices in Brazil for human consumption, so except for residues, which are burned as fuel in boilers, they are never used as a bioenergy source there. On the other hand, coconut palm has been used as the feedstock for biodiesel in the Philippines where it is the basis for that country's mandated B2 blended biodiesel for vehicle use.

- **Use of Coconut as a source of Biofuel in Jamaica**

For Jamaica, the primary use should be for human consumption, and as tourism is a major industry in Jamaica, it would not be recommended that this product be used for fuel, with such a high demand by tourists and locals alike. Besides that, coconut trees in Jamaica have been infected by a disease called "yellowing" that killed coconut plants throughout the island. This disease could be related to poor drainage, as it was diagnosed in Brazil, but there is no confirmation of those conditions causing the problem in Jamaica.

- **Significant of the loss of Jamaican tall varieties by lethal yellowing and other diseases**

It is quite dangerous to include this crop with that infection potential that may harm other options. It will be needed investments in breeding and cultural practices that only will have return in long term.

- **How it compares to castor as an option**

It loses in any comparison if the goal is to produce biodiesel. On the other hand, it probably will be more profitable for the growers because of the high values of its products for human consumption. The costs are higher as the risks compared to castor to produce oil for fuel.

Africa Oil Palm

- **Characteristics**

Oil palm is a crop that can be grown in areas with higher slopes than 12%. It is considered semi-perennial since it produces 3 years after planting and continues to 25 years with the peak of production happening after 7 to 9 years. It has many advantages in tropical areas, because it can grow with other crops (vegetables) in inter-row systems during most of its cycle. It can be manually cultivated and can produce yields from 7 tonne/ha of fruits in the third year, increasing to 14 tonne/ha in the fourth year, and reaching 25 t/ha at maturity with stable production of 22 tonne between 10^{th} and 20^{th} year before declining. These yields are currently achieved in Brazil by specialized farmers who use good cultural practices to produce fruit with a 25% of oil content at an average yearly costs of US$ 150.00/ha.

Oil palm is not tolerant to flooding, and when it happens, the trees show symptoms of yellowing, so good drainage practices are important. Its introduction into Jamaica must be done carefully because of diseases that might be prevalent.

- **Experience in similar conditions to Jamaica as a feedstock for biodiesel**

In the last few years, major palm oil companies from Malaysia have set up large new palm oil plantations, and In Brazil, it is grown in the northeast, close to the rain forest, in conditions quite similar to some Jamaican areas. The average productivity of oil in Brazil is of 5t/ha year. This oil is very much appreciated as spicy oil for some typical foods, and this makes the price in the market more attractive for other purposes than fuel.

- **Potential lethal yellowing and other diseases**

Since African oil palm in Brazil is also susceptible to a disease similar to coconut yellowing, and to ensure that other serious diseases are not prevalent, it is strongly recommended that some trials should be conducted under local conditions before any large scale planting of oil palm is undertaken in Jamaica.

- **How palm compares to castor as an option**

Palm will produce more oil than castor, but disease prevention is a challenge that cannot be ignored, and the risks of total loss of the crop by disease are high. All the knowledge of production systems for oil palm comes from its use for human consumption in very restricted sites.

<u>Jatropha</u>

- **Characteristics**

Some advocates consider Jatropha as the preferred oil plant for biodiesel due to its non-competitiveness as a food crop and its ability to be grown on poor soils, where other oil crops are not economical. On a worldwide basis, while some good results in field trials have been achieved, transferring these to larger scale commercial applications has proven generally elusive. Specific experience in Brazil thus far has not been conclusive.

Jatropha is a perennial crop that will grow in poor soils and withstand dry periods but it responds well to better soil conditions and adequate water. It is suitable for manual labor and can be planted where mechanization is not possible. It grows in shady conditions, which means that it does not need total land clearing to plant it. Due to limited field trials, the tolerance of Jatropha to pests and diseases is largely unknown, but it does seem to be generally resistant. It does leave a residue very rich in organic matter that can be used for energy purposes with the resulting ash recycled for fertilization with high phosphorus and potassium contents. The harvest occurs over about 6 months but can be increased by the use of irrigation when regular rainfall is seasonal, and jatropha is very tolerant to salinity and salted water. It grows fast and helps in controlling erosion and desertification, and it can be used as a live fence (20 cm of spacing) for cattle, pigs and others. It can grow in combination with castor and leucena, and it matches very well with apiculture for pollination. It flowers 3 to 5 times a year. It produces celluloses from its cultivation and is quite tolerant to drought. The produced oil also doesn't contain sulfur and has superior yield in ester, around 90%.

The theoretical production is of 5 tonne of beans/ha, with 38% of oil content or 1,650 liter of oil /ha. The residual cake would be 3,200 kg/ha. The actual average in Brazil is half of this value, and although not all reports are reliable, the cost of production, which depends on hand labor for harvesting, appears to be decreasing with time.

- **Experience in similar conditions to Jamaica as a feedstock for biodiesel**

The field experience in Brazil to date has not demonstrated the many advantages claimed for Jatropha. One important issue is the wide variation in the genetic material showing that this crop is not completely domesticated. When grown commercially, in larger areas, wide variations occur in productivity. As yet there is inadequate information to draw conclusions concerning longer term potential.

- **How it compares to castor as an option**

If all the advocates' reasons to plant jatropha are valid, the plant is potentially a better alternative to castor. In any case, it can be an option for marginal lands, including those with steep slopes, and trial plantings could be pursued in combination with castor in small hilly areas. As with castor, extensive field trails are needed over several years before deciding on introduction at large commercial scale.

Other

- **Sunflower**

This crop will compete for land with all other crops. Perhaps it can be used as crop rotation with sugar cane between ratoon replacements.

- **Tropical sugar beet**

Tropical sugar beet can be an option in very particular cases. Some tests are being conducted in inter-row systems, but there remain lots of gaps in knowledge to recommend it as an option for Jamaica. Sugar cane has much higher yield and seems a more appropriate "sugar" crop than sugar beet.

2.4 Biomass as supplemental fuel

To maximize the benefit of high efficiency cogeneration at sugar mills and ethanol plants, the cogeneration plants should be designed to run year round. While the cane cutting and milling season can be lengthened and some bagasse can be stored as means to reduce the time period when supplemental fuel is required, there is still likely to be a period of several months when supplemental fuel will be required.

Biomass crops vary widely, and the Petroleum Corporation of Jamaica has conducted fuelwood research jointly with sugar mills in the past and continues to work in this area today. Energy forests with eucalyptus could be an option as well as elephant grass and bamboo. In all cases they are quite marginal, as sources of biomass for electricity generation have to have a cost lower than conventional fuels to be economic. In Brazil, the eucalyptus is grown principally for cellulose production, and the wastes are used to recycle nutrients in soil or for energy. Large areas are also devoted to charcoal for the steel industry, and very little of the wood is used as fuel. It takes seven years for the first crop, followed by two additional harvests at seven-year intervals, and yields range from 160 m^3 to 260 m^3 of wood per hectare for each seven-year cycle, depending on crop, soil, management, etc. The quality and the caloric value of this material depend on climate conditions, variety and technology used. The amount of waste material depends upon the harvesting technology.

The annual yield of herbaceous grasses (e.g. elephant grass) can reach over 30 t/ha of dry mass with advanced technology and storage capability. Like bamboo (and cane), grass has a ripening period, and sugar accumulation may harm the tubes of boilers, so it has to be harvested "green" and then dried either naturally or thermally. Suitable timing for harvesting can only be determined after local studies. Usually harvest occurs once or twice in a year, and the material will have to be stored during the rest of the time, so the value of these options depends on timing in relation to local use, e.g., when sugarcane is not being processed.

In cultivating any of these crops, one must bear in mind that they will only be used during discreet time intervals, like the off-season for sugar cane, unless they provide fuel for dedicated boilers that operate year-round. The photosynthesis efficiency of eucalyptus is much lower than cane, sorghum, grasses and bamboo. Bamboo is a crop with some limitations similar to herbaceous grasses. It also has to be harvested green and left to dry before it can be used as a boiler fuel. In dry seasons it fits well but will compete with the sugar cane production that occurs in the dry season as well. The only advantage is that both bamboo and grass can be stored without problems of fermentation, as it would happen with cane because of their lower sugar content.

3. Human and Institutional Resources and Roles

3.1 Ethanol Industry

Since Jamaican cane ethanol capacity will be built on top of the existing (or an expanded) sugarcane infrastructure, a significant amount of agriculture and cane processing skills already exists in the country's sugar industry. The additional skills that will be required at the engineering and operating levels are related to the ethanol production portion of the process: (1) Fermentation and (2) Distillation. Both processes are off-the-shelf and hence well established and delivered as turn-key operations with adequate training available from the manufacturers.

Experience in industrial microbiology will be needed to operate and maintain the fermentation units of sugar and/or molasses to ethanol. It will be essential for the plant to have a microbiologist or chemical engineer with experience in a fermentation setting, such as beer, wine or spirits production in Jamaica or other countries. Yeast is the fermentative organism employed in ethanol production; hence, the microbiologist/engineer should understand thoroughly the field of yeast metabolism, inoculation, cultivation, harvesting, and contamination control.

Equally important is expertise in the operation and maintenance of distillation units consisting of distillation columns and molecular sieves. Ethanol produced during fermentation is dilute, usually 5-10% in water. As a result, distillation is necessary to remove large quantities of water and concentrate ethanol to 95.6% by weight, which is hydrous ethanol. The final step for production of anhydrous ethanol, which is the only appropriate form for blending with gasoline, requires the use of molecular sieves. Personnel with such skills can be recruited from other industries that employ distillation processes, such as Jamaica's three dehydration facilities or foreign cane or corn ethanol plants.

Power cogeneration and the necessary human skills are essential to the long-term success of the cane ethanol industry, as the Brazilian experience has demonstrated. Bagasse, which constitutes approximately 13% of the raw cane mass, is an excellent fuel for power generation. Power generation from bagasse is practiced extensively in Brazil and South Florida using low- or high-pressure boiler systems to satisfy almost entirely the power and steam needed for sugar extraction and refining. Excess electricity is exported to the grid. As emphasized throughout this report, cogeneration is essential to the long-term financial viability of the cane ethanol industry.

Cane trash, available in roughly equal amounts as bagasse, is an additional fuel, but it is currently left in the fields. As foreign sugar mills are evaluating the use of cane trash, Jamaica can benefit from future developments in this area.

3.2 Biodiesel Industry

The transesterification process, which converts crude vegetable or recycled oil (and fats) to biodiesel, is well established in Central America, Brazil, and the US. Several manufacturers deliver turnkey operations that can be run by a small number of trained staff members. The key types of expertise in biodiesel production are chemical (or related) engineering and chemistry, as it involves chemical reactions at elevated temperatures (50-60^{0}C), the use of chemical reagents (methanol and alkali), and phase separation. Personnel with proper experience can be recruited from other chemical operations in Jamaica and from the country's research institutions. Training provided by the equipment manufacturer should suffice to start, operate, and maintain a biodiesel production plant regardless of the feedstock used.

3.3 Role of Research Institutions

The development of the appropriate workforce for the country's ethanol industry should be served by the country's Universities and other research institutions, which offer education, provide training, and conduct research. If necessary, Jamaican institutions, such as the very capable CERE, SRC, and SIRI, should be encouraged to collaborate with US, Brazilian, Colombian or other international institutions to bring to Jamaica knowledge and practices regarding biofuels production. Regarding R&D, it is essential to support the ethanol and biodiesel industry, particularly in the area of agronomy and agriculture to develop plant varieties best suited for Jamaica's weather and soil and to support the local farmers with best practices in cultivation, maintenance, and harvesting of crops. Such programs in Brazil have resulted in phenomenal productivity improvements over the years, such as 33% increase in sugarcane yield (tons per hectare)[7]. Close collaboration with Brazilian and Colombian experts will also benefit the industry with fermentation, distillation, and vinasse handling (ethanol) and transesterification (biodiesel) improvements.

The research institutions, as well as PetroJam, can support the ethanol and biodiesel industries with analytical method development, chemical analysis, and quality control issues as they are possess appropriate expertise and instrumentation. Chemistry departments have the faculty expertise and student availability to establish the necessary analytical protocols. The analysis of methylesters (biodiesel), in particular, requires a battery of tests to ensure that the final product conforms to a certain standard that the industry will need to adopt. It could be the European biodiesel standard EN14214 or the US standard ASTM D6751, and the Bureau of Standards of Jamaica is considering recommendations to stipulate the ASTM standard in the Petroleum Quality Control Regulations governing biodiesel blends up to B5. Regardless of the standard adopted, a laboratory should be set up in Jamaica either at the biodiesel plant or at a University or other research organization to address this critical need. Training for equipment operators should be sought from qualified personnel in countries such as the US or Brazil.

[7] Isaias de Carvalho Macedo, Sugarcane's Energy, Unica, Sao Paulo, 2007.

Finally, Universities can also provide support in the evaluation of cellulosic biomass conversion to ethanol using 2nd generation technologies developed in the US and other countries. A thriving cane ethanol industry provides ideal conditions (co-location benefits) for the deployment of bagasse-to-ethanol technologies with the prospect of significantly increasing the amount of ethanol produced per ton of sugarcane.

As with sugarcane, R&D in plant agronomy and genetics will be valuable in identifying and improving promising varieties of castor beans, jatropha, and other biodiesel feedstocks and in supporting Jamaican farmers to ensure continuous and high-yield supplies of feedstocks. Because biodiesel production is not as energy intensive as cane ethanol, power co-generation is usually not practiced. However, given Jamaica's future needs of additional power and the fact that biodiesel feedstocks generate considerable amounts of biomass, the feasibility of a centrally located power generation plant should be examined. If the logistics make sense, a more economical alternative could be to have biomass from biodiesel plants transported to a cane ethanol facility equipped with cogeneration. There, such biomass can supplement bagasse for the production of energy and heat.

4. Economic Analysis

4.1 Pricing Formulae for Biofuels Compared to Petroleum Fuels

The first consideration should be a realistic evaluation of the cost of production of biofuels in Jamaica. A preliminary assessment should be carried out as soon as possible by organizations like CERE and SIRI, which must have in their possession all pertinent data, including land, feedstock, and labor costs. From a technology standpoint, both cane ethanol and biodiesel production plants can be obtained as turn-key operations from a number of manufacturers. The Brazilian company Dedini is the dominant supplier to the Brazilian sugarcane industry, whereas the Indian company Praj dominates in Southeast Asia and has made inroads into the Americas (e.g. Colombia). In the area of biodiesel, there are numerous manufacturers of modular transesterification units, which can handle a variety of feedstocks some of which may require a pretreatment step.

Once the capacity of a cane ethanol plant is defined, engineering and construction companies, such as Dedini and Praj, can be approached to solicit preliminary capital and operating cost information. Brazil has always been the lowest-cost producer of ethanol in the world. Even with the strengthening of the Brazilian currency in the last 2 years, the cost is estimated at about $1.40/gallon ($0.37/liter) making cane ethanol competitive with gasoline at oil prices of $40 or higher. However, the Brazilian ethanol industry has benefited from almost 40 years of hands-on experience. Moreover, Jamaica is facing low average sugarcane yields (55 tons/ha) compared to other countries in the Americas, such as Brazil (80 tons/ha), Guatemala and Nicaragua (over 90 tons/ha). Such inefficiencies need to be addressed immediately through agronomic and agriculture research and support to the Jamaican sugarcane farming community; otherwise the cost of production will be too high to compete with gasoline.

In the biodiesel sector, typically more than 80% of the cost of production is associated with the cost of the feedstock. This fact simplifies calculations, as it allows for a quick estimate of which feedstocks can be promising as cost-competitive with diesel in the country. CERE has already done a detailed preliminary assessment and concluded that castor beans and jatropha show promise.

Government support for locally produced biofuels exists in practically all biofuels-producing countries. It comes in various forms legislated through policies at the local, regional, and national levels. These policies include:

- Direct payments to producers or blenders of biofuels located in Jamaica
- Direct payments to farmers growing biofuels crops
- Exemption from or reduction in fuel excise taxes for biofuels
- Grants or low interest loans or loans guaranteed by the government for capital expenditures of biofuels facilities

- Exemption from import duties of capital equipment for biofuels facilities
- Exemption from or reduction in income taxes for biofuels producers for a period of time
- Grants for biofuels research and development
- Tariffs on imported biofuels

In most countries some of these incentives are accompanied by biofuels mandates, similar to the E10 mandate currently in effect in Jamaica. The mandates define the minimal market size and reduce the risk of investment in biofuels. As mandates come into effect, some countries (e.g. member states of the European Union) eliminate the excise tax exemptions of biofuels, thus passing the costs of biofuels directly to the consumers.

Below we review the biofuels pricing practices of countries considered global or regional leaders in production and use of biofuels.

Brazil

With all subsidies removed, ethanol in Brazil is priced based on its actual cost and the spread between production cost and the price of gasoline, always taking into consideration that ethanol has only 67% of the energy density of gasoline. In the case of biodiesel, this energy disadvantage differs from one feedstock to another, but in general biodiesel delivers over 90% of the energy of diesel.

In Jamaica we envision that one of the socioeconomic benefits of biofuels will be the opportunity an ethanol or biodiesel facility (most likely centrally located) to provide steady income to farmers who will grow cane or oil-seed crops on a long-term basis. The price paid for the feedstock should reflect the farmer's cost of production and any subsidies the government is willing to provide to the agricultural community to incentivize them. At the same time that price has to be reasonable enough to allow profitable or near-profitable production of biofuels. Brazilian sugarcane farmers and sugar/ethanol producers have negotiated a formula that determines what fraction of the sugar/ethanol revenues go to each party[8]:

- In the case of sugar production, 59.5% of the revenues to the cane farmers and 41.5% to the industry (sugar processors).
- In the case of ethanol production, 62.1% of the revenues to the cane farmers and 37.9% to the industry (sugar processors).
- Of course this issue does not exist for operations that are vertically integrated to include both production of sugarcane and conversion to ethanol.

Colombia

In Colombia the government guarantees ethanol producers a floor price for their product. Hence, at times when oil prices are low, the state is willing to subsidize the production of biofuels to sustain the industry. As mentioned earlier, although such subsidies represent a cost

[8] Produção e uso do Etanol combustível no Brazil, Unica, Sao Paulo, 2007.

to the national budget, the money is invested in the local economy and not spent on oil imports.

<u>Thailand</u>

Another pricing model that Jamaica can consider is that of Thailand, where – just as in Jamaica - ethanol is blended and distributed by both state-run and private companies[9]. Ethanol is priced based to the ethanol FOB price at the Brazilian Commodity Exchange in Sao Paulo. The price is adjusted for freight, insurance, loss, and additional costs (survey, testing, shipping) as calculated for a hypothetical shipment from Sao Paulo to Thailand.

The government subsidizes certain blends to advance its policy of promoting the use of domestic biofuels at the expense of imported oil. For example, the retail price of E20 is set 6 cents/liter (¢23/gal) lower than E10 and 18 cents/liter (¢68/gal) lower than gasoline. The table below shows the types and prices of fuels (per liter) available in the Bangkok Metropolitan Area on Oct. 17, 2009 (based on an exchange rate of 33.4 baht to the US dollar):

Table 3: Thai Fuel Prices (2009)

E10 (octane 91)	**$0.89**
E10 (octane 95)	**$0.91**
E20	**$0.85**
E85	**$0.56**
Gasoline (octane 95)	**$1.03**

<u>USA</u>

In the United States, mandatory E10 blending is practiced by several states, whereas biodiesel blending above B2 level remains optional. In Midwestern states, where practically all US corn ethanol is produced, E85 blends for use with flexible-fuel vehicles are widely available. Ethanol prices are largely set by free market dynamics, which take into account the cost of production and the varying price of gasoline. However, there is a subsidy in the form of a credit of $0.45/gal, which is paid by the federal government to the oil companies that blend ethanol with gasoline. The government also provides a credit of $1.00/gal to biodiesel blenders, reflecting the precarious financial viability of biodiesel production in the country, although diesel use in the USA is just 1/3 of gasoline use. The subsidies certainly enhance the cost competitiveness of locally produced biofuels and hence secure thousands of jobs associated with them, but they come at a cost. Just the ethanol subsidy costs the country annually an estimated $6 billion.

The ethanol credit, usually referred to as "blender's credit", is officially called the Volumetric Ethanol Excise Tax Credit (VEETC) and was instituted in 2005. It was recently extended for one year and will expire at the end of 2011, unless the US Congress takes further action. Efforts are underway to both extend the credit and block it. The extension is supported primarily by corn

[9] C. Boyd, An Update on Ethanol Production and Utilization in Thailand, PNNL, 2009.

farmers and Midwestern states, whereas the opposition is led by environmental groups and others who see the program as uneconomical for one reason or another.

The practical significance for Jamaica is that as a member of the Caribbean Basin Initiative, the country can take advantage of the credit without offsetting tariffs, but the future of the credit is highly uncertain and probably would entail significant risk for an investor who relied on it. On the other hand, a renewable fuel standard established by the Energy Independence and Security Act of 2007 requires 12.95 billion gallons from renewable sources in 2010, increasing to 36 billion gallons per year by 2022. Greenhouse gas and other environmental criteria may favor cane-derived ethanol over other sources.

European Union

In the EU both ethanol and biodiesel receive government financial support in almost all member states predominantly in the form of reduced fuel excise taxes for biofuels. A recent study[10] concludes that EU governments spent $4.8 billion in 2006 to support biofuels in an effort to reduce reliance on oil. By 2008 the financial support dropped to $3.9 billion on 1.68 billion gallons of produced ethanol and 2.33 billion gallons of produced biodiesel because excise taxes on biofuels were raised as mandatory biofuels blending policy gained popularity. This government support translates to $3.64/gal for ethanol and $2.46/gal for biodiesel (calculated at an exchange rate of $1.30 per euro).

Interestingly, the same study makes the following recommendations to European policy makers:
Institute a "polluter pays" principle, a form of carbon tax, to account for the consequences of fossil fuel use;

- Phase out biofuels support except for research and development (R&D) programs;
- Eliminate tariffs on imported fuel ethanol;
- Implement transparency concerning EU member states' biofuels policies to allow proper evaluation of their support measures.

Australia

In 2001 Australia set a production target (but not a mandate) of 350M liters per year (92 mgy) of biofuels by 2010. The country has so far assisted biofuels prices mainly through an excise tax rebate of $1.34/gal to producers (calculated at an exchange rate of A$1.07 per US$). The subsidy is provided to domestically produced ethanol and biodiesel, as well as – surprisingly – to imported biodiesel, but not to imported ethanol. As a result, biofuels will enjoy an excise tax-free status until June 30, 2011. Subsequently, the taxes will progressively rise to 50% of the level of those imposed on gasoline and diesel by 2015-16 on an energy equivalent basis.

[10] Jung, A. *et al.*, "Biofuels – At What Cost? Government support for ethanol and biodiesel in the European Union – 2010 Update", International Institute for Sustainable Development, Geneva, Switzerland, July 2010.

Moreover, producers of ethanol and biodiesel have received federal grants for capital investments through the Biofuels Capital Grants Program. The grants have been used to build ethanol and biodiesel facilities, restructure the sugar industry, and promote innovation.

Conclusion

Biofuels pricing will have to be based on actual production costs, but the government may wish to provide floor price support or other direct or indirect financial incentives, such reduced excise taxes and/or duty-free importation of biofuels equipment, to encourage the establishment of a domestic biofuels industry. Hence, the decision will rely heavily on political will.

4.2 Markets for Biofuel Products

Biofuel processing, especially sugarcane, results in an array of products, all of which have value in the marketplace and can generate revenue to pay the cost of the feedstock and the facility and its operation. Addressed below are ethanol, biodiesel and electric power.

Ethanol

Jamaica currently has had an established E-10 program in place throughout the island since late 2009. Motor gasoline sales amount to just under 200 million gallons per year, providing a potential market for nearly 20 million gallons per year of anhydrous ethanol. Currently, this ethanol is imported from the US at a cost of between $1.67 and $1.70 US per gallon, plus $0.10 shipping from Texas, according to Petrojam sources. (Slightly below the current US average. See http://www.dtnprogressivefarmer.com/dtnag/markets)

Prospective local producers enjoy no preference besides lower shipping cost in supplying this market, since Petrojam is required to purchase supplies on the world market through open tenders. On the other hand, Jamaican producers will presumably be free to export ethanol to other countries. In the US, where the blending tax credit (described earlier) is due to expire at the end of 2011, along with the corresponding tariff for sources outside the CBI, a renewable fuel standard established by the Energy Independence and Security Act of 2007 requires 12.95 billion gallons from renewable sources in 2010, increasing to 36 billion gallons per year by 2022. (See http://www.epa.gov/oms/renewablefuels/420f10007.htm) Greenhouse gas and other environmental criteria there may favor cane-derived ethanol over other sources. European countries also have a variety of incentives for ethanol and other renewable fuels, including Sweden, for example, where E-85 (from imported ethanol) is widely used. With the world demand for renewable fuels expanding as it is, Jamaica should be at an advantage if it can position itself as a net supplier of ethanol from cane. More on world prices at: http://www.icis.com/home/default.aspx.

Biodiesel

Plant lipids can be converted to fuel either by traditional petroleum refining, with minor process changes (See http://www.nrel.gov/docs/fy04osti/34796.pdf), or as described above to form methyl esters. The caloric value of the esters is approximately 10% less than traditional diesel fuel and the fuel has a variety of other advantages and disadvantages, including lower combustion emissions (except NOx), and shorter storage life. A by-product is crude glycerol (about 10 percent of the product volume; 80 per cent purity), worth 10 US cents per gallon or less, currently, due to a worldwide glut created by already ongoing biodiesel production.

The Jamaican market for biodiesel has several segments. A national plan currently under consideration calls for B-5 blends, analogous to the E-10 ethanol mandate, and Petrojam Limited has elected to adopt US standards for fuel composition and testing and has undertaken independent evaluations of engine performance on biodiesel blends. Based on information at the PCJ web site[11], total fuel consumption for road and rail transport was 5.8 million barrels in 2008. Of this about 4.3 million barrels was unleaded gasoline, leaving 1.5 million barrels (63 million gallons) of diesel, which represents a nationwide market of roughly 3 million gallons per year of plant methyl esters for B-5. This small volume may not justify a national campaign to introduce the blend, but an advantage would lie in the contribution of the plant esters to fuel lubricity, which is more difficult to achieve at 15 ppm sulfur levels projected for three years from now.

Another alternative market sector would be truck fleets, which could consume B-100. Diesel trucks represent nearly 90 percent of the 20,727 diesel vehicles on the island and no doubt a higher percentage of the fuel consumption. If a number of large fleet operators were to convert to B-100, as a trash collector has apparently proposed, biodiesel could displace a larger fraction of the 63 million gallons than the 5 percent upper limit of B-5.

Stationary engines represent an even larger market. Just over 6 million barrels (252 million gallons) of petroleum, including heavy fuel oil and auto diesel, are consumed for electricity generation. Assuming the 2.4 million barrels of auto diesel remaining after subtracting transport fuel from total production is for power generation that would represent 100 million gallons per year of potential market for B-100 for stationary diesel engines and combustion turbines. Biodiesel could also displace bunker fuel, but the value would be reduced.

In any case, the August 19, 2010 price of auto diesel at the Petrojam refinery gate was $95.86 US per barrel, or $2.28 per gallon. Accounting for the 10 percent lower calorific value, the equivalent value of biodiesel would be $2.05 per gallon.

Electric Power

Sugarcane processing can contribute renewable electric power through cogeneration fueled by bagasse. Power sales to the electric utility can defray production costs, and the utility system saves on fuel, at a minimum and possibly generating capacity and power transmission costs, depending on location and timing considerations.

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[11] http://www.pcj.com/dnn/Statisticsbyproduct/tabid/144/Default.aspx,

In Jamaica, the Office of Utility Regulation (OUR) has an established policy regarding independent power and cogeneration, including incentives for renewable resources. While rates offered for cogeneration in the current regime are artificially low, OUR has recently published an updated expansion plan for power generation and is presently revising the policy to conform with the recent National Energy Policy and take into account plans by PCJ to import LNG for power generation and other purposes.

Part of the OUR expansion plan involves near-term acquisition of 480 MW of new generating capacity through a request for bids from prospective investors, due on March 31, 2011. The goal, according to OUR, is to replace five antiquated heavy oil-fired steam generating stations with new technology, preferably fueled with natural gas from imported LNG with a provision for oil as a fallback to offset supply risk. That would leave in place several low and medium speed diesels, combustion turbines and a 114 MW combined cycle unit, along with several independent power producers.

According to OUR's *Generation Expansion Plan (2010)*, Table 6.7-1, the heat rates for the remaining heavy fuel oil-fueled diesels, including the newer independent power producers', is 8,144 kJ/kWh or better, so they would likely be base-loaded in preference to the auto diesel-fueled combustion turbines, which JPS does not plan to retire (Expansion Plan, p. 54). The latter would likely be the marginal generators curtailed under a priority dispatch system if additional cogenerated power became available from sugar cane processing.

At 137,000 kJ per gallon, and Petrojam's August 2010 refinery gate price of $2.28, the diesel for the combustion turbines costs $16.60 per million kJ. At the lowest heat rate, 9,133 kJ/kWh, corresponding to the one combined cycle unit at maximum capacity, the fuel cost alone is 15 cents per kWh. The simple cycle units have efficiencies ranging from 11,807 to 14,908 kJ/kWh, so their fuel costs are between 20 cents and 25 cents per kWh at rated capacity. At lower outputs, the units are less efficient, so the fuel costs are higher. Even if one assumes that power from sugarcane cogeneration displaces power from a new combined cycle plant (Expansion Plan, Table 8.3-1) with a heat rate of 7,654 kJ/kWh, the avoided fuel cost would be 13 cents/kWh.

Obviously, the actual avoided cost depends on timing relative to system peaks, but the value to the Jamaican economy likely falls within a range of 15 to 25 cents per kWh. That does not include any credit for capacity, as power from cogeneration allows new generation capacity investments to be postponed and offsets risks due to delays, and power generated at sugar mills may also alleviate transmission and distribution costs in rural areas where transmission capacity is currently strained, as it appears it may be on the eastern end of the island, where some sugarcane is now produced.

Finally, the OUR Expansion Plan could have provided for sugarcane bagasse-fueled facilities to replace the aging oil-fired steam generators. These older plants, at 60-69 MW each, correspond roughly in scale to large sugar mills, which could operate year-round with supplemental fuel, possibly at lower total cost and financial risk than new LNG combustion turbines, tied, as LNG cost would be, to future world energy prices. As it stands, the plan devotes one page to renewable resources in Section 6.10, which indicates a potential contribution of ">100 MW" from biomass (Expansion Plan, Table 6.10-1). The bids for new capacity, to be submitted in March 2011, will provide a clearer indication of what new capacity will cost, and biomass-fueled generation could save.

4.3 Financial Requirements, Financing Regime, and Capital Development Options

The cost of developing a biofuels industry in Jamaica depends on a number of parameters, the most important of which are:

1. Use only existing sugarcane production or develop additional capacity on appropriate land.
2. Build one large centralized ethanol processing facility or several small decentralized ones.

The first issue is critical, as sugarcane plantations in Jamaica have shrunk over the years. At the present production level of 1.65M tons per year, the potential for ethanol production (using industry best practices) is just 36M gallons, even if all cane production was directed to ethanol. This is just 21% of current gasoline use, hence limiting the country's ability to replace considerable amounts of imported oil with domestic ethanol.

Putting additional land into sugarcane production requires both money and time. Pressure from land developers is expected to complicate matters, as it will certainly raise social and political issues even for land owned by the government. Eventually, it becomes a matter of policy and economics: a political decision about the country's sustainable economic growth will have to be made with agriculture playing a pivotal role. Independent farmers will favor sugarcane plantations only if they can be guaranteed reasonable long-term financial returns for their hard work and commitment to the country's biofuels vision.

The second issue – one centralized facility or several smaller ones - is equally important. Economies of scale are of paramount importance for ethanol production. Even a 36M gallon facility by ethanol industry standards is considered a small-size facility. If a decision is made to utilize only a portion of cane for ethanol production, then the ethanol facility will be even smaller. Similarly, if instead of a centrally located ethanol facility several smaller ones are built, they will suffer from higher operating costs and the total investment required will end up being higher for the country. Our advice is to opt for a single ethanol plant either located at the largest existing sugar mill or built in a central location that minimizes overall logistical costs.

Based on information from Brazil for 100M gallon facilities, the cost of new (greenfield) sugarcane ethanol plants is approximately $1.50 per annual gallon of ethanol capacity if the agricultural infrastructure already exists. The cost jumps to about $3.50 per annual gallon of ethanol if the sugarcane plantations need to be developed de novo. In Jamaica, based on current cane productivity for a new ethanol plant of rather small size (36M gal), a cost of around \$2.50 per annual gallon of ethanol capacity may be a reasonable first estimate. Hence, the investment required for an operation of 36M gallons could reach \$90M or more.

In the case of biodiesel, the challenges are more daunting as the agricultural infrastructure for feedstock production simply does not exist in Jamaica. We understand that castor beans and jatropha are considered the most promising feedstocks. However, practices in Central and South America indicate that African palm has the highest oil yield, whereas castor beans are cultivated extensively only in Brazil. Moreover, there is no large-scale commercial experience with jatropha anywhere in the world, hence developing a national program based on this crop, regardless of its promise, entails high risk and significant investment. On the positive side, capital requirements for new biodiesel production facilities are approximately \$1.00 per gallon of biodiesel capacity, including storage tanks for feedstock, chemicals, and product. Furthermore, for biodiesel, economies of scale are not as critical as for ethanol. Biodiesel plants tent to be modular allowing for easy capacity expansion at any time.

Establishment of a biofuels industry in Jamaica will eventually depend on the success of project financing. Usually such financing is secured through a combination of debt and equity at a debt-to-equity ratio of 80:20 or lower. Equity will be sought from local and international investors, whereas the debt will be secured from regional and international banks provided that long-term contracts for key components of the plant's operation can be arranged:

- Cane or oil-seed supply contracts
- Ethanol or biodiesel off-take contracts
- By-product (e.g. molasses) off-take contracts
- Electricity sales agreements (if excess power is available)

Such long-term contracts, covering 10-20 years, reduce the risks of the project and make the return on the investment attractive. Fig. 6, which shows a typical project finance structure, demonstrates the complex arrangements necessary for a successful biofuels industry. Saleable by-products of an ethanol project include molasses, carbon dioxide (CO_2), fertilizer, biogas, and carbon credits, whereas for a biodiesel plant they are glycerin, fertilizer, and carbon credits. Excess electricity, if any, requires the operation of a cogeneration plant within the biofuels facility.

Procurement of the design and engineering of the plant should be done through an open solicitation calling for expression of interest in a turn-key operation to ensure that one entity can be held responsible for the entire facility. To help the Jamaican economy, terms of the solicitation should mandate the use of local labor, contractors, and fabrication to the extent possible.

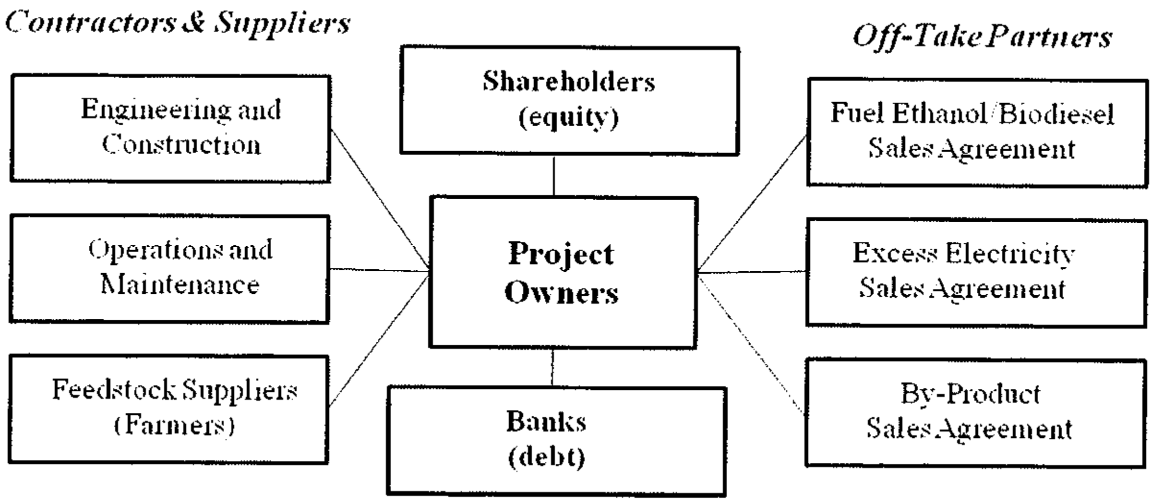

Figure 6: Typical financing structure for a biofuels project

In addition to the biofuels production facility itself, additional significant investment will be required:

- Road improvement and construction will be needed to allow for efficient transportation of sugarcane to the ethanol plant and ethanol fuel to Petrojam and other blending facilities around the island. In general, the condition of Jamaica's road infrastructure appears to be in urgent need of repairs and expansion.
- A public education campaign is sorely needed to inform Jamaicans about the properties, proper use, and benefits of biofuels.
- Sugarcane harvesters will need to be introduced, if cane harvesting will be partially or fully mechanized to enhance productivity at least on relatively flat land. Each harvester reportedly costs in excess of $250K. Even if large harvesters are out of the question, the use of other means to accelerate harvesting, such as hand-operated cane mowing machines used in Brazil, should be seriously considered.
- Tank clean-up at gas stations will be needed, if not already done, to remove gasoline deposits and preserve fuel quality, since ethanol has detergent properties. Moreover, repairs to or replacement of leaky gas station tanks will be needed to prevent water from entering E10 storage facilities and causing phase separation, which can damage car engines.
- If and when blends over E10 or B20 are introduced, adjustments to gas station tanks and pumps will be necessary to enable them to handle such biofuels blends (replacement of rubber components with neoprene or EPDM).

The costs of each of the above can be estimated only when appropriate data are available.

The financial and capital requirements for developing a biofuels industry in Jamaica will have to come from the private sector with the possible involvement of the World Bank and other regional and international development banks for a combination of equity and debt financing. For example, the Brazilian Export Bank is known to finance over 80% of sugarcane ethanol facilities as long as Brazilian equipment is procured.

5. Processing and Distribution

5.1 Technology-neutral processing regime required to activate the desired biofuel developments

Sugarcane Processing

The total amount of energy in 1 t of cane (aerials part) is about 7400 MJ, more than a barrel of oil (6000 MJ), but it is divided about 2400 MJ in sugars, 2500 MJ in the bagasse and 2500 MJ in the straw (mainly leaves and sometimes called cane trash). The efficiency of recovery of the sugar, in various final non-energy forms, and the balance as energy differs between each type due to the process differences. While sugar recovery reaches efficiencies of over 90% with current technology, the recovery of the energy in terms of process steam and electricity by using the bagasse as a boiler fuel is lower. Whereas modern high-pressure bagasse boilers can achieve thermal efficiencies of 85%, older lower pressure units have efficiencies often below 75%. In addition, the overall steam to electricity conversion efficiencies that for modern units can exceed 30% is often lower than 10% at older plants. In order to reduce the cost of ethanol produced from the cane sugar whether in the case of a combined granular sugar and ethanol plant or is a purpose built cane to ethanol with no granular sugar plant, the main approach adopted in the last 20 years has been to introduce higher energy efficiency in the processes such that surplus electricity can be maximized and sold to create additional revenue that can be used to reduce the price of the ethanol when this is needed for overall financial viability. Longer term research, development and initial pre-commercialization of advanced biofuel production processes that begin after the hydrolysis of the fiber (celluloses and hemicelluloses), offer the prospect of an approach that provided better overall returns and will make sugar cane almost unbeatable in terms of energy production. This new technology will place greater emphasis on developing varieties of cane that may be higher in fiber and or mature earlier or later. It will certainly increase the needs for well-managed operations in the field as well as in the process to maximize outputs and minimize unit costs.

Ethanol production can be built as an extension of current sugar mill operations with the addition primarily of fermentation and distillation capabilities, as the dashed section of Figure 7 shows. Sugarcane processing for ethanol production is a well-established commercial process that can be readily purchased and installed off the shelf as a turn-key operation by a small number of international suppliers. As seen in Fig. 7, sugarcane delivered to the plant is crushed to extract the sugar juice. The sucrose-rich juice is then concentrated and processed to sugar and molasses (for rum production) or fermented by yeast to ethanol in continuous stirred fermentation units. The dilute fermentation broth is directed to a distillation column, where ethanol is recovered as a 95.6% (by weight) aqueous solution. In Jamaica the molasses are turned into rum by the country's spirits industry.

The ethanol solution is further refined to anhydrous ethanol using molecular sieves to remove the remaining water. The sieves consist of zeolites, which facilitate the separation of ethanol from water at elevated temperatures and pressures. Although dehydration can be carried out via a number of processes, the use of molecular sieves is advised, since both of the existing dehydration facilities in Jamaica employ them.

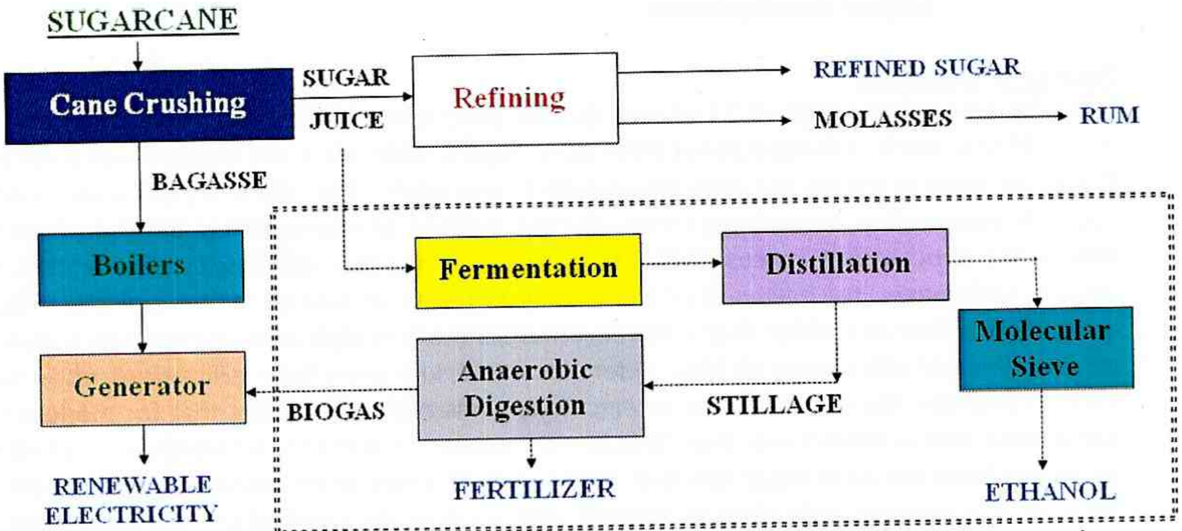

Figure 7: Schematic representation of ethanol production (within dashed lines) integrated in an existing sugar mill with cogeneration capability

Carbon dioxide produced during the fermentation (in a 1:1 molecular ratio to ethanol) is appropriate for use by the food and beverage industry, thus producing an additional revenue source for the plant. The stillage (vinasse), the solid-liquid mixture obtained from the bottom of the distillation column, is rich in potassium and other inorganic elements absorbed by sugarcane from the local soil. It has high BOD and COD loads that can be reduced via anaerobic digestion, while generating valuable methane-rich biogas, which can improve the energy balance of the whole operation. The digested solids can then be used as a natural fertilizer in the fields to provide soil nourishment. Indeed, in Brazil, Colombia, and other countries vinasse is used as a fertilizer that is applied to the cane fields via irrigation water ("fertirrigation") to replenish the soil of the sugarcane fields with essential nutrients cutting down on the use of fertilizers. A similar application is envisioned in Jamaica using the experience of other countries.

Finally, the bagasse residue recovered from the crushed cane should be treated as a fuel for cogeneration at the sugar ethanol plant. Medium (65 bar) or high (100 bar) pressure boilers are recommended to increase energy efficiency. Such power (and heat) generation can provide for the electricity and steam needs of the plant making the investment more attractive and shielding the plant from the high cost and uncertain reliability of grid power.

Most sugarcane producing countries, including Jamaica, have a rainy summer and fall, which interrupts harvesting and hence the operation of the mill. Because cane cannot be stored without degradation, this reality will also affect ethanol production. Unless surplus molasses are produced and stored for later processing, ethanol operations will have to coincide with cane operations, which in Jamaica means about 250 days a year during the January-June period. During off-season maintenance and repairs will be performed throughout the plant. It should be noted that the dehydration section of the plant can be available during off-season for production of anhydrous ethanol from imported hydrous ethanol, if the economics of gasoline vs. ethanol make dehydration profitable.

Oil-seed Crop Processing

In the absence of commercial oil-seed crops in Jamaica, large plots of land will have to be dedicated to cultivation of plants, like castor beans, to support a biodiesel industry. Just like the sugarcane-to-ethanol operation, the crop-to-biodiesel process is well established in many countries regardless of the feedstock used. Today, off-the-shelf biodiesel production units from numerous manufacturers can handle a variety of feedstocks.

From a processing standpoint, seeds will be harvested manually and/or mechanically and sent to a crusher for extraction of crude vegetable oil. Recycled oil can also be used, but depending on its free fatty acid (FAA) content, pretreatment may be needed (Fig. 8). However, such a unit can be ordered as a standard part of the integrated modular biodiesel unit to allow maximal flexibility in dealing with a variety of virgin and recycled feedstocks.

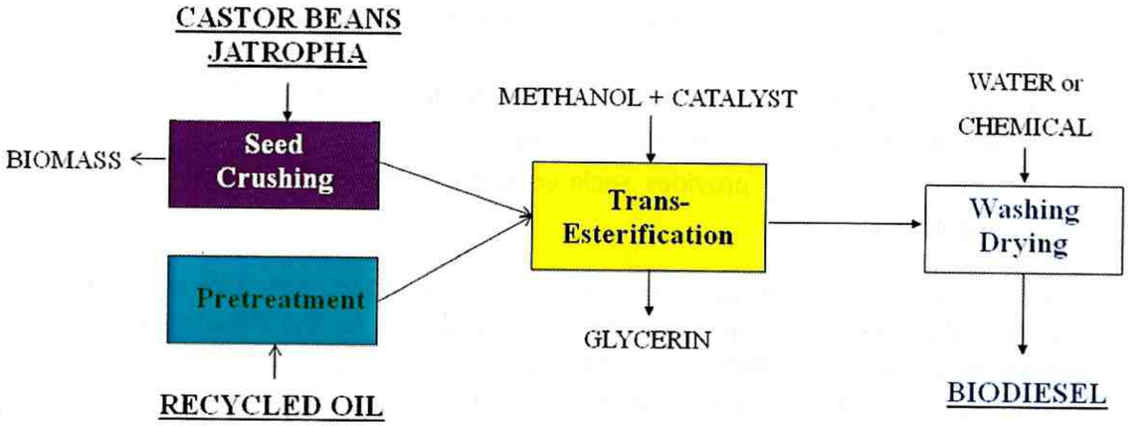

Figure 8: Schematic representation of biodiesel production from oil-seed plants and recycled oil

The oil is subsequently led through a series of vessels, where the transesterification process takes place at 50-60^{0}C in the presence of excess methanol and potassium hydroxide, which catalyzes the reaction. This standard process leads to the formation of primarily a mix of methyl esters (biodiesel) and glycerin in a weight ratio of approximately 10:1. After a series of washing and drying steps to remove impurities (methanol) and moisture, the biodiesel is ready for testing to qualify it as appropriate for commercial use through blending with diesel. The glycerin is generated as a dilute aqueous solution that can be used in a number of ways, such as:

- Subjected to anaerobic digestion for conversion to methane, which can be used as a fuel for power and/or heat generation.
- Mixed with animal feed (as long as it is methanol-free) as a carbon supplement.
- Upgraded through distillation to a high purity (and high value) product that has applications in the cosmetics industry.

The latter application requires the purchase and operation of a distillation column, whereas anaerobic digestion and animal feed are lower value, but also lower-cost, options with modest revenue-generating potential.

The solid leftovers from the crushing of the seeds, along with other plant material, constitute a steady source of biomass that should be considered as the basis for cogeneration or for use as a natural fertilizer. Although cogeneration is usually not practiced at biodiesel plants due to their rather small size (and hence limited quantities of biomass), this possibility should be re-examined in Jamaica particularly in coordination with the cogeneration plans of the sugarcane-to-ethanol industry.

5.2 Harvesting, storing, transporting, blending and distributing products

The vast majority of sugarcane operations around the world are based on manual harvesting for two main reasons:

- Mechanical harvesting requires a significant investment (as the cost of each harvester exceeds $250K) and rather flat landscape.
- Manual harvesting provides socio-economic benefits to communities in the form of employment.

Even in Brazil, the largest sugarcane producer in the world, only 30% of harvesting is done mechanically. In Jamaica manual harvesting is practiced by the industry and most likely will remain so in the foreseeable future. Sugarcane needs to be processed as soon as possible – preferably within 12 hours because the sucrose in cane is susceptible to fermentation by natural microorganisms. Such degradation represents a loss in sugar yield and quality (and will negatively impact the economics), as sugar is converted to organic acids and other metabolites, especially at the warm temperatures and humidity prevalent in the fields of Jamaica during harvesting.

As mentioned earlier, ethanol produced at the plant has to be in anhydrous form via molecular sieves that break the azeotropic 95.6% ethanol-water solution derived from the distillation column. Only anhydrous ethanol is appropriate for blending with gasoline. Because of ethanol's hygroscopic nature and Jamaica's mostly humid climate and aging infrastructure, anhydrous ethanol storage at the plant and E10 storage at gas stations should be done with precautions to prevent water absorption, which will cause undesirable phase separation between ethanol and gasoline. Arrangements will need to be made between the ethanol plant operator and PCJ (and other blenders) for the delivery of ethanol to appropriate fuel storage facilities, where ethanol will be blended in line or in tank with gasoline to form the desirable final blend(s), such as E5, E10 or other. The same is true for biodiesel blends with diesel. The blends are then ready for distribution to gas station tanks and from there for sale to the public.

It should be noted that blends of gasoline up to E10 and diesel up to B20 are in general considered compatible with vehicles manufactured after 1995. Higher blends should not be used, except in Flex Fuel Vehicles (FFV), without the original manufacturer's prior consent regarding the vehicle's warranty and operation.

6. Technology Assessment - economic & technical aspects of current and emerging biofuel technologies

As explained earlier, both cane ethanol and biodiesel technologies (so-called "1st generation") are fully commercial and available off-the-shelf. Skilled personnel will be needed to run and maintain such operations, and expertise from Brazil and other countries in the hemisphere should be sought to optimize industrial operations. In Jamaica improvements are sorely needed on the agricultural side, where yields of cane per hectare are simply not competitive and may make the cost of biofuels prohibitive. Assistance from sugarcane experts in Brazil and Colombia will be essential to close the productivity gap, as is research in Jamaican institutions to improve cane varieties and adapt them to the Jamaican soil and weather conditions. This is also essential for the biodiesel industry, which will need significant support in terms of identifying and improving appropriate feedstocks.

A promising extension of present fermentation technology involves organisms modified to produce butanol instead of ethanol from sugar-containing media. Advantages of butanol-gasoline blends over E-10 are higher calorific value, lower volatility and improved moisture tolerance. A 15 percent butanol blend also contains the same proportion of oxygen as E-10 for controlling exhaust emissions. Although processes are not yet available for licensing, large-scale industrial pilot facilities are in operation, and the technology may be an option for Jamaican producers within a year or two.

Beyond 1st generation biofuels, there are promising developments in advanced biofuels – biofuels derived from non-edible materials, such as ethanol from sugarcane bagasse. Biomass in general consists primarily of cellulose, hemicelluloses, and lignin. The two main technological pathways being pursued are the biochemical and the thermochemical.

In the biochemical path dilute chemicals and cellulase enzymes are employed to reduce the hemicellulosic and cellulosic fractions of biomass, respectively, to simple sugars - mainly glucose and xylose (Fig. 9). The sugars are subsequently fermented to ethanol, which is recovered via distillation and molecular sieves, as done in a conventional sugarcane ethanol operation. Lignin and other solids in the stillage can serve as fuel for power cogeneration.

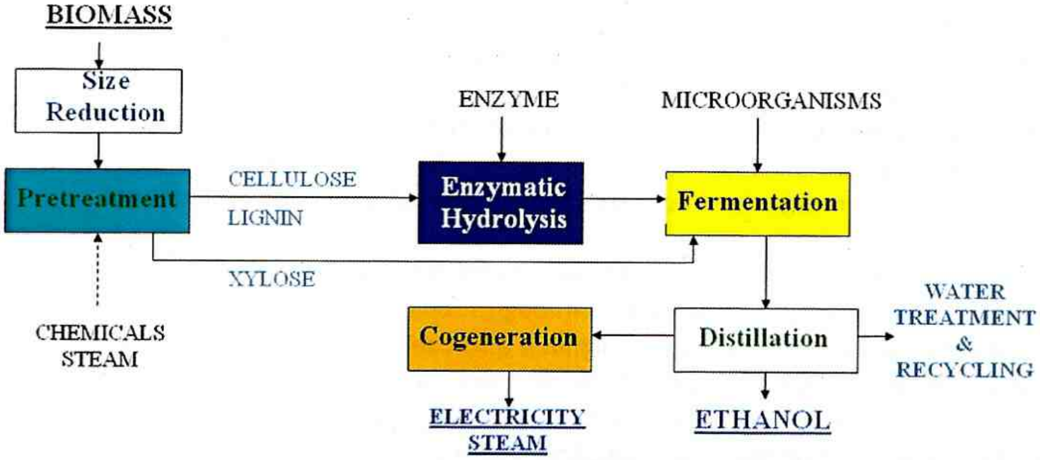

Figure 9: Schematic representation of the biochemical process for the conversion of biomass, such as sugarcane bagasse, to ethanol

In the thermochemical path all the organic components of biomass (cellulose, hemicellulose, and lignin) are turned into synthesis gas via gasification (Fig. 10). The syngas is conditioned to remove tars and is subsequently converted in the presence of catalysts to alcohols or hydrocarbons depending on the catalyst employed.

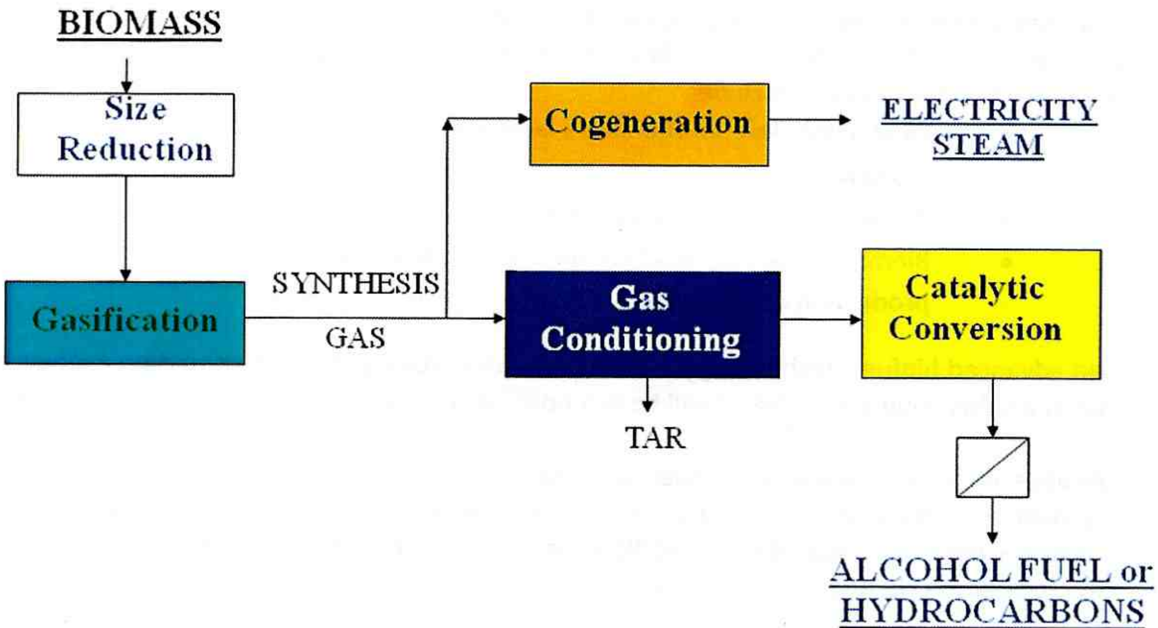

Figure 10: Schematic representation of the thermochemical process for the conversion of biomass, such as sugarcane bagasse, to alcohol or hydrocarbon fuels

Each technology has advantages and disadvantages. The biochemical technology requires costly cellulase enzymes and fermentation of two classes of sugars: (a) 6-carbon sugars consisting primarily of glucose derived from cellulose and (b) 5-carbon sugars consisting primarily of xylose derived from hemicellulose. Moreover, lignin cannot be utilized for ethanol production and is instead used as low-grade fuel in the boilers. On the positive side, fermentative microorganisms convert the sugars to almost exclusively ethanol.

The thermochemical technology has the advantage of using well-established coal gasification and Fischer-Tropsch (F-T) processes, although modifications are needed to adapt them to the peculiarities of biomass. Moreover, lignin is also converted to biofuels, along with cellulose and hemicelluloses, adding an extra 20% or more to the biofuels yield potential of biomass. Challenges, on the other hand, include the use of expensive catalysts in the F-T reactions and the production of hydrocarbon or alcohol mixtures, as opposed to a single fuel.

The ability to convert bagasse to ethanol could significantly increase the capacity of a sugarcane ethanol plant especially using the biochemical process, since it is compatible with existing sugarcane ethanol operations, as it involves fermentation and distillation. Bagasse typically constitutes around 13% of the raw cane's mass. Preliminary assessments of the biochemical technology indicate that approximately 80 gallons of ethanol can be produced from each ton of bagasse (dry basis). Thermochemical yields approach 100 gallons per ton because gasification makes use not only of cellulose and hemicelluloses, but of lignin (20-25% of bagasse) as well.

However, if the cane ethanol plant possesses a cogeneration facility, as we have recommended, another fuel will have to be identified for the boilers to replace any bagasse converted to ethanol. Possible solutions include:

- Cane trash left in the fields and generated in roughly similar quantities as bagasse.
- Wood waste from near-by forest operations.
- Biomass residues of any kind from agricultural operations, such as those for production of biodiesel.

No advanced biofuels technology has been commercialized yet. As the situation evolves in the US and other countries, Jamaica will be in a position to benefit at some point in the future.

Besides terrestrial biomass, another promising advanced biofuels technology involves algae cultivation in open shallow ponds, followed by cell harvesting and extraction of lipids. The lipids are either transesterified to biodiesel or thermocatalytically converted to diesel and other hydrocarbons (Fig. 11).

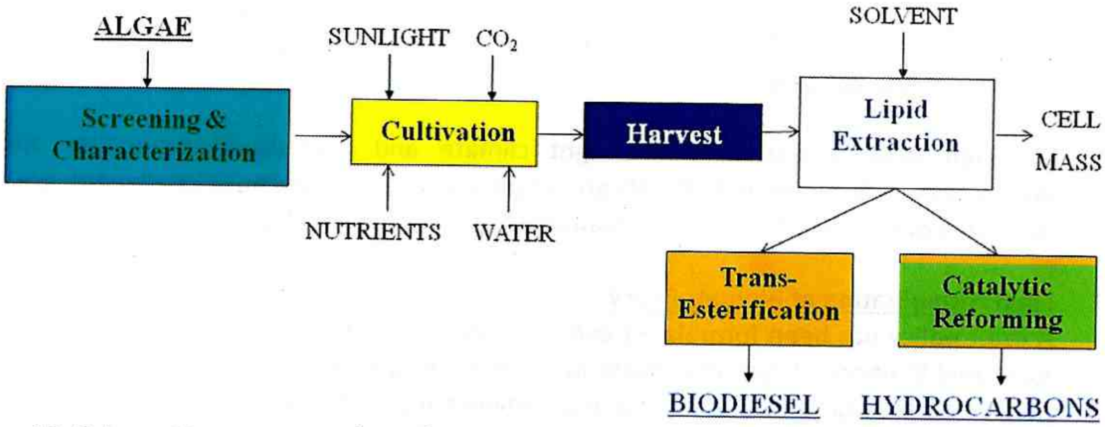

Figure 11: Schematic representation of algal cultivation for production of renewable fuels

The algal fuel technologies combine a number of advantages: use of marginal land to grow the algae in ponds, use of brackish or even saline water (instead of more precious process water), and absorption of CO_2 photosynthetically by the microorganisms. However, challenges abound as well:

- large plots of land to build an extensive network of ponds;
- exposure to inclement weather and contamination; and
- processing difficulties in algae dewatering and lipid recovery, as well as in conversion of the lipids to fuels.

Although Jamaica has plenty of sun exposure and favorable climate to pursue algal fuels, the technology is several years away from commercialization. In contrast, biochemical and thermochemical processes for conversion of biomass to biofuels, which have been intensively developed over the last 10 years, have entered the demonstration stage in North America and are likely to become commercial within a few years.

7. Risk Assessment

Although Jamaica possesses the right climate and agricultural experience for biofuels production, it is faced with significant challenges. Some of those challenges are within its control, whilst others are not. The main risks and means of mitigation are as follows.

Final Formalization of Biofuels Policy

A draft policy has been formulated and is currently undergoing stakeholder consultations prior to formal issuance. A national vision in the form of a long-term renewable energy or biofuels policy will provide a strong incentive for investment in Jamaica. Conversely, the absence of legislated renewable fuel goals or mandates is perceived as a lack of will to support the development of this new industry. A biofuels policy will provide the umbrella that stimulates investment by reducing the risk of investing and doing business in the country. The cases of Brazil and, more recently, Colombia provide ample proof of the benefit of policy adoption to the growth of biofuels. Brazil since 1973 and Colombia since 2001 have legislated state-supported biofuels programs clearly intended to reduce their exclusive reliance on imported oil. This kind of strong commitment has attracted domestic and foreign investment to the two countries enabling them to realize economic, social, and environmental benefits of domestically produced ethanol and biodiesel.

Jamaica can follow the example of Colombia by providing incentives for the establishment of biofuels capacity and infrastructure in its economy. It has already adopted gasoline-ethanol E10 blending and should also consider promoting biodiesel as well. Until recently, however, the ethanol has been imported in its hydrous form from Brazil and dehydrated in Jamaica with minimal positive impact on the country's economy. The biofuels policy has to focus on ways to spur domestic biofuels production.

Political Uncertainty

The creation of a biofuels industry and infrastructure in the country will require significant foreign investment from the private sector and from international development banks. However, such investment requires political stability that transcends party politics, since energy production/distribution has always been a public-private partnership and as such it is vulnerable to political fluidity.

In particular, civil unrest, corruption, and lack of protection for intellectual property and business contracts constitute tremendous barriers to the flow of US and other foreign investment in biofuels and other industries in the region. Democratic rule, open market economics, and business transparency are needed to secure investment.

Weak Legal and Regulatory Framework

As biofuels represent a new industry, their production, distribution, and use need to be regulated under a clear and stable framework that transcends political changes. Jamaica needs a strong regulatory and legal framework regarding the creation and operation of agroenergy/biofuels operations in the country. Jamaica needs to institute expedient industrial permitting review and licensing procedures for new biofuels facilities, so investors can have a good understanding as to what it will take and how long to see their investments generate profits. A single agency, such as NEPA, should provide a "one-stop-shop" to interested parties, coordinate with other government agencies, and streamline and accelerate the process. Moreover, quality standards for the produced biofuels need to be instituted or adopted from other regions of the world, such as the US or the European Union.

Lack of Business Incentives

The lack of business incentives for domestic production and use of biofuels will be a key obstacle to the adoption of biofuels in Jamaica. Just like every nascent industry, biofuels will need state support to establish themselves as a viable option, especially in light of their sustainable nature, economic contribution, and environmental friendliness. Jamaica should develop and adopt policies promoting the local production and use of ethanol and biodiesel, such as revenue tax exemptions for biofuels-producing operations, reduced sales taxes on biofuels compared to fossil fuels, reduced import duties on flexible fuel cars, and no import duties on equipment used for the manufacturing and R&D of biofuels. Such measures should remain in effect until the biofuels sector has matured to stand on its own. Colombia has set a great example in the region. Following in the footsteps of Brazil, the country implemented biofuels legislation (Law 693) since 2001 promoting the production of ethanol from agriculture and mandating its use throughout the country as a blend with gasoline.

Despite these challenges, biofuels constitute a major opportunity for Jamaica in terms of energy security, foreign investment, economic growth, job creation, international trade, and climate protection. In 2007 the US and Brazil signed a Memorandum of Understanding agreeing to jointly help certain Latin American and Caribbean countries, including Jamaica, develop a biofuels industry. Technical, business, and policy experts from the two countries have visited the region to offer biofuels guidance to governments and the private sector.

With policy, technical, and financial support from the US and Brazil, the country can boost the value of agriculture by co-producing food, biofuels, and renewable power. By focusing on systematically addressing the outlined challenges and obstacles, Jamaica can take advantage of the excellent economic opportunity that biofuels, current and future, represent for its people.

Low oil prices

This is a challenge beyond Jamaica's control, but a significant one as it affects the profitability of biofuels production in the country. Low oil prices will render biofuels more expensive and may create public backlash as blended gasoline and diesel will be more expensive. However, the country has already implemented E10 in both types of gasoline available (octane 87 and 90), therefore unblended gasoline is not an option at gas stations. The same should be done with diesel.

Mitigation of this risk lies in the pursuit of increased productivity by the Jamaican ethanol industry through high yields in both the field (tons of cane per hectare) and the plant (gallons of ethanol per ton of cane). Moreover, the probability of low oil prices is rather remote as global future predictions point to increased oil demand by developing countries, like China and India, and reduced oil reserves.