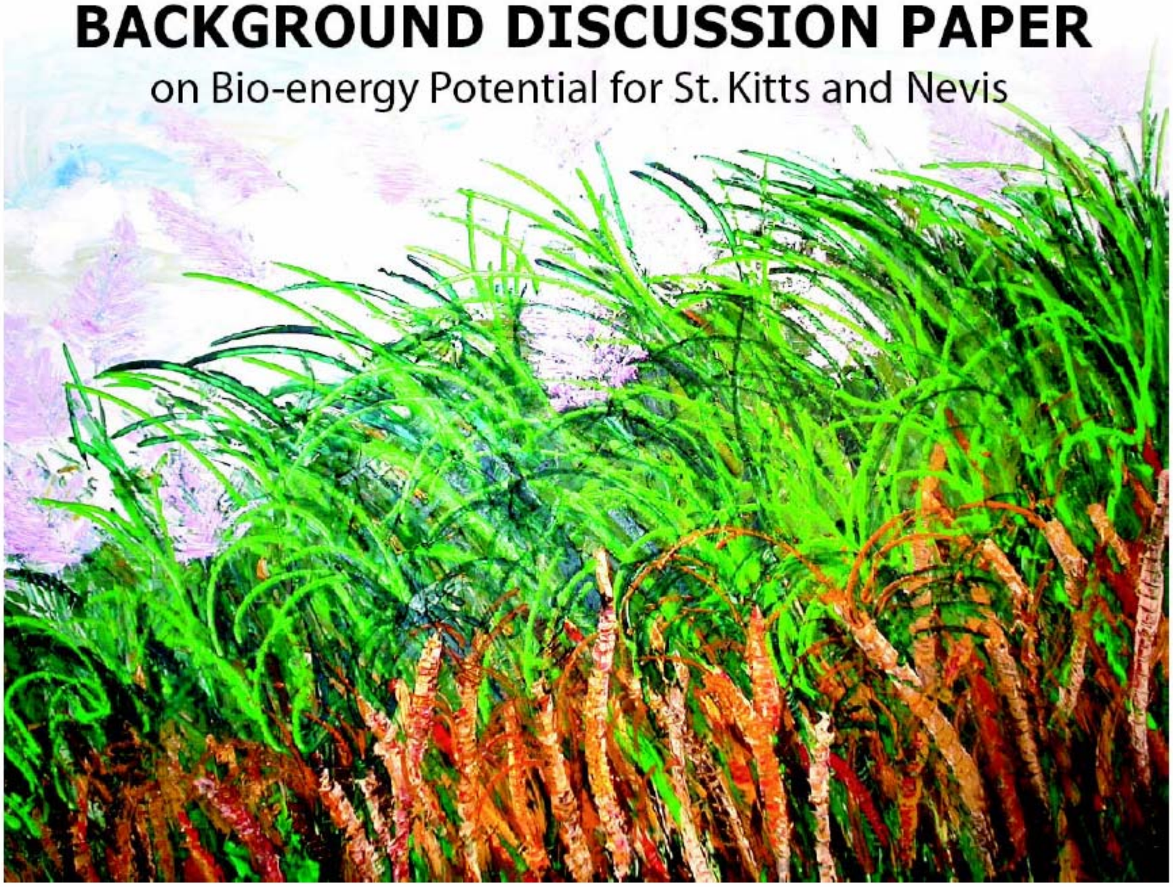
BACKGROUND DISCUSSION PAPER

on Bio-energy Potential for St. Kitts and Nevis



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List of Acronyms

ACP	Africa, Caribbean, and Pacific
BESAS	Biomass Energy Systems Assessment Study
BMW	Bio-Municipal Waste
CAFTA	Central America Free Trade Agreement
CARICOM	Caribbean Community and Common Market
CBI	Caribbean Basin Initiative
CDM	Clean Development Mechanism
CET	Common External Tariff agreement
CH4	Methane
CHO	Carbon, Hydrogen, and Oxygen
CHP	Combined Heat and Power generation
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DR	Dominican Republic
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gas (CO_2, N_2O, CH_4, etc.)
GSEII	Global Sustainable Energy Islands Initiative
GWh	Gigawatt hours
H_2	Hydrogen
ha	hectare
HHV	high heating value
IG	Imperial gallons
kW	Kilowatts
kWh	Kilowatt-hour
kPa	Kilopascal
LHV	lower heating value
MGallons	Millions of gallons
MJ	Mega joule
MM	million
MSW	municipal solid waste
MW	Megawatts
MWe	Megawatts of electricity
MWh	Megawatt-hour
NYBOT	New York Board of Trade
OFMSW	organic fraction of the municipal solid waste
O&M	operation and maintenance
RDF	refuse derived fuel
RME	Rapeseed Methyl Ester
RTP	Rapid Thermal Processing
SIDS	Small Island Developing State
SKED	St. Kitts Electricity Department
SSMC	St. Kitts Sugar Manufacturing Company

SWMC	Solid Waste Management Corporation
TC/TS 96°	Tons of cane to tons of sugar ratio
TS/TC	Tons of sugar to tons of cane ratio
TRQ	Tariff Rate Quota
USDA	United States Department of Agriculture
w.b.	Wet-basis moisture content

Executive Summary

Background

St. Kitts and Nevis is a Small Island Developing State (SIDS) that is confronting multiple socio-economic challenges. For over 350 years, sugar production was an important component of its economy. For many of those years sugar meant wealth and jobs.

As a result of the nationalization of sugarcane fields and the central sugar factory during the 1960s, subsequent losses (or profits) were attributed to the federation government. During the late 1990s and early 2000s, the spread between the EU guaranteed price for sugar (sugar from St. Kitts and Nevis was always sold under guaranteed market conditions, either directly to the United Kingdom, or beginning in 1975 with the adoption of the Sugar Protocol, to the European Union) and the cost of production grew to the point at which, in the summer of 2005 the St. Kitts Sugar Manufacturing Company (SSMC) was forced to stop its operations. With it, all agricultural activities related to sugar were halted.

In an effort to maintain many of the benefits of sugarcane production – including environmental aspects, erosion protection, agricultural employment, cultural and tourism benefits – The Federation Government via the Ministry of Sustainable Development, the lead Government agency for renewable energy initiatives, facilitated discussions between GSEII and the Sugar Transition Team instituted by the Federation Government to investigate alternatives for the industry, with a focus on possible use of the sugarcane for electricity and/or bio-fuel production.

Through its activities in the Caribbean islands, the Global Sustainable Energy Islands Initiative (GSEII-UNIDO) committed to supporting the activities of the Ministry of Sustainable Development and the Sugar Transition Team. GSEII is a consortium of international NGOs and multilateral institutions organized to support the interest of all small island states and potential donors by bringing renewable energy and energy efficiency projects, models, and concepts together in a sustainable plan for small island nations. GSEII seeks to showcase national efforts to significantly reduce greenhouse gas emissions. Recent efforts by the GSEII have focused on the island nations of St. Kitts and Nevis, St. Lucia, Grenada, and Dominica. As part of the national sustainable energy planning process activities have included, clean energy project identification, policy support, capacity building and institutional strengthening, and financing facilitation. Key GSEII partners include the Organization of American States (OAS), the Energy and Security Group, and Climate Institute. Funding support for the work in St. Kitts has been provided by the UN Foundation (UNF), and its implementing agency the United Nations Industrial Development Organization (UNIDO), the Italian Government, the Austrian Government, REEEP and USAID.

Study Purpose and Objectives

The purpose of this document is to provide a realistic assessment of the potential – both economic and technical – for the conversion of biomass[1] feedstocks to energy on a sustainable basis, given the current and/or potential conditions in St. Kitts and Nevis. It is expected that this study may be used as a benchmark study for identifying key criteria to aid the Government of St. Kitts and Nevis in the evaluation and selection of commercial biomass energy systems. In addition to this study, the Federation Government has received a number of proposals (largely unsolicited) from private developers proposing a biomass-to-energy path. The authors of this study are not making comment nor reference to the quality nor any of the specific aspects of those proposals.

When considering bio-energy one may consider a large diversity of biomass-to-energy conversion options, end uses, and applications involved. In the context of St. Kitts, there are two main sources of biomass: one is sugarcane and the other is the organic portion of Municipal Solid Waste (MSW)[2]. These biomass sources have to either be cultivated or collected, transported, and if necessary pre-treated and/or stored. The biomass can then be converted to energy through a variety of processes. The primary energy outputs to be considered by this study include biomass-to-ethanol (for use as a transportation fuel) and biomass-to-electricity. The ultimate process choice depends on the type and quality of the available biomass feedstock, desired end-use application, energy regulations, environmental standards, economic conditions, and socio-ethical factors.

This report provides an overview of the available quantities and quality of the biomass resources on St. Kitts. Relevant biomass energy systems for St. Kitts are identified and a pre-selection is made to describe possible biomass energy system scenarios, as well as the technical, economic, and socio-environmental characteristics of these scenarios. The results of this report are presented to the Government of St. Kitts and Nevis for their ultimate determination on how (or whether) to move forward with a sustainable biomass energy program for the island.

The key objectives of this study are twofold:

1) To analyze the technical, economic, and socio-environmental characteristics of biomass-to-energy systems for converting the locally available biomass to energy in the context of St. Kitts and Nevis.

2) To identify key criteria to select sustainable and commercially viable biomass-to-energy systems in the context of St. Kitts and Nevis.

The priority is placed on biomass energy systems that use sugarcane as the primary feedstock to produce ethanol and/or electricity. In cases where the feasibility of this system is limited, the organic portion of available MSW may function as an additional

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[1] B*iomass* is the organic matter, coming from products, waste and residues from agricultural (including animal and vegetal substances), forestry and related industries, as well as the organic fraction of industrial and municipal waste.

[2] Cuba de, K.H., "Towards a Sustainable Energy Plan for St. Kitts and Nevis," Department of Science, Technology and Society, Utrecht University, 2006.

feedstock for the conversion system to generate electricity and/or bio-fuel in a more cost-effective manner.

Report Highlights

The following areas were addressed in the study:

Study approach

The report provides a detailed discussion of the study approach, the methodologies used, and the types of information that are addressed in the report. Figure ES-1 provides an overview of the assessment process.

Biomass-to-Energy Assessment Process

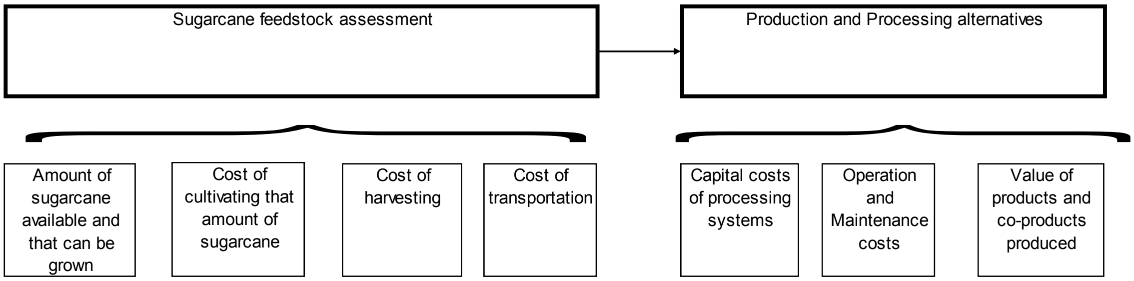

Figure ES-1. Schematic Overview of the Biomass-to-Energy Assessment Process

Baseline information St. Kitts' Demography, Energy and Transport Sector

The Federation of St. Kitts and Nevis is located in the north-eastern Caribbean region. The islands cover a total area of 269 sq. km (104 sq. mi.), of which St. Kitts is 176 sq. km. (68 sq. mi.) in size. The two islands are separated by a two mile stretch of water.[3] The population of St. Kitts and Nevis is about 42,740 (2005) where on St. Kitts it is around 32,397 (75.8% of the total of 42,740), with a population density of 186 persons per sq. km. About 40% of the St. Kitts population lives in the Basseterre capital region.

In St. Kitts there is one utility that manages the production, transmission, and distribution of electricity. The St. Kitts Electricity Department (SKED) is a state-owned utility with installed power production capacity of 33.5 MWe (as of 2006). The SKED operates one power plant, the Needmust power plant, which contains seven diesel No. 2 fuel oil-fueled generators. The generators range in size from 3.5 MW to 7.9 MW in capacity. The SKED's total electricity production in 2005 was 124,741 MWh. This electricity is transmitted via two busses, an 11.2 and an 11.4 kV, to the national grid. The average capacity factor of the power plant was 0.43, with a load factor of 0.71 and with an average fuel consumption rate of 17.4 kWh/imperial gallons (IG) (14.5 kWh/US gallon). The total fuel consumption at the Needmust power plant in 2005 was 7,156,452 IG[4]

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[3] Climate Institute website, http://unfccc.int/resource/docs/natc/kitnc1.pdf (visited November 2006)

[4] "Needmust Gensets Performance Indicators 2005," St. Kitts Electricity Department (2006).

(204,632 US barrels[5]). The total cost of generation in the year 2005 amounted to EC$60.5 million[6] (US$22.4 million), including fuel costs, O&M costs, and capital charge, this lead to an electricity generation cost of EC$0.45/kWh (US$0.17/kWh).

The transportation sector is the second largest energy-intensive sector in St. Kitts. The total number of registered vehicles on the island of St. Kitts in the year 2005 was 12,217 vehicles. The vehicle fleet consists primarily of cars manufactured during the 1970s and 1980s, and studies show that there is a possibility of mixing ethanol in up to 10% of the tank capacity for these vehicles without modifying the engines.[7] The total imported amount of gasoline and diesel to the island of St. Kitts in 2005 was 3.3 million (MM) gallons and 9.1 MM gallons respectively. There is no significant use of the imported gasoline other than for transportation. In the year 2005, about 10.6 million US$ was spend on importation of gasoline. Limited data on the gasoline prices indicate that it has been fluctuating from EC$6.90/gallon in the first quarter of 2005 to EC$8.30/gallon in March 2005, rising to EC$10.50/gallon in November 2005. From a recent mission to St. Kitts in 2007 a price range of EC$9.86 to EC$13.5 per gallon (3.65 – 5.0 US$/gallon) at the pump was observed.

Biomass costs, availability, and characteristics

The study addressed the availability and characteristics of biomass resources in St. Kitts. As part of this assessment, two primary types of biomass sources were considered — sugarcane (which would be considered a dedicated energy crop for these purposes) and the organic portion of the municipal solid waste (MSW) stream, also known as the biodegradable municipal waste (BMW). The BMW in this study is considered to be the combination of organic materials and paper/cardboard.

In order to evaluate the potential for converting biomass to energy, one must consider the quantity, characteristics, and the frequency of supply availability of these resources. With regard to sugarcane, this study assumes that the Federation Government would make available approximately 6,000 acres (2,428 hectares) for this energy crop. This figure is based on estimates provided by the current government officials and incorporates the fact that several thousand acres of sugar lands have been removed from cultivation since the closure of the sugar industry in 2005. The majority of the lands removed from cultivation have been allocated for other economic land use purposes including tourism (golf courses and hotel infrastructure development).

Based on the sugarcane cultivation and harvesting practices in 2005, this study provides estimates regarding the potential quantity, characteristics and availability of sugarcane for energy production. (See Table ES.1 below). In addition to the general resource data provided in Table ES.1, technical/composition data pertaining to sugarcane is available in Chapter 3 of this Study.

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[5] 1 UK gallon = 0.02859 U.S. barrels; source: UNEP Guidelines for Calculating GHG Emissions, http://www.uneptie.org/energy/publications/files/ghgind.htm.

[6] "Generation Costs SKED & Effect of PetroCaribe 2006-2008," St. Kitts Electricity Department (2006).

[7] Renewable Fuels Association. 'Ethanol Facts' http://www.ethanolrfa.org/resource/facts/engine/ 2006

Table ES.1. Sugarcane Quantities and Characteristics for St. Kitts

Parameter	Typical	Value range	Unit
Available cultivable area	6,000	5,500 – 6,500	acres
Sugarcane yield[8]	24.5	20.5 – 32.3	tons/acre
Average distance of fields to mill	12.4	10–15	Miles
Sugarcane production	147,000	112,750 – 209,950	tons/yr
Sugarcane production	1,225	805 – 2,100	tons/day
Sugarcane fiber content (w.b.)	19.0	0.18 – 0.20	% w.b.
Projected bagasse production	27,930	20,295 – 41,990	dry tons/yr
Average length of grow cycle	303	303 – 365	days/yr
Duration of crushing/harvesting season	120	100 – 150	days/yr
Amount of reaping per ratoon[9] planted	5	5 – 6	reaping/ratoon
Estimated cost of sugarcane as delivered to the processing plant	32.7[10]	32.7-49.5	US$/ton

As an energy feedstock, sugarcane is a high quality resource in many regards. However, the fact that it is only available on a limited basis according to its harvest cycle – in this case approximately 120 days or 4 months of the year. And, as an energy feedstock raw sugarcane offers virtually no storage capabilities once harvested because it quickly decomposes. The baseline assessment in this report, therefore assumes that sugarcane would only be available during the harvest season. Several storage/fuel preparation alternatives are discuss and presented in the full study.

In order to compliment the limited availability of the sugarcane additional biomass resources were explored during this study. The only significant resource that is immediately available is the organic fraction of the municipal solid waste stream. Based on interviews and reviews of the waste management facility statistics (there is one landfill site on the island of St. Kitts), the total amount of BMW has been estimated at 8,500 tons per year. Table ES.2 below provides an overview of the key characteristics of this biomass source.

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[8] The sugarcane yield incorporates the ratio between reaped and cultivable area of 0.84.

[9] The ratoon is the shoot sprouting from the plant base.

[10] The lower end of the sugarcane production costs are assumed, because it is most likely that any new bio-energy investments in St. Kitts would adopt the basic production efficiency improvements, including mechanized harvesting, transportation improvements and use of stillage as fertilizer in order to reach this value. Further efficiency improvements below this value of at least 10% is possible given advanced agricultural practices.

Table ES.2. Municipal Solid Waste Quantities and Characteristics for St. Kitts

Waste category	2004 Weight (ton)	Organic fraction (%)	BMW (ton)
Green waste	1,455	90	1,310
Household	10,390	42.5	4,416
Land clearing	3,514	75	2,636
Institutional	150	90	135
Sludge (Septic tank waste)	1,876	-	-
Ship generated waste	6	42.5	2.6
Total			**8,500**

Based on the available quantities and characteristics of biomass in St. Kitts, this study estimates the potential primary energy content that may be available for conversion into commercial energy products. This study assumes that all of the sugarcane product would be used in an energy production scenario. In this case the primary energy content of the resources (sugarcane and BMW) ranges between 983 – 3,180 TJ per year. See Table ES.3 below.

Table ES.3. Biomass Availability and Energy Supply Potential for 2004.

Source	Biomass supply (tons/ year)	Energy content (GJ/ton) HHV	Moisture content (% of wet material)	Ash content (% of dry material)	Energy supply, primary (TJp/year)
Sugarcane (directly fired)	112,750 – 209,950	17.0 – 18.1	30 – 50	2.2 – 2.4	958 – 2660
Bagasse alone[11]	20,295 – 41,990	16.5 – 19.0	40 – 50	2.2 – 2.4	167 – 479
BMW	8,500	7.4 –15.0	50 – 60	N.A.	25 – 64
Bagasse + MBW	**28,795 – 50,490**	**-**	**-**	**-**	**192 - 543**
Sugarcane + BMW	**121,250 – 218,450**	**-**	**-**	**-**	**983 - 3180**

Biomass-to-energy technology overview

The report reviewed the relevant commercially available biomass-to-energy conversion technologies to narrow the field for viable solutions in St. Kitts. It examined the conversion processes, technical parameters/limitations, and socio-economic impacts of the technologies discussed. The report also looked at case studies for bio-energy production in other small island nations. A selection of technology options was identified based on three criteria: (1) commercial availability; (2) existing processing capacities based on the available biomass feedstock types/quantities in St. Kitts; and (3) existence of companies with experience in the commercial implementation of these projects/technologies.

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[11] Note that the bagasse is produced as a waste product when crushing and milling the sugarcane. The energy content of this bagasse is of interest if one considers this source for power and heat production in an ethanol processing/power plant.

The baseline set for bio-energy conversion technologies identified and analyzed in detail in the study included:

- electricity production via direct combustion, and
- ethanol production through fermentation/distillation.

Additionally, several optimization scenarios were reviewed in an effort to improve the economic and/or technical feasibility of the scenarios. These alternative approaches included:

- adapt ethanol production system to produce hydrated ethanol for export,
- adapt electricity generation system to co-fire with alternative fuels (i.e. coal) during non-harvest periods;
- utilize innovative electricity generation technologies (i.e. gasification).

Biomass-to-energy conversion results

Based on the above inputs, including the biomass resources – their characteristics, quantities, and costs – and the available technologies, a series of economic models were developed to identify one or more scenario through which an economically viable energy production system might be developed. Multiple techno-economic and sensitivity analyses were performed for the key scenarios.

Biomass-to-Ethanol Findings

The primary end use application in this scenario is dehydrated ethanol, or simply ethanol, a finished product that can be blended with gasoline (functioning as a replacement for methyl tertiary butyl ether MTBE) for transportation use. Ethanol can be mixed up to 10% of tank-volume with gasoline without the need for adaptations in existing transport vehicles. Further, it is also that the process will result in excess electricity that may be sold to the national grid; this will depend on the amount of heat and electricity that is required to produce ethanol.

In order to calculate the overall costs of an ethanol production system appropriate to the amount of available feedstock projected, the initial investment costs are based on a 3 million gallon/year facility (for this study it is estimated that such a facility would cost US$19 million).

Given the cost and expenses shown in this study, as well as the income and financing requirements of such a plant, the following results were obtained for this potential ethanol facility. The annual outputs in this case are estimated at 2,736,872 gallons of ethanol and 8,609 MWh electricity for sale to the national grid. The costs of production derived by this analysis suggests an ethanol production cost in the range of US$1.78 to US$2.87 per gallon.

Note: The projected costs are based on current costs of inputs, and it is likely that reductions in output costs for ethanol may be derived by improving feedstock processes, in particular, the agricultural procedures to reduce the costs of the sugarcane as a feedstock (from the current costs of US$32.7/ton). Also the analysis suggests that the electricity generation cost of this scenario is about 0.087 US$/kWh and is lower than the current 0.17 US$/kWh generation cost on St. Kitts. Such a margin may provide an electricity rate with an acceptable rate of return (depending on the electricity sales), while still providing cheaper electricity to the consumer. For this base case scenario an electricity sales rate of 0.13 US$/kWh (thus a revenue margin of 0.044 US$/kWh) is assumed to assess the effect of this revenue on the ethanol production cost.[12] Table ES.4 below presents a summary of these results.

Table ES.4. Summary of the Results for Scenario 1 –Ethanol Production

Input/Output	Average Value	Unit	Range
Land under cultivation	6,000	Acres	5,500 – 6,500
Sugarcane feedstock	147,000	Ton/yr	112,750 – 334,100[13]
Ethanol Produced	2,736,872	Gallons/yr	2,099,199 – 6,220,332
Estimated Cost of Ethanol Production	2.12	US$/gallon	1.856 - 2.867
Electricity Available to the Grid	8,609	MWh/yr	6,603 – 21,250
Estimated Cost of Electricity Production	0.087	US$/kWh	0.075 - 0.117
Set Electricity Sales	0.13	US$/kWh	
Cost of Ethanol (incl. electr. Sales)	1.78	US$/gallon	

Biomass-to-Electricity Findings

It is assumed that the sugarcane is used directly as fuel for a direct combustion electricity generation system. Sugarcane availability depends on the harvesting period; which in this case is estimate to be between 3 – 5 months per year; or 100-150 days of available harvest per year. Based on the available 6,000 acres of land at the time of this study, and a yield of 24.5 tons per acre (based on the 10-year average of full operation of the SSMC), there is a baseline sugarcane production of 147,000 tons per year. If the full quantity of the sugarcane produced (147,000 tons/yr) were fully converted into electricity during the 100-150 available days, according to the average energy content, efficiencies, and load factors, a power plant in the range of 30 to 50 MW would be feasible.

However, a 30 to 50 MW power plant is not an option given the current and near term projected demand for power in St. Kitts. Biomass electricity is best utilized in a baseload situation. According to the current and projected demand (as shown in section 7.2.3) the optimal baseload supply from this operation is projected to be 10 MW of installed capacity. The estimated investment costs for such a facility is US$15 million (based on an estimate of US$1,500 per kilowatt installed).

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[12] Note that the buy-in rate is dependant on the Power Purchase Agreements (PPA) that are subject to future plans for energy development on St. Kitts and Nevis.

[13] This value reflects the optimizations assumed in yield improvements.

Accordingly, such a plant would produce approximately 20,156 MWh over the period of 100-150 days per year. The estimated cost of electricity resulting from this baseline strategy ranges from US$0.085 to US$0.170 per kWh, with a projected average estimate of US$0.13/kWh. A quantity of sugarcane juice is produced that can be sold to alcohol distilling/beverage companies.

The required land to cultivate the necessary feedstock to supply a 10 MW facility over 100-150 days is approximately 1,340 acres (to produce 32,830 tons per year of sugarcane). Several strategies may be pursued to extend the period of operations of the plant beyond the harvest season. These strategies may include: developing revolving crop cycles to vary/extend the crop availability; importing biomass materials from other countries; importing coal or other fossil fuels; and utilizing the BMW as a feedstock. If no co-firing strategy is pursued, this plant would remain off-line during the remainder of the year. See Table ES.5 below.

Table ES.5. Summary of the Results for Scenario 2 Electricity Production

Input/Output	Quantity	Unit	Notes; Cost range
Sugarcane feedstock required for 10 MW power plant	32,830 274	Ton/yr Ton/day	
Land required to produce necessary sugarcane feedstock	1,340	Acres	
Estimated power conversion load factor	0.7		Biomass-fueled Rankine cycle plant
Electrical efficiency	0.26		
Electricity to grid	20,156	MWh/yr	The entire electricity supply is generated and delivered during 100-150 days per year
Estimated Cost of Electricity	0.13	US$/kWh	0.085 - 0.170

Energy market analysis

The report examined the key factors regarding bio-energy inputs and outputs to evaluate the cost-effectiveness of an investment in biomass to electricity or biomass to ethanol in St. Kitts. This included the price of agricultural products, related support subsidies, local and global policies related to bio-energy development (e.g., EU Sugar Protocol, U.S. Tariff Rate Quota, CAFTA, etc), productivity of agricultural activities, world market prices for ethanol, local prices for gasoline, and local prices for electricity. These markets are highly volatile and the prices are derived by forces external to St. Kitts.

Ethanol Prices

Figure ES.2 below shows the ethanol market prices over a period of 18 months, from September 2005 through March 2007 varied from US$1.70 to US$4.00 per gallon. Note, these reflect the prices per gallon of ethanol delivered at several ports in the USA. The latest figures list the port delivered price of ethanol at US$2.20-US$2.40/gallon as of March 2007. The wholesale price of ethanol produced in other countries of the Americas is estimated to be (several sources cited below):

Brazil:

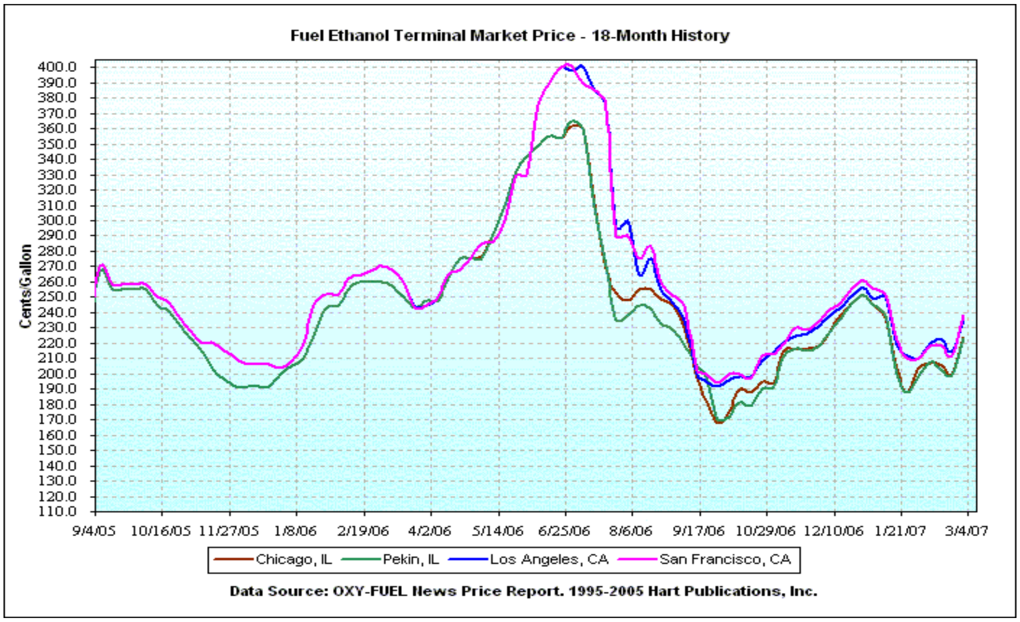
- US$0.68 – 0.95 /gallon (cane based ethanol production cost) (UNEP, IEA, 2004)
- US$0.76 per gallon (cane based ethanol production cost) (Centre for Strategic Management and Studies - CGEE, Brazil)
- US$0.83 per gallon (cane based ethanol production cost) (OECD, 2006)

USA:

- US$1.779 per gallon (corn based ethanol production cost)(Centre for Strategic Management and Studies - CGEE, Brazil)
- US$1.80 – 2.06 per gallon (corn based ethanol whole sale price) (CRS, 2006)

Guyana:

- 0.308 – 0.408 US$/L -> 1.166 – 1.544 US$/gallon (cane based ethanol production cost) – ECLAC, 2007


Fuel Ethanol Terminal Market Price - 18-Month History

Data Source: OXY-FUEL News Price Report. 1995-2005 Hart Publications, Inc.

Figure ES.2 U.S. Ethanol Market Price Over the Last 18 Months

St. Kitts Gasoline and Electricity Costs

As described above, in St. Kitts there is one utility that manages the production, transmission, and distribution of electricity. The St. Kitts Electricity Department (SKED) is a state-owned utility with installed power production capacity of 33.5 MWe (as of 2006). The SKED's total electricity production in 2005 was 124,741 MWh. The total cost of generation in the year 2005 amounted to EC$60.5 million[14] (US$22.4 million), including fuel costs, O&M costs, and capital charge, this lead to an electricity generation cost of EC$0.45/kWh (US$0.17/kWh).

With respect to the transportation sector, the total imported amount of gasoline to the island of St. Kitts in 2005 was 3.3 million (MM) gallons. In the year 2005, about 10.6

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[14] "Generation Costs SKED & Effect of PetroCaribe 2006-2008," St. Kitts Electricity Department (2006).

million US$ was spend on importation of gasoline. Limited data on the gasoline prices indicate that it has been fluctuating from EC$6.90/gallon in the first quarter of 2005 to EC$8.30/gallon in March 2005, rising to EC$10.50/gallon in November 2005 and is currently within a range of EC$9.86 to EC$13.5 per gallon (3.65 – 5.0 US$/gallon) (2007).

Report Conclusions and Recommendations

In reviewing the report conclusions, one has to keep in mind that St. Kitts and Nevis is a small island state in a globalizing market economy, where the market value of its products are subject to international market price fluctuations and competition. The conclusions and recommendations offered in this report are intended to serve as a starting point, or baseline for evaluating or considering a possible bioenergy development initiative in St. Kitts. The evaluation focused on off-the-shelf, current technologies and the agricultural system in place with minimal changes or advancements. It is expected that commercial developers may be able to beat the estimates provided here.

The broad conclusions as a result of this study suggest that there is a reasonable expectation for a competitive bioenergy business based on sugarcane crops. The Government of St. Kitts and Nevis, is therefore encouraged to seek viable offers/private sector partners for the development and implementation of this opportunity.

Principal Product: Ethanol (dehydrated)

The projected wholesale cost of ethanol for St. Kitts according to this study is US$1.78 to US$2.87 per gallon with a mean cost of US$2.12 per gallon. This compares with ethanol production costs of approximately US$0.75 per gallon in Brazil, US$1.80 per gallon in the United States, and US$1.40 per gallon in Guyana. This suggests that without significant advancements in the technology and/or processing systems, ethanol production in St. Kitts is challenging proposition from a market competition perspective.

When considering the domestic use of ethanol as a transportation fuel, near term local ethanol demand is limited to approximately 10% blending capacity with gasoline. This amounts to 409,619 gallons/year of ethanol while the projected ethanol production is approximately 2.7 million gallons per year. As a result, an excess of 2.3 million gallons of ethanol would be available for export. Without significant reductions in the projected costs, it would seem that the export potential to the U.S., E.U. or other international markets for this fuel is limited. At the sub-regional level (e.g. OECS region), there may exist possibilities for cost competitive export, due to close proximity of islands, the high local/regional gasoline prices and common regulatory and commercial frameworks in place.

In considering alternatives to improve the economics of an ethanol-based strategy the following issues warrant further consideration:

Importing hydrated ethanol from Brazil:

Economies of scale can be improved by importing hydrated ethanol mainly from Brazil for distillation into de-hydrated ethanol for further export to the U.S. market under the

Caribbean Basin Initiative (CBI). The feasibility of this alternative needs to be further analyzed.

Aggregating biomass feedstocks or an intermediate product (i.e. hydrated ethanol) among several Caribbean countries in an effort to improve the economies of scale:
Locally produced hydrated ethanol could be exported to a centralized distillation unit elsewhere in the Caribbean to contribute to the improvement of the economies of scale of that alternative process system. Also sugarcane juice may be considered an export product for further processing elsewhere in the Caribbean.

Principal Product: Electricity
The projected electricity production costs for St. Kitts according to this study are US$0.050 to US$0.17 per kWh (including results of the optimization options). The produced juice after the fuel preparation process for combustion can be sold to alcohol/beverage distilleries that in general are of smaller capacities and are under influence of a different market, whereby different levels of economies of scale are required. Given that the projected electricity costs (not giving an economical value to the remaining juice) are lower than the estimated current production costs of electricity, it is suggested that this represents a promising opportunity for development.

In considering alternatives to improve the economics of an electricity-based strategy the following issues warrant further consideration:

The seasonal availability of sugarcane as a feedstock:
Sugarcane is seasonal in its nature and is as feedstock limited to the harvesting period (3-5 months per year). This limits the opportunity for a base load operation of the biomass power plant where lower operating cost can be achieved. Options as sugarcane drying and storage may be of interest (detailed exergy and economic analysis are required). Also alternative fuels (e.g. coal) can be imported and co-fired to extent the fuel availability, provide base load electricity and improve operating economics. Another alternative is looking at the possibility of year-round (energy) cane cultivation. Since the main objective of cane-to-energy is to cultivate a higher fiber content cane, this type of cane has higher environmental resistance levels (e.g. droughts and saline conditions) and can stay in the field for longer periods between harvesting and it has a much deeper root system that can benefit the regeneration capacity to sub-soil freshwater aquifers.[15]

The relatively high cost of sugarcane as a feedstock:
The baseline operation conditions on St. Kitts resulted in the sugarcane feedstock cost of 49.5 US$/ton, this reflected an inefficient harvesting system with limited mechanization and high transport costs (antiquated equipments). With minimal advancements this price may be reduced to 32.7 US$/ton, but even at this level it still remains the highest cost factor for the system and were further optimization (using efficient and low-maintenance equipments) is deemed feasible and recommendable.

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[15] Conversation with and Presentation by Dr. Al Binger, National Bio-Energy Stakeholders Consultation, Organized by OAS/GSEII and partners, St. Kitts and Nevis, August 2007.

The relatively small demand for electricity on St. Kitts:
The energy demand on St. Kitts forms a determining factor for the scale and design of the sugarcane-to-electricity power plant. The available 6,000 acres of land would provide excessive energy. This suggests for the downscaling of the available primary energy (less land) to supply a projected base load demand of 10 MWe over the period 2008 – 2010.

Optimizing the heat and power production
When opting for a CHP plant the heat to electricity rate can be adjusted to the respective demands. One needs to assess the heat demand (e.g. for other industries, households or hotel sector) to evaluate the viability of this alternative.

Build in the incentives available via carbon credits:
The Federation as signature to the Kyoto Protocol has Carbon Financing Mechanisms as the Clean Development Mechanism (CDM) to its disposal whereby a biomass or biomass/coal co-firing system is recognized as a GHG emission reduction system. This will provide additional credits to lower the initial capital investment for such a system.

Export to Nevis:
Since the current available 6,000 acres could yield enough energy to install a 44.8 MWe power plant, there may be possibilities to interconnect the island of St. Kitts with Nevis via submerged cables to export the excessive electricity produced. Alternatively the biomass feedstock could be exported to the island of Nevis to make it possible to combust this feedstock with the available MSW on the island of Nevis.

I. Introduction

1.1 Study Purpose and Objectives

The purpose of this document is to provide a comprehensive assessment of the feasibility for converting available biomass[16] in St. Kitts and Nevis to electricity or bio-fuel on a sustainable basis. Entitled "Background Discussion Paper on Bio-energy Potential on St. Kitts and Nevis" this study provides a framework for the Government of St. Kitts and Nevis in the evaluation and selection of commercial biomass energy systems.

The key objectives of this study are twofold:

1) To analyze the technical, economic, and socio-environmental characteristics of biomass-to-energy systems for converting the locally available biomass to energy in the context of St. Kitts and Nevis.

2) To identify key criteria to select sustainable and commercially viable biomass-to-energy systems in the context of St. Kitts and Nevis.

The priority is placed on biomass energy systems that use sugarcane as a feedstock to produce ethanol and/or electricity. In cases where the feasibility of this system is limited, the organic portion of available MSW can function as an additional feedstock for the conversion system to generate electricity and/or bio-fuel in a more cost-effective manner.

1.2 Structure of the Report

The report is organized as follows.

- Chapter 2 presents the methodology used to perform the biomass-to-energy assessment.
- Chapter 3 deals with the biomass availability, sugarcane characteristics, and the organic fraction of the Municipal Solid Waste. The background and conditions of sugar production on St. Kitts are also described.
- Chapter 4 provides a discussion of the sugar and ethanol markets on the island.
- Chapter 5 reviews the power production and transport sectors, and the waste management practices on St. Kitts.
- Chapter 6 reviews biomass-to-energy technologies and presents a pre-selection of commercially available biomass-to-energy conversion technologies.
- Chapter 7 describes the pre-selected biomass-to-energy conversion technologies, taking into account different end-use applications or products. The assumptions and input data for each scenario are provided as well as the associated techno-economic analysis. The results and sensitivity analyses are depicted and discussed, optimization options are provided and the results are summarized and discussed.
- The main report conclusions are summarized in Chapter 8.

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[16] B*iomass* is the organic matter, coming from products, waste and residues from agricultural (including animal and vegetal substances), forestry and related industries, as well as the organic fraction of industrial and municipal waste.

2. Methodology

This chapter provides an overview of the study approach, the methodologies used, and the types of information that can be expected in the report. The following figure summarized how the biomass-to-energy system assessment was performed.

Biomass-to-Energy Assessment Process

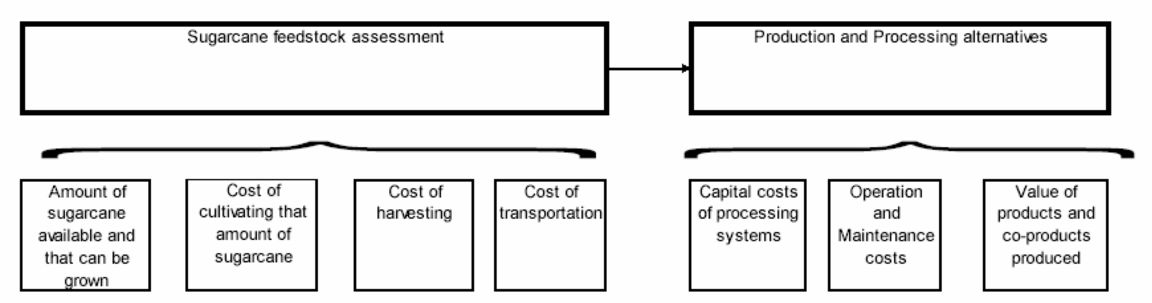

Figure 2.1. Schematic Overview of the Biomass-to-Energy Assessment Process

2.1 Biomass Resource Assessment

As the starting point for the assessment, an investigation was performed to determine the available biomass resources on the island of St. Kitts. This assessment was performed as a follow-up to a pre-feasibility study finalized in the beginning of 2006,[17] where two main sources of biomass were identified—sugarcane and the organic portion of Municipal Solid Waste, also known as Bio-Municipal Waste (BMW[18]).

The St. Kitts Sugar Manufacturing Company was visited to gather costing and technical information. To evaluate sugarcane production, the sugarcane yield, characteristics, availability, and production cost were investigated. To evaluate the BMW, four main aspects were targeted: availability, supply pattern, composition, and delivery costs.

Further, in addition to the Sugar Manufacturing Company, several ministries were contacted to gather views and relevant information about ongoing activities and land use plans. These included the Ministries of Environment, Planning, Sustainable Development, and Agriculture.

2.2 Biomass-to-Energy Rationale and Scope

To describe the scope, socio-economic, and environmental implications of introducing a biomass-to-energy system on the island of St. Kitts, some sections of this report are dedicated to assessing sugar and ethanol market developments. The electricity and transport sectors are described in more detail and the waste management system is highlighted. By describing these sectors or areas, a big-picture view is provided and the rationale for introducing a biomass-to-energy system is established.

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[17] Cuba de, K.H., "Towards a Sustainable Energy Plan for St. Kitts and Nevis," Department of Science, Technology and Society, Utrecht University, 2006.

[18] In this study *BMW* is considered the organic fraction of MSW (kitchen & garden, green waste) + paper/cardboard waste.

Figures 2.2 and 2.3 provide a general overview of the possible developments on St. Kitts, regardless of whether the country chooses to pursue a biomass-to-energy system.

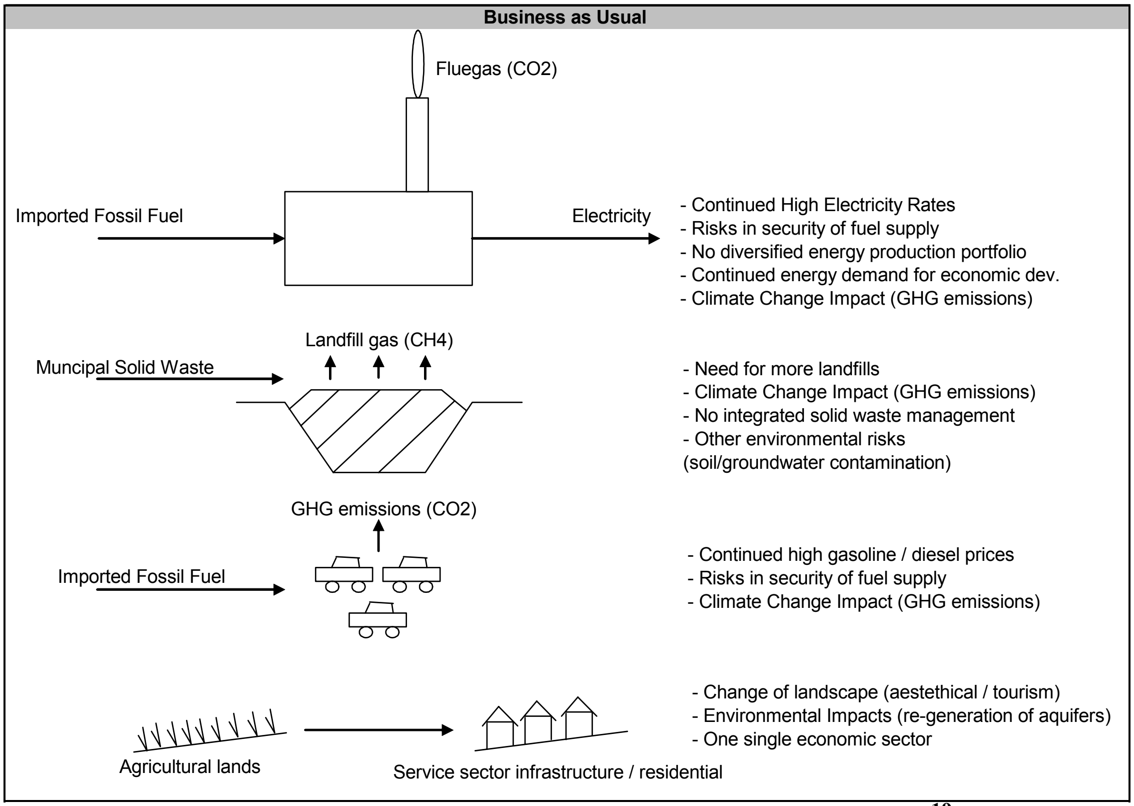

Figure 2.2. Business-as-Usual Development on St. Kitts[19]

Figure 2.2 shows possible developments on St. Kitts where no biomass-to-energy system is introduced. The overall big picture could mean that the country would continue to import volatile and costly fossil fuels for the power and transport sectors. The power sector will remain dependent on one source and system for energy production with its related greenhouse gas (GHG) emissions that contribute to climate change. The current landfills would reach their maximum landfill capacity with high environmental and health risks. Agricultural lands would be used for other economic activities such as infrastructure for tourism/service sector development and residential areas. All of this would mean that St. Kitts as a country could lock itself into one single economic sector (tourism) that is prone to external factors and international competition, which calls for a reliable energy production service and a clean and healthy environment for tourism development.

The alternative development is one with the inclusion of a biomass-to-energy system that may result in the re-activation of agricultural activities, prevention of land degradation, and the creation of a diversified economy. In this alternative, indigenous biomass sources are used for either the power or the transport sector and simultaneously decrease the country's risks due to insecurity of the fuel supply and climate change impacts.

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[19] Note: this figure is provided here just as an illustrative means of possible future developments

Alternatively the waste management sector could be re-organized and its associated environmental and public health risks could be decreased, whereby parts of the MSW could be included in the biomass-to-energy system.

Figure 2.3 summarizes the above-mentioned possible developments and demonstrates the focus of this study on assessing various biomass-to-energy conversion systems for the island of St. Kitts.

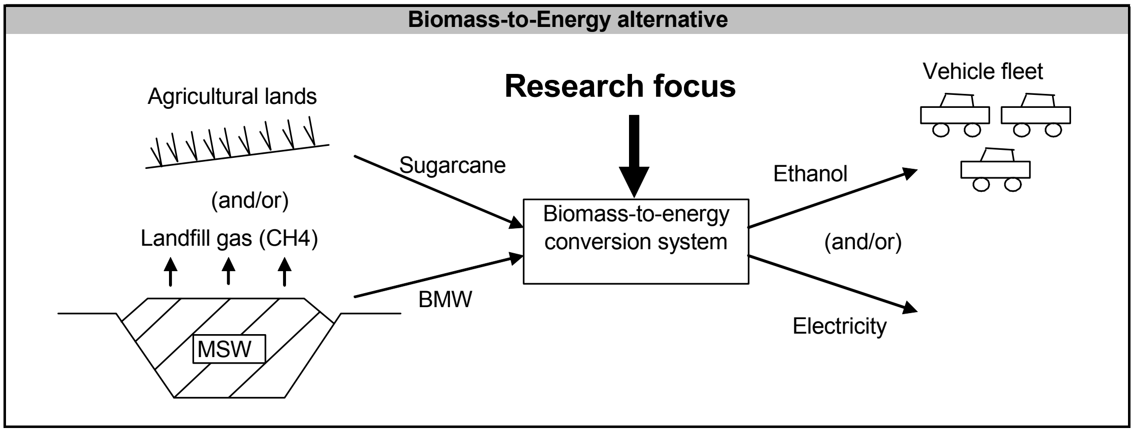

Figure 2.3 Alternative Development Including a Biomass-to-Energy System on St. Kitts

Note that all the above-mentioned developments require further discussion. Additionally, the socio-economic and environmental aspects need to be further investigated to provide a complete view of the pros and cons of the proposed scenarios. This study attempts to cover these aspects to the greatest extent possible, acknowledging the constraints of limited time and information availability.

2.3 Pre-selection of Biomass-to-Energy Conversion Technologies

The objective of this activity is to identify and assess the cost range of alternatives for the conversion of sugarcane into ethanol and/or electricity. Because of the wide variety of biomass-to-energy conversion technologies for both ethanol and electricity production, a general overview is provided to explain the principles of the main conversion alternatives. A pre-selection is then made based on the technical limitations of each conversion alternative and its commercial availability in the context of a small developing island state. These technical limitations, such as the treatment capacity size, depend on the characteristics and quantity of the biomass feedstock and the commercial availability relies on the development stage of the technology. Another consideration influencing technology availability is the feedstock pre-treatment requirement. Thus pre-selection criteria consist of system capacity size, commercial availability, and biomass pre-treatment requirements.

2.4 Biomass Energy System Scenario Build-up

This study attempts to include all relevant conversion alternatives by creating scenarios where a variety of combinations of biomass feedstock, conversion technologies, and end-use applications are described. Of the pre-selected biomass-to-energy systems, the current state of the art technology is considered. The selection of a specific brand or sub-technology is outside the scope of this study, which focuses on identification of commercial alternatives and provision of cost ranges for each scenario. In addition, detailed energy assessments are necessary to select an adequate biomass-to-energy conversion sub-technology.

2.5 Biomass Energy Systems Scenario Evaluation

As a minimum threshold to evaluate the performance of each scenario, the current electricity price on St. Kitts and the international ethanol or other energy carrier market value are compared to the output of each scenario. This allows for the pre-selection of financially feasible scenarios that can be further investigated.

Depending on operating conditions, electricity and/or ethanol production from sugarcane and/or BMW can be more or less expensive than the cost of business-as-usual electricity generation on St. Kitts and/or the ethanol/energy carrier market value. Therefore it is important to identify the various cost and socio-environmental benefits of each system in order to account for these externalities and conduct a more comprehensive analysis. Toward this end, the present study aims to include a life-cycle assessment and techno-economic analysis for a complete evaluation of the scenarios.[20]

Life-cycle assessment

To achieve an accurate economic valuation of the several biomass energy scenarios the entire life cycle of each system should be considered. This means accounting for the entire value chain, from biomass production up to the end-use product. Since this is an intensive and complicated task, and the scope of this study is to identify commercial alternatives, provide cost ranges, and create a baseline for the attraction of investors, the life-cycle assessment is limited to a techno-economic analysis of biomass–to-energy conversion alternatives, utilizing baseline assumptions for the input parameters and later evaluating the effects of changing these on the cost of output products.

Techno-economic analysis

In this analysis the scenarios are evaluated by identifying the common denominator between energy and material, and quantifying the conversions and outputs. In the case of the biomass-to-energy conversion systems using sugarcane and/or BMW as primary fuel input, there are two types of energy carriers of economic importance: ethanol and electricity. The electricity (US$/kWh) and ethanol (US$/gallon) production costs are calculated by adding all expenses, including: the variable costs—primary fuel cost,

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[20] Awerbuch, S., Risky Business: Fossil risk mitigation and enhanced energy security from renewables, Renewable Energy World, July-August 2006, Vol9 (4), p.139-149, website: http://www.renewable-energy-world.com/display_article/271577/121/ARCHI/none/none/Risky-business:-Fossil-risk-mitigation-and-enhanced-energy-security-from-renewables/.

operation and maintenance (O&M) costs; fixed costs; and the capital recovery cost of the equipment and installation.

Financial sensitivity analysis

As discussed previously, the biomass feedstock cost is a significant component of the biomass energy system's overall cost. Therefore it is important to investigate the impact of a change in this feedstock cost on the biomass-to-energy conversion process and outputs. Other factors such as capital investment, interest rate, debt ratio, equity cost, taxation, and incorporation of carbon credits under a clean development mechanism (CDM) scheme are also included in the analysis to determine the impact of the factors on the cost of electricity and/or ethanol production.

Socio-environmental qualitative analysis

In this analysis an overview will be provided of the socio-environmental impacts of the biomass–to-energy conversion alternatives. Issues such as land degradation, fertilizer usage, emissions, and job provision are some factors that are taken into account. This is briefly analyzed to highlight possible big-picture socio-environmental constraints.

Study output

An outline of optimal biomass–to-energy systems and the requirements and possible approaches to their development are also described. Additionally, a table with cost ranges and sensitivity results for each biomass-to-energy conversion scenario for St. Kitts is provided. These results can be used along with a standard evaluation matrix to evaluate the feasibility of a bio-energy system for the island.

3. Biomass Costs, Availability, and Characteristics

In this chapter the availability and characteristics of biomass in St. Kitts are described. A brief description of the sugarcane cultivation and processing is provided. As part of this assessment, a distinction is made between biomass sources—i.e., dedicated crops compared to non-dedicated sources, and primary and secondary biomass residues. The cost of production of the dedicated crop (sugarcane) is provided and the characteristics and energy content of the organic portion of the MSW, also known as the biodegradable municipal waste (BMW), is described.

3.1 Biomass Resources on St. Kitts

Dedicated crops are specifically cultivated for energy purposes; in this study, the sugarcane produced on St. Kitts is considered a dedicated crop. Primary biomass residue is produced during production or harvesting of food and via dedicated crops. For St. Kitts, this is the sugarcane residual that remains in the field after harvesting is complete. The secondary biomass residue becomes available after a biomass-derived commodity has been processed—meaning a diversity of waste streams, which varies from the organic fraction of MSW (BMW) to waste water sludge. Table 3.1 provides a brief description of the biomass sources reviewed in this study.

Table 3.1. Biomass Sources Identified on St. Kitts.

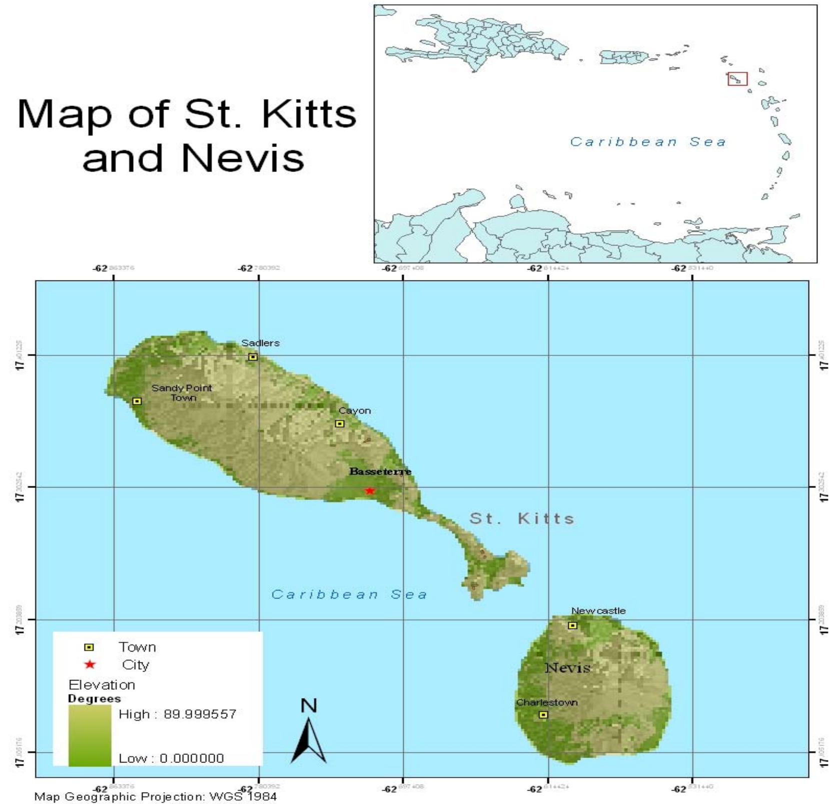
Biomass stream	Description	Supply pattern
Agriculture		
Sugarcane	Sugarcane is described in this study as a dedicated energy crop.	January - June
Sugarcane residues	Sugarcane residue availability depends on the harvesting methods used.	January - June
Organic wastes		
Organic fraction of MSW	This is the organic portion of MSW. In general this contains remains of kitchen and garden waste.	All year
Waste paper/cardboard	This category consists of old paper and cardboard coming from households or the service sector.	All year
Sludge		
Waste Water Treatment	This is wet sludge coming from septic tanks.	All year

The specific properties of each biomass feedstock determine which biomass energy conversion technologies are the best options, based on technical and economic feasibility and environmental criteria. Properties as moisture content, mineral proportions, density, and degree of contamination (e.g. heavy and alkaline metals, nitrogen, sulfur, and chlorine) differ widely depending on the source of the biomass. The following section will discuss the characteristics of the biomass that is available on the island of St. Kitts.

In this study two main biomass sources are considered: sugarcane and BMW. The priority is assessing the feasibility of converting sugarcane into ethanol and/or electricity. Other biomass sources, such as MSW, may be considered in the optimization section based on the findings of the technical and economic analyses.

3.2 Sugarcane

In this section a brief description of sugarcane cultivation and processing at the St. Kitts Sugar Manufacturing Company (SSMC) is provided to get a better insight of the conditions on St. Kitts. The data related to the sugarcane and bagasse characteristics are provided and the energy resource is assessed. Figure 3.1 shows the geographical location and size of the islands.



Map Geographic Projection: WGS 1984
Source: Nicole Alleyne

Figure 3.1. Elevation Map of St. Kitts and Nevis

The sugarcane lands are located around the mountain tops. The green areas have the lowest elevation, and this is where generally the sugarcane is planted.

Sugarcane cultivation on St. Kitts[21]

The sugarcane produced on St. Kitts is based on a plant cane and ratoon system. The Fall/Autumn planted cane crop is reaped after 16-18 months while the Spring planted crop is reaped within 10-12 months. Once harvested, the crop is ratooned and reaped approximately every 10-12 months annually for a five-year period, with decreasing

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[21] From communications with Mr. Kelly (former SSMC agronomist), December 2006.

yields. The cane harvest season lasts about 4 months (120 ± 20 days) generally between January and June, depending on the start date of harvesting.

Cane cultivation procedures depend on whether it is plant cane or ratoon cane. In the case of plant cane, the land is harrowed (about 3 passes with tractor drawn implements) to kill the old cane stools and till the soil to incorporate the organic material. The land is furrowed and seed cane pieces are dropped manually in the furrow and covered mechanically. Row spacing is 4.5 feet and a pre-early post emergent herbicide is applied within 10 days of covering. Four weeks after emergence, a fertilizer is applied mechanically and at 10-14 weeks, nitrogen is applied in the form of ammonium sulphate. Post emergent herbicides are applied as required for weed control up to canopy closure (e.g., two applications/crop/year).

In the case of ratoon fields, after harvesting, the trash is re-spread uniformly across the surface (for manually cut fields) to conserve soil and moisture and aid in weed control. Post emergent herbicide applications are made as required to canopy closure (typically one to two applications). The dominant grass, *Panicum maxicum* (guinea grass) is dug manually. In the case of mechanically harvested fields there is no need to re-spread trash. For all ratoon sugarcane crops, the same fertilizer regime is followed as for plant cane, with the initial application done 3-4 weeks after harvest.

Green cane harvesting is the primary practice in St. Kitts except for fields that contain obstacles; in this case the cane is burned prior to harvesting. The cane is harvested either manually or mechanically. In St. Kitts about 70-75% of the cane is harvested manually due to the sloping topography. However it is known that up to 60-70% of the fields can be harvested mechanically if track harvesters are used and the land is prepared accordingly. Manual harvest means that the whole cane stalk is cut by hand cutters (3-4 tons/man-day) and loaded mechanically utilizing grab loaders. The payload for transporting whole-stalk cane is 3 tons. Typically, a mechanical grab loader handles 60-75 loads per 10 hour day at 3 tons/load depending on the distance to transport the cane to transfer sidings for trans-loading by mechanical cranes to rail trucks.

In the case of mechanical harvesting, the whole cane stalk is cut and chopped into billets by chopper harvesters. The harvester removes the tops, cuts the cane stalk (including leaves and chops) it into billets, and separates the leaves from the cane by fans. The cane is loaded directly into tractor drawn trailers with a pay load of approximately 3.5 to 4.0 tons. Typically, chopper harvesters cut and load at a rate of 12 tons/hr operating at a mechanical time efficiency of 60%. Efficiency is limited by downtime waiting for rail trucks and mechanical breakdowns due to aging equipment. Chopped canes are transferred to rail trucks utilizing self-tipping, tractor drawn, and hydraulically operated trailers. Both whole stalk canes and chopped canes are transported from the transfer sidings to the factory via rail (cane trains).

The sugarcane processing entails sugar milling and extraction using tandem mills, clarification and evaporation, boiling and drying, grading, and bagging.

Delivery, preparation, and milling

The delivered sugarcane is milled by tandem roller mills, to destroy the cell structure and extract the sugar juice. A shredder is used to fraction the cane, increase the surface of the sugarcane exposed to the mills, and improve the juice extraction. There are five rollers installed in series at the SSMC, as shown in Figure 3.2 below.

Figure 3.2. Conveyer Belt Entrance to SSMC Milling Facility (left) and the Five Installed Roller Mills at the SSMC (right)

Mill water is added to dissolve and extract the juice through a process called imbibition. The cane fiber that comes out of the mills as residue is called bagasse. This bagasse is conveyed to storage facilities where, in a later stage, it is used as boiler fuel to produce steam for process heat or electricity production for in-house consumption. Because the bagasse is used as fuel, the moisture content should be as low as possible, which conflicts with the imbibition process described before. This is because although a higher imbibition rate will increase the juice extraction, it requires more energy to evaporate later in the process.

Clarification and evaporation

After the extraction of the juice, it is clarified to remove impurities. At the SSMC, lime is added to the juice, eliminating most organic acids and destroying part of the coloring matter. Next, the juice is gravitationally separated into dense and clear juice in sedimentation tanks. The dense remainder is filtered and re-inserted into the clarifier to reduce sugar losses. The residual filter cake is collected and can be used as fertilizer.

The clear sugar juice is heated gradually in several steps. First, the sugar has to reach its saturation point to crystallize. The heating takes place in the vapor cell and evaporators, where the juice is turned into syrup. At the SSMC five evaporator tanks are installed in series. By lowering the pressure in each sequential evaporator tank the remaining heat from the previous tank can be effectively used to heat the syrup. However, the higher the temperature, the higher the required vacuum, and the more energy is required.

Figure 3.3 provides a simplified schematic diagram of the sugar processing and the final products and by-products produced.

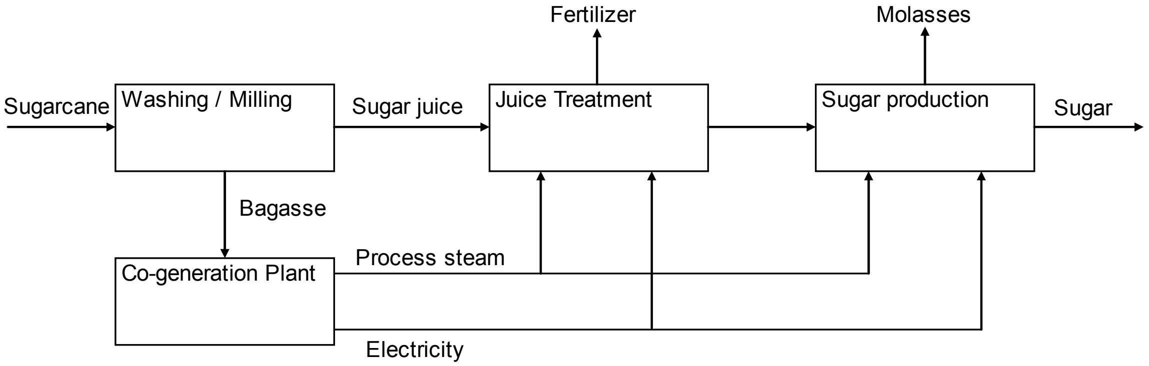

Figure 3.3. Conventional Sugarcane Processing Scheme

Boiling, drying, grading, and bagging

When the syrup is close to its saturation point, it is fed into vacuum pans for further boiling. During the boiling process crystals start to appear as the saturation point is surpassed and boiling continues until almost all the water is evaporated. This is then fed to the crystallizers where it is stirred to optimize the crystallization. The substance is then separated into sugar and molasses using centrifuges. The first filtrate is the A-sugar, which is further processed into the final sugar. The residual is the A-molasses, which are further boiled and centrifuged to obtain B-sugar and B-molasses. This process is repeated once more with the B-sugar to produce C-molasses that are not suitable for sugar production and are generally sold to the ethanol industry. The B- and C-sugars obtained after this process are re-inserted at the beginning of the boiling stage. The A-sugar is dried and then graded according to grain size, and finally bagged. The St. Kitts raw sugar is then ready for export. The crystallization process is very energy intensive and considered the highest consumer of process heat.

Sugarcane lands and yields

In 2004 (last available data), St. Kitts was estimated to house a total cultivable area of about 3,197 hectares (ha) (7,900 acres). This is equal to 18.2% of the total surface area of St. Kitts, which is 17,610 ha (43,520 acres[22]). The area under sugarcane cultivation accounted for about 2,839 ha (7,015 acres) of the total cultivable area.[23] The use of the remaining land (398 ha or 984 acres) is not known.

In 2004, the sugarcane-producing area of 2,839 ha generated 171,915 tons of sugarcane and consequently 14,384 tons of sugar. Based on the size of the sugarcane-producing area, the yield was about 60.6 tons/ha (24.5 tons/acre) and the tons of cane to tons of

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[22] This is equal to 176.1 km^2.

[23] From communication with representatives of the Saint Kitts Sugar Manufacturing Company (SSMC, 2006).

sugar ratio (TC/TS 96°) was 11.95.[24] Table 3.2 provides an overview of sugarcane production in several countries in the Caribbean for the year 2004 to serve as a reference point.

Table 3.2. Sugarcane Production Statistics for the Caribbean, 2004.[25]

	Unit	Trinidad	Jamaica	Belize	Guyana	Barbados	St. Kitts
Total cultivated area	ha	8,505	30,581	26,500	43,258	6,993	2,839
	acres	21,020	75,570	65,480	106,900	17,280	7,015
Cane production	tons	616,452	1,993,145	1,167,924	3,867,222	361,237	171,915
Cane yield (based on area reaped)	tons/ha	72.5	65.2	44.1	89.4	51.7	60.6
	tons/acre	29.3	26.4	17.8	36.2	20.9	24.5
Raw Sugar production	tons	43,500	183,672	122,969	335,988	34,358	14,384
TS/TC ratio	%	7.06	9.22	10.53	8.69	9.51	8.37
TC/TS 96° ratio		14.17	10.85	9.50	11.51	10.51	11.95

The sugarcane yield in St. Kitts of 60.6 tons/ha (24.5 tons/acre) is within the range of 44.1–89.4 tons/ha (17.8–36.2 tons/acre) observed in the Caribbean region. One particular note is that the sugarcane to raw sugar ratio of St. Kitts (8.37%) is, along with Trinidad's, among the lowest in the range for the region (7.06–10.53%), and this is indicative of inefficiencies in the sugarcane-to-sugar conversion process. The sugarcane yield is of particular importance for the viability of converting biomass to energy. Based on communications with ex-SSMC agronomist there is a potential to increase the yield level up to about 100 tons/ha (40.5 tons/acre). Further, considering the observed yields of other countries, there is theoretical potential to increase the sugarcane yield up to at least 89.4 tons/ha (36.2 tons/acre). This will depend on a number of factors including climatologically conditions, cultivation and harvesting techniques, and use of sugarcane varieties. The sugarcane yield has historically fluctuated between 20.5 – 32.3 ton/acre (51.3 – 80.8 ton/ha) and is initially used for the sensitivity analysis.

Figure 3.4 shows the historical development of sugarcane production on St. Kitts. The figure illustrates that the sugarcane production and reaped areas have fluctuated over the years. It also shows that the available cultivable area since 2002 has decreased rapidly in the last few years. Over the period 2003-2004, there was an unusual drought that caused the yield to decrease considerably. From 2004 to mid-2005, a decrease of 230 acres was

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[24] *Raw value* of any quantity of sugar means its equivalent in terms of raw sugar testing 96 sugar degrees, as determined by a polarimetric test performed in accordance with procedures recognized by the International Commission for Uniform Methods of Sugar Analysis (ICUMSA); see: a257.g.akamaitech.net/7/257/2422/14mar20010800/edocket.access.gpo.gov/cfr_2002/janqtr/pdf/7cfr1435.2.pdf.

[25] 2004 Statistics Summary, Sugar Association of the Caribbean (SAC).

observed; this is due in part to the anticipated closing of the sugarcane industry. Appendix A provides more detail.

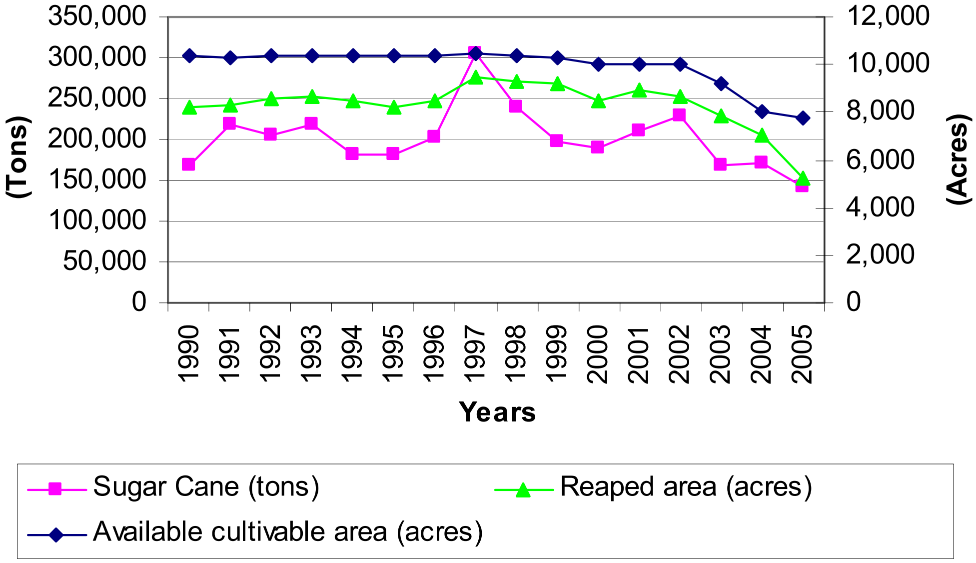

Figure 3.4. Sugarcane Production Compared to Cultivable and Reaped Areas of St. Kitts from 1990 to 2005 (SSMC).

Communications in December 2006 with representatives of the Sugar Transition Team, the Ministry of Sustainable Development, and ex-SSMC employees have revealed that the current available cultivable area of St. Kitts is 2,428 ha (6,000 acres). Over the 15-year period shown above, the area under cultivation was on average 84% of the total area available. As depicted above, the rate of decrease in available cultivable land is worrisome, especially when the objective is to investigate economic alternatives for the sugar industry.

Sugar production activities ceased in the summer of 2005, which explains the lower sugarcane production values in 2005 compared to 2004. For this reason, the present analysis uses the sugarcane yield of 2004 as the baseline data, to represent operations under business-as-usual conditions. In addition, the 2004 sugarcane yield of 60.6 tons/ha (24.5 tons/acre) is representative of the average yield observed over the prior 10-year period (see Appendix A for more detail). For the sugarcane production assessment, the amount of available land is just as important as crop yield. For the present analysis, the year 2006 value will be used, which as stated above is believed to be 2,428 ha (6,000 acres).

Sugarcane and bagasse characteristics

On St. Kitts a large variety of sugarcane crops are being cultivated. The typical composition of the sugarcane produced on St. Kitts can be described as having 18-20% fiber content (In the literature the bagasse recovery can range between 0.28-0.5[26,27] w.b.),

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[26] Deepchand, K, Sugar Cane Bagasse for Electricity Generation in Africa, 2004, source: http://www.afrepren.org/Pubs/articles/deepchnd.htm

12-15% sucrose, and a moisture content range of 40-60% w.b. (wet basis moisture content). (In the literature the moisture content of sugarcane can vary between 48-74%[28],[29]) The energy content of the sugarcane can have a heating value ranging between 17-18.1MJ/kg (HHV).[30,31,32,33,34] As for chemical composition, the bulk composition of biomass in terms of carbon, hydrogen, and oxygen (CHO) does not differ much among different biomass sources. Therefore, for this study, the typical (dry) weight percentages used for C, H, and O are 45-50%, 5-6%, and 38-45%, respectively.[35] The ash content is about 2.2-2.4%.[36]

Box 3.1. Higher and lower heating values of biomass fuels.
For biomass fuels (like wood or cane) the following formulas are used for determining the lower heating value. Biomass often contains substantial amounts of water from itself. In the case of determining the lower heating value of biomass, also this amount of water is assumed to be in the gaseous form after combustion. The lower heating value of biomass fuels therefore can be calculated as follows:

$$\mathrm{EHHV,wb} = \mathrm{EHHV,dry} \cdot (1 - w) \qquad [1a]$$

$$\mathrm{ELHV,wb} = \mathrm{EHHV,wb} - h \cdot \mathrm{Ew,evap} \cdot \mathrm{mH2O} \cdot (1 - w) - \mathrm{Ew,evap} \cdot w \quad [1b]$$

in which:
EHHV,wb = the higher heating value of the fuel on a wet basis
EHHV,dry = the higher heating value of the fuel on an oven dry basis
ELHV,wb = the lower heating value of the fuel on a wet basis
Ew,evap = the energy required for evaporation of water (2.26 MJ/kg at 25 °C)
h = the fraction of hydrogen in the oven dry fuel (by weight)
mH2O = the mass of water created per unit mass of hydrogen (8.9 kg/kg)
w = the fraction of water in the biomass on a wet fuel basis.

One generally distinguishes oven dry (w = 0); air dry (w = 20 - 35%) and harvested (for wood e.g. w = 50%). For woody biomass, EHHV typically is 20 MJ/kg (oven dry).

As part of the sugar production process in St. Kitts, the sugarcane was milled in order to extract sugarcane juice that could be further processed to sugar, producing molasses as by-product. These molasses can be converted into ethanol. The typical conversion efficiency from molasses to ethanol is about 40%[37]. The energy content of ethanol varies depending on the origin of the molasses, thus the crop used. Typical LHV for ethanol is around 21.1MJ/L[38].

The residual fibrous material remaining after the milling process is called bagasse; this is used as fuel for a boiler to produce steam, which is then used for process heat and

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[27] Ferguson, A.R.B., Sugarcane and Energy, July 1999, source: http://www.members.aol.com/optjournal/sugar.doc
[28] Jakeway, L. and Nakahata, M., Closed-loop biomass co-firing, Hawaiian Commercial and Sugar Company, July 2000, website: www.osti.gov/bridge/servlets/purl/763410-ncrzkk/webviewable/763410.pdf.
[29] Hamelinck, C.N., Outlook for advances biofuels – thesis, Copernicus Institute, Utrecht University, website: igitur-archive.library.uu.nl/dissertations/2005-0209-113022/c4.pdf.
[30] Wirsenius, S., *The Biomass metabolism of the food system – A model based survey of the global and regional turnover of food biomass,* Journal of Industrial Ecology, volume 7, number 1, website: www.mitpress.mit.edu/jie.
[31] Larson, E.D., Presentation: Lifecycle analysis of GHG Impacts of Biofuels for Transport, Princeton Environmental Institute, Princeton University, Washington D.C., March 2006.
[32] Hamelinck, C.N., Outlook for advances biofuels – thesis, Copernicus Institute, Utrecht University, website: igitur-archive.library.uu.nl/dissertations/2005-0209-113022/c4.pdf.
[33] Hassuani et al., "Biomass power generation," Sugarcane bagasse and trash, UNDP Brazil, 2005, page 26.
[34] Scurlock, J., Oak Ridge National Laboratory, http://bio-energy.ornl.gov/papers/misc/biochar_factsheet.html
[35] Faaij, A.P.C., "Biomass Combustion," Chapter of the Encyclopedia of Energy; Copernicus Institute, Utrecht University, the Netherlands.
[36] Pandey et al., "Biotechnological potential of agro-industrial residues: I. Sugarcane bagasse," 2000.
[37] State of Louisiana website: http://dnr.louisiana.gov/sec/execdiv/techasmt/alternative_fuels/ethanol/fuel_alcohol_1987/008.htm (visited December 2006).
[38] Bio Energy Conversion Factors, website: http://bioenergy.ornl.gov/papers/misc/energy_conv.html.

electricity production. Bagasse has a typical moisture content around 40 – 55%.[39,40,41] The heating value of bagasse from the sugarcane could range between 16.5 - 19MJ/kg (HHV).[42,43,44,45,46] Since this bagasse can function as a fuel source for biomass-to-energy alternatives, the characteristics of the bagasse are also investigated here.

Table 3.3 provides an overview of relevant parameters that have influence on the sugarcane and bagasse production. Because of the uncertainty in the available cultivable lands, it is decided to add a margin of 6,000 ± 500 acres (2,428 ± 202 ha). Multiplying this range with the range in yield of 20.5 – 32.3 ton/acre, these results in a potential sugarcane production range of 112,750– 209,950 tons per year. Bagasse recovery rate can be between 0.15 – 0.30 dry kg/kg wet sugarcane.[47,48] The fiber content of the sugarcane defines the dry bagasse production; the range for the sugarcane on St. Kitts is between 18-20%. The weighted average of 19% is used to assess the bagasse production potential that results in a range of 21,423 – 39,891 tons of bagasse per year.

The sucrose content range of between 12 – 15% is found for sugarcane types cultivated on St. Kitts. The energy content of sucrose varies between 17 - 21.5 MJ/kg.[49],[50] Approximately 138 to 163 gallons of ethanol per ton of sucrose[51],[52] can be produced. The availability of the sugarcane depends on the cultivation method; the land has to be prepared, the ratoon planted, the cultivation phase initiated (16 – 18 months), and the harvesting/crushing period (150 – 180 days/year) begun, generally between January to June. Once this is terminated, the growing cycle starts again with an average growing period length of 303 days. This cycle continues for 6 years up until the ratoon is replaced. Table 3.3 summarizes all the gathered data on the sugarcane and bagasse characteristics.

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[39] Food and Agricultural Organization (FAO), website: http://www.fao.org/docrep/008/j0926e/J0926e06.htm.

[40] Mbohwa, C. and Fukuda, S., Electricity from Bagasse in Zimbabwe, Tokyo Metropolitan Institute of Technology, Japan

[41] Environmental Protection Agency (EPA), AP-42 chapter 1.8 Bagasse combustion in sugar mills, website: www.epa.gov/ttn/chief/ap42/ch01/final/c01s08.pdf.

[42] Yamamoto, H., Development of an Asean biomass model and the simulation results, CRIEPI, website: unit.aist.go.jp/internat/biomassws/03workshop/material/yamamoto.pdf.

[43] Damen, K., “Future prospects for bio-fuel production in Brazil”, A chain analysis of ethanol from sugar cane and methanol from eucalyptus in Sao Paulo State, Utrecht University, 2001

[44] World Energy Council (WEC), website: http://www.worldenergy.org/wec-geis/publications/default/tech_papers/17th_congress/3_2_02.asp#Heading6

[45] Cortez, L.A.B. and Gomez, E.O., A method for Exergy Analysis of sugarcane bagasse boilers, School of Agricultural Engineering, State University of Campinas, Brazilian Journal of Chemical Engineering, volume 10, number 1, march 1998.

[46]http://www.reap-canada.com/online_library/Reports%20and%20Newsletters/Bio-energy/284,8,Slide 8

[47] Wirsenius, S., *The Biomass metabolism of the food system – A model based survey of the global and regional turnover of food biomass,* Journal of Industrial Ecology, volume 7, number 1, website: www.mitpress.mit.edu/jie.

[48] Larson, E.D., Presentation: Lifecycle analysis of GHG Impacts of Biofuels for Transport, Princeton Environmental Institute, Princeton University, Washington D.C., March 2006.

[49] Reid, M. and Hammersley, R., The effects of Sucrose and Maize Oil on subsequent food intake and mood, Britische Journal of Nutrition, volume 82, number 6, 1999, website: http://www.ingentaconnect.com/content/cabi/bjn/1999/00000082/00000006/art00004.

[50] Wikipedia website: http://en.wikipedia.org/wiki/Sucrose

[51] U.S. Department of Agriculture, *The Economic feasibility of Ethanol production from sugar in the United States*, July 2006

[52] Macedo, I.C., Unicamp, Campinas, Brazil, website: http://www.carensa.net/Brazil.htm

Table 3.3. Assumptions for Current (2006) Sugarcane Production Potential on St. Kitts

Parameter	Typical	Value range	Unit
Available cultivable area	2,428	2,226 – 2,630	ha
	6,000	5,500 – 6,500	acres
Sugarcane yield[53]	60.5	51.3 – 80.8	tons/ha
	24.5	20.5 – 32.3	tons/acre
Average distance of fields to mill	20	16–24	Km
	12.4	10–15	Miles
Sugarcane production	147,000	112,750 – 209,950	tons/yr
Projected bagasse production (18-20% fiber content)	27,930	20,295 – 41,990	dry tons/yr
Average length of grow cycle	303	303 – 365	days/yr
Duration of crushing/harvesting season	120	100 – 150	days/yr
Amount of reaping per ratoon[54] planted	5	5 – 6	reaping/ratoon

The composition of the delivered sugarcane depends on factors such as the sugarcane type (either wet or dry type), as the sucrose level will vary accordingly. In the dry case, higher sucrose content will be observed. The harvesting method (mechanized or manual labor), can also have an impact on the composition. Some mechanized harvesting equipments and transportation methods can compact the sugarcane and squeeze out moisture that can result in lower moisture content delivered to the processing facility. In 2004/05, 25-30% of the sugarcane lands were mechanically harvested, with areas containing high inclination levels served by manual labor. Table 3.4 provides an overview of the composition of the sugarcane and bagasse. The data is collected from interviews with SSMC experts and a literature review.

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[53] The sugarcane yield incorporates the ratio between reaped and cultivable area of 0.84.

[54] The ratoon is the shoot sprouting from the plant base.

Table 3.4. Chemical Composition of the Sugarcane and Bagasse on St. Kitts

Parameter	Typical	Value	Unit
Moisture content of harvested sugarcane	50	40 – 60	%
Sugarcane fiber content	19	18 – 20	%
HHV of sugarcane	17.0	17.0 – 18.1	MJ/kg
HHV of bagasse	16.5	16.5 – 19.0	MJ/kg
Bagasse moisture content	45	40 – 50	%
Bagasse cellulose[55]	32 – 48		%
Bagasse hemi cellulose	19 – 24		%
Bagasse Lignin content	23 – 32		%
Carbon content[56] ©	45 – 50		%
Hydrogen content (H_2)	5 – 6		%
Oxygen content (O_2)	38 – 45		%
Ash content	2.2		%
Sulfur content (S)	-		%

The typical or baseline heating values of the sugarcane and bagasse are set at the conservative end of what is theoretically possible. There are several optimization options to increase the yield of the delivered sugarcane on St. Kitts; it is estimated that with some adaptations in the cultivation and harvesting, a yield of about 100 ton/ha (40.5 ton/acre) can be reached[57]. One can think for instance of adding the sugarcane tops to the sugarcane stream, this will increase the fiber content and therefore also the energy content of the biomass, but on the other hand the moisture content is also increased, thus bringing down the heating value of the biomass.

Other general characteristics of bagasse[58]

- Bagasse is a by-product for the ethanol production process, its use as a fuel would therefore seem economically more desirable than the use of fuel oil, natural gas or coal.
- Bagasse is biomass; it is a renewable fuel and the CO_2 emissions from its combustion are offset by photosynthesis when sugarcane grows.
- Bagasse is sulfur free; no sulfur dioxides are produced when bagasse is burned.

3.3 Biomass from Bio-Municipal Solid Waste (BMW)

BMW production

Next to sugarcane production, the other main source of biomass on St. Kitts and Nevis is the bio-municipal solid waste (BMW). The BMW in this study is considered to be the combination of organic materials and paper/cardboard. BMW can, along with sugarcane

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[55] Scurlock, J., Oak Ridge National Laboratory, Bio-energy Feedstock Development Programs, website: http://bio-energy.ornl.gov/papers/misc/biochar_factsheet.html.

[56] Faaij, A.P.C., "Biomass Combustion," Chapter for the Encyclopedia of Energy, Copernicus Institute, Utrecht University, the Netherlands.

[57] From communications with Mr. Kelly (Former Chief Agronomist at the SSMC), 2006

[58] World Energy Council (WEC), website: http://www.worldenergy.org/wec-geis/publications/default/tech_papers/17th_congress/3_2_02.asp#Heading6

bagasse, be used to produce energy in the form of bio-fuels (e.g., bio-gas) and/or electricity (by waste-to-energy systems). Additionally, BMW can be incorporated into the sugarcane-based biomass feedstock stream to increase the total capacity of a bio-energy conversion system. Table 3.5 provides a comparative overview of the MSW composition in different countries.

Table 3.5. MSW Composition in T&T, U.S., Caribbean and St. Kitts.

Component	Trinidad & Tobago[59]	U.S. Average	Caribbean default values[60]	St. Kitts[61]
Organics	26.70%	24%	49.3%	27.20%
Paper/Cardboard	19.70%	38%	17%	20.50%
Glass	10.50%	6%	5.7%	8.10%
Metals	10.40%	8%	5.0%	8.80%
Plastics	19.90%	9%	9.9%	23.20%
Textiles	7.30%	15%	5.1%	7.40%
Others	5.30%	-	5.4%	4.80%
Organic fraction[62]	**46.4%**	**62%**	**66.3%**	**47.7%**

The composition of the MSW can vary between countries, region or even cities. Economic, socio-cultural, local product availability, and other technical factors play a role on the composition. In the case of St. Kitts, the BMW is estimated to be around 47-48 %. One can notice that the MSW on island states contain a lower share of organic waste.

Table 3.6 shows the biodegradable or organic waste fractions by waste categories. From a solid waste characterization study[63] performed in St. Kitts, it was concluded that the organic waste[64] accounted for 24-28% of the tonnage of the residential / rural and urban waste (household waste). The paper and paperboard, that can also be considered BMW, accounted for 14-19% of the total household waste. Thus the medium organic fraction of the household waste accounted for 4,416 tons (42.5% of household waste) in year 2004.

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[59] Caribbean CDM forum, Project Opportunities in the Waste Management Sector in the Caribbean, http://www.gcsi.ca/cdmforum/wastephase2report.htm#problem.

[60] Pipatti et. al., 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 2, 2006, online: www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_**Waste**_Data.pdf.

[61] Garraway, E., "Saint Kitts Solid Waste Characterization Study," OECS, Natural Resources Management Unit, Saint Lucia, 2002.

[62] In this study "organic fraction" is considered the organics + paper/cardboard fraction of the MSW.

[63] Garraway, E., "Saint Kitts Solid Waste Characterization Study", OECS, Natural Resources Management Unit, Saint Lucia, 2002

[64] In this study organic waste category is defined as a composition of food wastes, composite organic waste, and yard & agricultural wastes.

Table 3.6. Waste Quantity Information by Waste Category on St. Kitts[65]

Waste category	2004 Weight (ton)	Organic fraction (%)	BMW (ton)
Green waste	1,455	90	1,310
Household	10,390	42.5	4,416
Land clearing	3,514	*75*	2,636
Institutional	150	90	135
Sludge (Septic tank waste)	1,876	-	-
Ship generated waste	6	42.5	2.6
Total			**8,500**

Green waste in general refers to agricultural or forestry waste. The green waste production of St. Kitts was 1,455 tons in 2004. Septic tank waste generally consists of human or industrial waste in the form of sludge. This is the sedimentary particulate matter that enters storage/treatment tanks along with the waste water from toilets, kitchens, and industrial processes. Depending on its characteristics after dewatering, the sludge can be burned or digested. In general it is more efficient for digestion processes to be converted to bio-gas. The amount produced in 2004 was equal to 1,876 tons of sludge. The incorporation of this biodegradable waste stream will depend on the biomass-to-energy conversion systems taken in consideration in the next step of the analysis.

BMW characteristics

The composition of the BMW depends on a series of factors, e.g., the waste collection system (whether the waste is separated by source or by post-collection mechanical separation; its degree of contamination with heavy metals, plastics, etc.), the handling, and transportation methods used (compaction rate, moisture content). One important characteristic of the BMW for this study is the average energy content or heating value of the BMW. Table 3.7 shows an overview of ranges and the typical energy content of several components in the BMW.

Table 3.7. Typical Energy Content Values of BMW Components[66]

Component	Kg	Range (MJ/kg)	Energy range (MJ)	Typical energy (MJ)
Food/organic	0.285	3.5 - 7.0	1.0 – 2.0	1.5
Yard waste	0.285	2.3 - 18.6	0.7 – 5.3	3.0
Paper	0.215	11.6 - 18.6	2.5 – 4.0	3.3
Cardboard	0.215	14.0 - 17.4	3.0 – 3.7	3.4
BMW	**1.000**			**11.2**

As estimated in table 3.7, the typical BMW energy content on St. Kitts could be around 11.2 ± 3.8 MJ/kg. Based on the total amount of BMW estimated, the primary energy content is between 62,900 – 127,500 GJp.

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[65] Source: Saint Kitts Waste Management Corporation (2005)

[66] Tchobanoglous, G. et al., Integrated Solid Waste Management, Engineering principles and management issues, McGraw-Hill International Editions, 1993

3.4 Summary of Biomass Availability

In this section a brief description is provided on the total available biomass supply quantity and the primary energy potential for each biomass source.

Table 3.8. Biomass Availability and Energy Supply Potential for 2004.

Source	Biomass supply (tons/ year)	Energy content (GJ/ton) HHV	Moisture content (% of wet material)	Ash content (% of dry material)	Energy supply, primary (TJp/year)
Sugarcane (directly fired)	112,750 – 209,950	17.0 – 18.1	30 – 50	2.2 – 2.4	958 – 2,660
Bagasse	20,295 – 41,990	16.5 – 19.0	40 – 50	2.2 – 2.4	167 – 479
BMW	8,500	7.4 –15.0	50 – 60	N.A.	25 – 64
Bagasse + BMW	29,923 – 50,490	-	-	-	202 - 543
Sugarcane + BMW	121,250 – 218,450	-	-	-	983 – 3,180

When considering the combination of bagasse and BMW, based on the available information, this amounts between 202 - 543 TJ of primary energy per year. The combined bagasse and BMW biomass supply could range from 252 - 445 ton per day over a period of 4 months.[67] In opting for use of sugarcane as a fuel, combined with BMW, the energy supply potential is between 983 – 3,180 TJ of primary energy per year, with a feed of 1,203 – 2,216 tons per day over a period of 4 months.[68] Note that these values are based on the limited available waste data from 2004 and assume historical sugarcane production ranges. In addition the energy potential is expressed as primary energy—this means that the value is based on the energy content of the biomass resource. An assessment of the energy potential for ethanol or electricity must take into account that each conversion technology has its own energy conversion efficiency, which will bring down the energy output, whether it is ethanol or electricity.

Ethanol production potential?

In a study by Lucon et. al (2006)[69], estimations on ethanol production were made based on a yield of 60 ton/ha, that resulted in the need for about 8,000 ha of land to build a 0.5 million ton per year (9-10 Mgallon/yr) ethanol processing plant. This was considered the standard minimum commercial feasible ethanol capacity size.

In the case of St. Kitts, it is known that the available lands are 2,428 ha (6,000 acres), with yields of 60.6 ton/ha (24.5 ton/acre). To produce enough sugarcane to come to this minimal standard ethanol plant capacity, the yield should at least improve to 198 ton/ha,

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[67] For the bagasse amount an assumption is made on the operation or running time of 120 days (harvesting period) * 24 h * 0.8 (load factor) = 2304 h/yr (96 days/yr), for the BMW since this is not depending on seasonal harvesting is assessed using 365 days * 24 h * 0.8 (load factor) = 7008 h/yr (292 days/yr)

[68] For the sugarcane amount an assumption is made on the operation or running time of 120 days (harvesting period) * 24 h * 0.8 (load factor) = 2304 h/yr (96 days/yr), for the BMW since this is not depending on seasonal harvesting is assessed using 365 days * 24 h * 0.8 (load factor) = 7008 h/yr (292 days/yr)

[69] Article by Lucon and Goldemberg, E-10 for the Caribbean, 2006.

or a combination of several optimization options should be implemented. This describes the challenge confronting St. Kitts, where innovative or creative means should be investigated to come to feasible and optimal use of the available biomass resources.

4. Sugar and Ethanol Market Analysis

There are several factors that influence the bio-energy market potential on St. Kitts. The price of the agricultural product (in this case sugarcane to sugar) largely determines whether or not farming activities are economically feasible. Agricultural prices affect the claims made on land for agricultural purposes, as does the demand for land for other functions such as infrastructure, industry, housing, and ecological preservation. The productivity of agricultural activities—the average production per hectare—is subject to environmental standards, economic criteria, and the availability of capital and infrastructure.

In this chapter an extensive analysis is conducted on the sugar market for which the St. Kitts' sugar industry depends. Since this study investigates the bio-energy development potential on St. Kitts, the bio-fuel/energy market is also analyzed.

4.1 Costs of Production

In 2004, St. Kitts' sugar industry costs were among the highest in the Caribbean (see Figure 4.1). The sugar production cost at the St. Kitts Sugar Manufacturing Company (SSMC) was US\$871.3 per ton of sugar, this is equal to about 2.38 US$_{2004}$/gallon of sugar.[70]

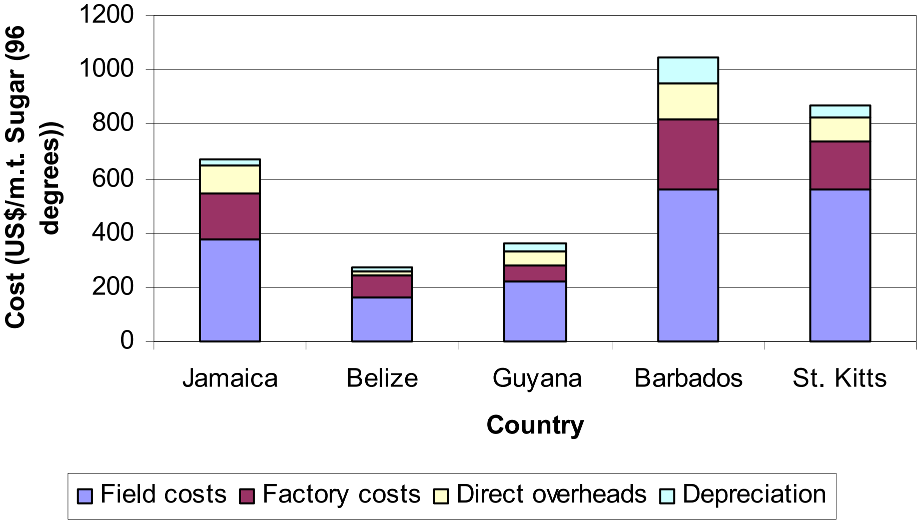

Figure 4.1. Cost of Sugar Production in the Caribbean in 2004.[71]

According to the Sugar Association of the Caribbean, the field costs (shown in purple in the above graph) represent the largest portion of the overall sugar production costs. In 2004 this field cost was about US\$557.8 per ton of sugar, representing 64% of the total. See Appendix B for more detail. The factory costs represent the cost of the conversion of

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[70] Density of sugar (721 kg/m^3 or 0.00273 ton/gallon)

[71] Source: Costs Statistics 2004, Sugar Association of the Caribbean (SAC).

the sugarcane into sugar; this cost was US$176.0 per ton of sugar and accounted for 20% of the total sugar production cost.

Thus, it is important to find alternatives to optimize the sugarcane production (field costs) to bring down the sugarcane feedstock production. When considering biomass-to-energy conversion systems, the general aim is to realize lower sugarcane-to-energy conversion costs to achieve lower output production costs.

4.2 Sugar Market

Sugar industries in the Caribbean islands depend almost entirely on the preferential European Union (EU) Sugar Protocol quota, the U.S. Tariff Rate Quota (TRQ), and the CARICOM Common External Tariff Agreement. More than 90% of the sugar produced in St. Kitts was exported to these markets, with the EU market being the largest. Simultaneously, there have been inter-related developments in the world sugar market that have played a significant role in the opportunities for Caribbean sugar industries. Important developments include the reform of the EU Sugar Protocol, the Central America Free Trade Agreement (CAFTA), and the Caribbean Basin Initiative (CBI)—together with the recent world sugar price increases, which affected the trade of goods in the Caribbean. To create a clear overview of the impacts of these developments, a brief description is provided on the status and projections of raw sugar prices related to St. Kitts and Nevis.

ACP-EU Sugar Protocol[72]

This agreement, signed in 1975, guarantees access to the EU market for fixed quantities of African, Caribbean, and Pacific (ACP) sugar at preferential prices over an indefinite period of time. St. Kitts and Nevis' latest ACP-EU raw sugar quota was 16,946.6 tons of raw sugar equivalent (2004/05).[73] As a result of the EU Sugar Protocol reform in 2005, the EU sugar price was to be reduced over the period 2006 to 2010 (see Table 4.1 for more detail). The raw sugar price was projected to decrease from US$671.9/ton to US$429.8/ton of sugar. This decrease in raw sugar prices is expected to create a loss in revenue of US$599,372,130[74] for the sum of all the ACP countries over the period 2006–2010.

Table 4.1 Future Changes in Price for ACP raw sugar.[75]

Year	Price (US$/ton)	% change (cumulative)
2005/06	671.9	0
2006/07	637.4	-5.10%
2007/08	637.4	-5.10%
2008/09	557.0	-17.10%
2009/10	429.8	-36.00%

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[72] African, Caribbean and Pacific Sugar Group website: http://www.acpsugar.org/Sugar%20Protocol.html.

[73] In July 2005, St. Kitts & Nevis officially closed their sugar industry, resulting in the discontinuation of the ACP-EU sugar quota of 16,946 tons of raw sugar equivalent; see http://agritrade.cta.int/sugar/executive_brief.htm.

[74] Conversion rate of 1 EUR = 1.28247 USD (December 2006)

[75] Extracted and modified from http://agritrade.cta.int/sugar/executive_brief.htm.

For St. Kitts and Nevis the loss over the period 2005–2010 would have represented a 36% decrease in revenues from the 2004/05 income of US$11,382,896.[76] This loss in revenue was deemed unsustainable and largely contributed to the closing down of the sugar industry.

U.S. Tariff Rate Quota[77]

The United States Department of Agriculture (USDA) issues sugar quotas under the TRQ system on a country-by-country basis. Under this system raw sugar is allowed into the U.S. duty-free. The current (2006/07) raw sugar allocation for St. Kitts and Nevis is 7,258 metric tons of raw sugar,[78] equal to the allocation for the 2004/05 period.[79]

The U.S. sugar market is controlled by the U.S. Federal Government. The quantity of sugar available in the domestic U.S. market is controlled by restricting the amount of sugar that foreign countries can export into the U.S. through TRQs or import quotas, and by limiting domestic sales through marketing allotments.[80] By balancing supply and demand through marketing allotments and import quotas, prices for U.S. sugar growers and processors are supported at economically viable and stable levels. Figure 4.2 provides a comparison of the U.S. and world raw sugar price trends.

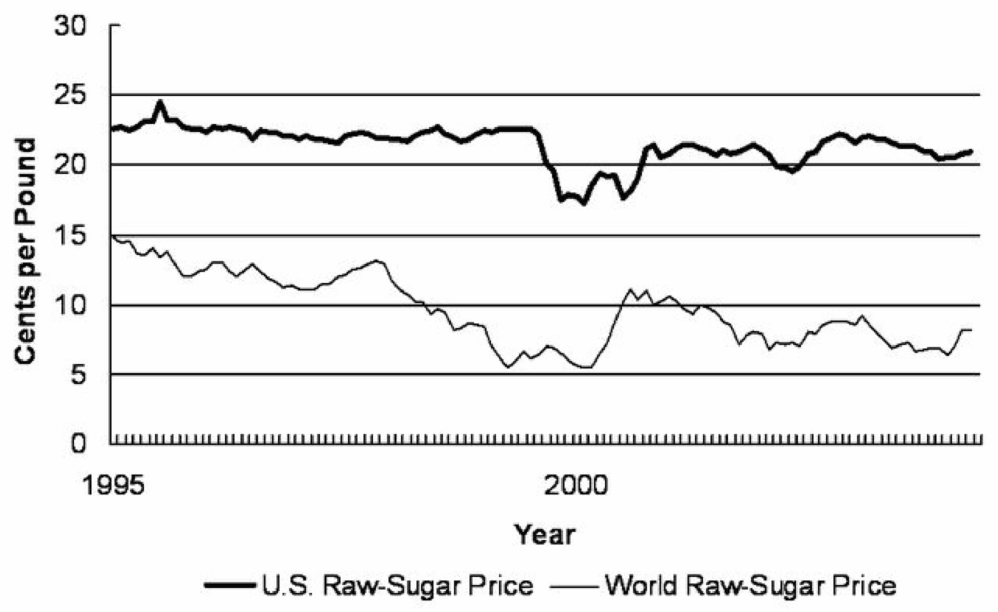

Figure 4.2 U.S. Raw Sugar Prices from 1996 to 2004.[81]

In 1999/2000 the U.S. sugar supply increased, primarily because of amplified domestic production, resulting in an oversupply of approximately 300,000 to 400,000 tons. The effect of the oversupply was immediately noticeable. In July of 1999, raw cane-sugar

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[76] Agro-trade website, See http://agritrade.cta.int/sugar/executive_brief.htm.

[77] Guyana Sugar Corporation website: http://www.guysuco.com/about_gsc/gsctoday/sugar_agreements/default.asp.

[78] U.S. Info State Government website: http://usinfo.state.gov/xarchives/display.html?p=texttransenglish&y=2006&m=August&x=20060803145244xjsnommis0.7426416.

[79] Source: Federal Register, Vol. 69, No. 147; Monday, August 2, 2004; Notices.

[80] This limits the amount of domestically produced sugar that can be marketed.

[81] Schmitz et al., CAFTA and US sugar, University of Florida website: http://edis.ifas.ufl.edu/FE578.

prices were 22.61 cents per pound (US$498.5/ton), however, by November of this year they had dropped to 17.45 cents per pound (US$384.7/ton), a price decline of 22.8%. This implies that an oversupply from either domestic production or increased imports can reduce the U.S. sugar market prices significantly.

In 2004 U.S. raw sugar price was about US$0.21/pound (US$462.6/ton), considerably lower than St. Kitts' US$871.3/ton sugar production cost. Therefore, the U.S. sugar market was not a realistic commercial opportunity for St. Kitts.

DR-CAFTA

In August 2005, the United States-Dominican Republic-Central America Free Trade Agreement (CAFTA) became Public Law in the United States. CAFTA is a trade agreement between the U.S. and Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and the Dominican Republic (DR) under which approximately 80% of U.S. exports immediately reach those markets duty-free, while tariffs on the remaining 20% will be phased out during the subsequent decade. Duties on U.S. imports originating from Central American/Caribbean countries other than those signing the Treaty will not be drastically reduced as they are already incorporated under the Caribbean Basin Initiative.

For sugar, the DR-CAFTA establishes preferential in-quota quantities for each of the qualifying countries, starting at an aggregate 107,000 metric tons in year one (compared to the TRQ for DR in 2004/05 of 185,335 tons[82]), and growing to about 151,000 metric tons in year fifteen; thereafter it grows by 2% annually. The total increase in the DR-CAFTA countries' access to the U.S. sugar market is about 1.2% of U.S. consumption in the first year, growing to about 1.7% in year fifteen. Despite the slight relative increase in the in-quota quantities established by the DR-CAFTA for each of the signing countries, the U.S. did not cut its over-quota duty on imported sugar—prohibitive at over 100% percent, it is one of the highest tariffs in the U.S. tariff schedule.[83] Under the agreement, the U.S. is allowed to compensate signing sugar-exporting countries when the country finds that a limit of sugar imports is necessary for stock management purposes.[84]

The impact of the DR-CAFTA on the U.S. sugar market is controversial. As outlined above, the U.S. has a protectionist policy towards the sugar sector, with a program that combines TRQs, import restraints, marketing allotments, and preferential loans to maintain the commodity's domestic price. But even with the sugar program in place, the American sugar lobby fears major price decreases, alleging that the market has already been over-supplied.[85] On the other hand, proponents of the agreement argue that DR-CAFTA will not have any destabilizing effects on the U.S. sugar market, both because the increase in sugar supply provided by signing countries will be relatively insignificant (compared to the consumption of sugar in the U.S.), and because the current sugar program provisions include a cushion of 1.4 million metric tons of total imports allowing

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[82] Source: Federal Register / Vol. 69, No. 147 / Monday, August 2, 2004 / Notices

[83] Office of the United States Trade Representative, Fact Sheet on Sugar in CAFTA-DR (2005), see: http://www.ustr.gov/Document_Library/Fact_Sheets/2004/Fact_Sheet_on_Sugar_in_CAFTA-DR.html.

[84] Marheim, D., The Heritage Foundation, see: http://www.heritage.org/Research/TradeandForeignAid/bg1868.cfm.

[85] U.S. Sugar Industry, January 2004, see: http://www.smbsc.com/why_the_united_states_sugar_indu.htm.

for stated marketing allotments.[86] Therefore one can conclude that since the increased import of sugar from the DR-CAFTA countries is matched by a reduction of the internal production (via marketing allotments) or an increase of the demand, the influence on the U.S. sugar price will be limited. The fact remains that as long as the U.S. price per ton remains lower than St. Kitts' production costs, this equates to no market opportunity.

CARICOM Common External Tariff Agreement (CET)

Under the Caribbean Community and Common Market (CARICOM), the Common External Tariff (CET) was established to protect certain products (including sugar) produced in the region. In the case of brown (raw) cane sugar, a 40% duty was imposed for extra regional sources. This duty in effect allows sugar-producing countries that have surplus sugar available within the Common Market to assist with meeting the intra-regional requirements at competitive prices. This agreement functions the same as the EU system, where the regional sugar producers are protected against external sugar supply. However, the CET does not benefit St. Kitts because (1) the demand for sugar within the region does not exceed individual countries' ability to supply their own needs; and (2) as one of the most expensive sugar producers in the Caribbean, even without a duty, opportunities for intra-regional exports from St. Kitts and Nevis are limited.

World raw sugar price fluctuations

An interesting development in recent years is the increase in world raw sugar prices (see Figure 4.3). From January 2004, the price increased from approximately US$0.06/pound (US$132.2/ton) to US$0.18/pound (US$396.5/ton) in January 2006—an increase of about 200% over two years. However, 2006 data from the New York Board of Trade (NYBOT)[87] indicates that the world sugar price has dropped again to levels below US$0.12/pound (see Figure 4.4).

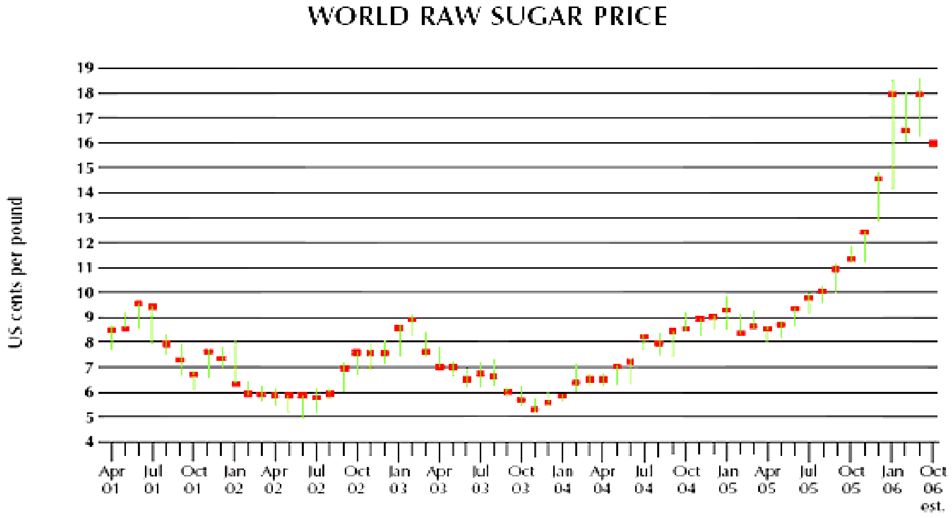

Figure 4.3. World Raw Sugar Prices, April 2001 to January 2006.[88]

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[86] Office of the United States Trade Representative, Fact Sheet on Sugar in CAFTA-DR (2005), see: http://www.ustr.gov/Document_Library/Fact_Sheets/2004/Fact_Sheet_on_Sugar_in_CAFTA-DR.html.

[87] Source: New York Board of Trade (NYBOT), http://www.nybot.com/.

[88] Source: http://www.illovo.co.za/worldofsugar/internationalSugarStats.htm

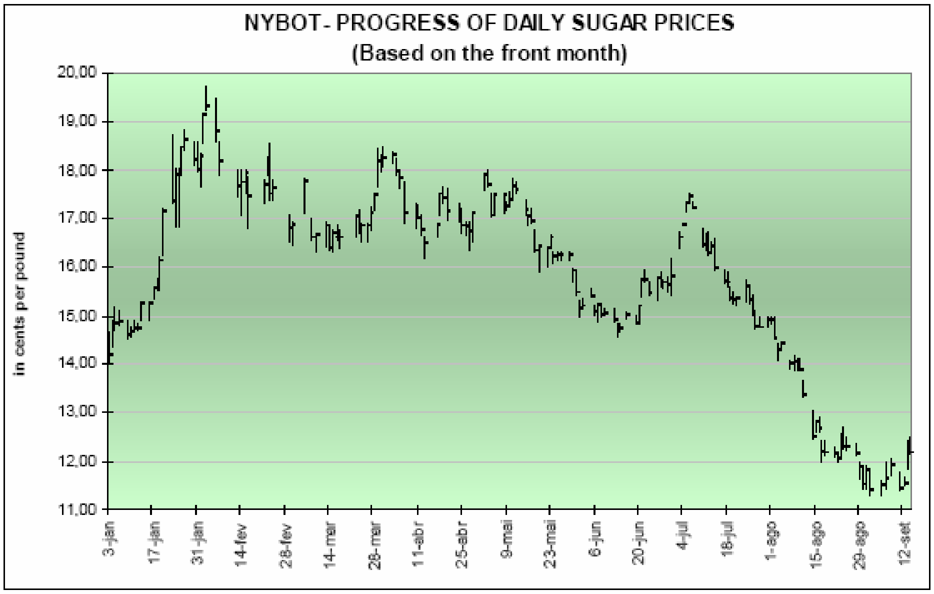

Figure 4.4. Daily Sugar Price Development, January to September 2006 (NYBOT).

At the end of 2004, the global raw sugar price was about US$0.085/pound, which is equal to US$187.4/ton of raw sugar and, as with the U.S. raw sugar market price, the global price is much lower than the sugar production cost of US$871.3/ton in 2004 on St. Kitts.

4.3 Ethanol Market

U.S. ethanol market

Recent bio-energy developments in the Caribbean have been mainly focused on producing ethanol for export to the United States. The Caribbean Basin Initiative (CBI), initially launched in 1983 and expanded in 2000 until September 2008[89], is intended to facilitate the economic and export diversification of countries in the Caribbean region. The CBI provides 24 beneficiary countries, including St. Kitts and Nevis, with duty-free access to U.S. markets for most goods produced in the beneficiary country.

The agreement allows countries covered under the CBI to export dehydrated ethanol produced by foreign feedstock (including hydrous ethanol from a third country) into the U.S. duty-free, equaling up to seven percent of total U.S. ethanol production (which was about 4,288 million gallons in 2005[90]), thus an amount of 300 million gallons. Beyond this, an additional 35 million gallons can be imported into the U.S. duty-free, provided that at least 30% of the ethanol is derived from local feedstock. Anything above the additional 35 million gallons is duty-free if at least 50% of the ethanol is derived from local feed stocks.[91]

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[89] Caribbean Basin Initiative website: http://www.mac.doc.gov/CBI/FAQs/faqcbi-all.htm#Five.

[90] Hunt, S. and Forster, E., "Biofuels for transportation: global potential and implications for sustainable agriculture and energy in the 21st century", online at http://www.renewable-energy-world.com/display_article/271573/121/ARCHI/none/none/Biofuels-for-transportation:-Global-potential-and-implications-for-sustainable-agriculture-and-energy-in-the-21st-century/

[91] *Ethanol Today,* "Ethanol Import Debate Looms." April 2005.

U.S. ethanol imports over the period 1999 to 2005 (see Figure 4.5) show a considerable increase in imports from Brazil in 2004 and 2005. U.S. ethanol imports from the Caribbean Basin (Central America and Caribbean islands) in 2005 represented about 55% of the country's total ethanol imports (about 100 million gallons). Brazil's hydrated ethanol exports to the Caribbean in 2005 totaled US$60,584,467 (161,932,354 kg).[92]

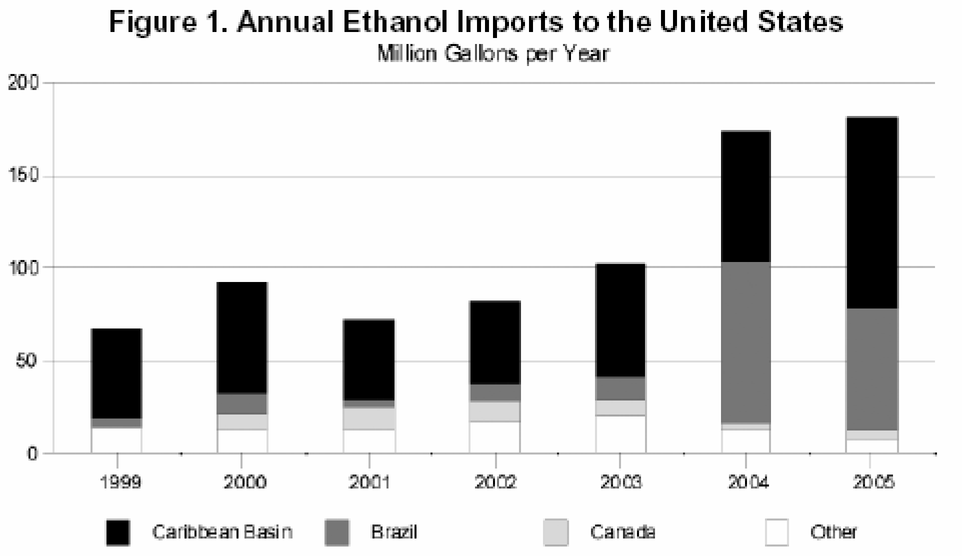

Figure 4.5. Annual Ethanol Imports to the United States (Million Gallons per Year).[93]

In the Caribbean and Central America, there are currently four countries that supply ethanol to the U.S. market (see Table 4.2.): Jamaica, Costa Rica, El Salvador, and Trinidad and Tobago. Together they supplied 45.5 million gallons in 2002. By the year 2005, total ethanol exports from the region to the U.S. equaled 103.4 million gallons. [94] This amount only covered about 34% of the 300 million gallons allowed to be exported to the U.S. in the year 2005. It is estimated that about 86% of the Caribbean export was based on Brazilian sugar, amounting to about 39.8 million gallons.[95] It should be noted that up to the year 2005 all the dehydrated ethanol produced in Jamaica was made of imported hydrated ethanol from Brazil. However, sugarcane is abundantly grown in Jamaica and will eventually be used in the production of ethanol.

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[92] Minister for Development, Industry and External Commerce, Brazil, see: www.mdic.gov.br.

[93] U.S. International Trade Commission, Interactive Tariff and Trade DataWeb, at *http://dataweb.unitc.gov*, March 9, 2006.

[94] Renewable Fuels Association. 'Industry Statistics' www.ethnolrfa.org/imdustry/statistics/#F.2006.

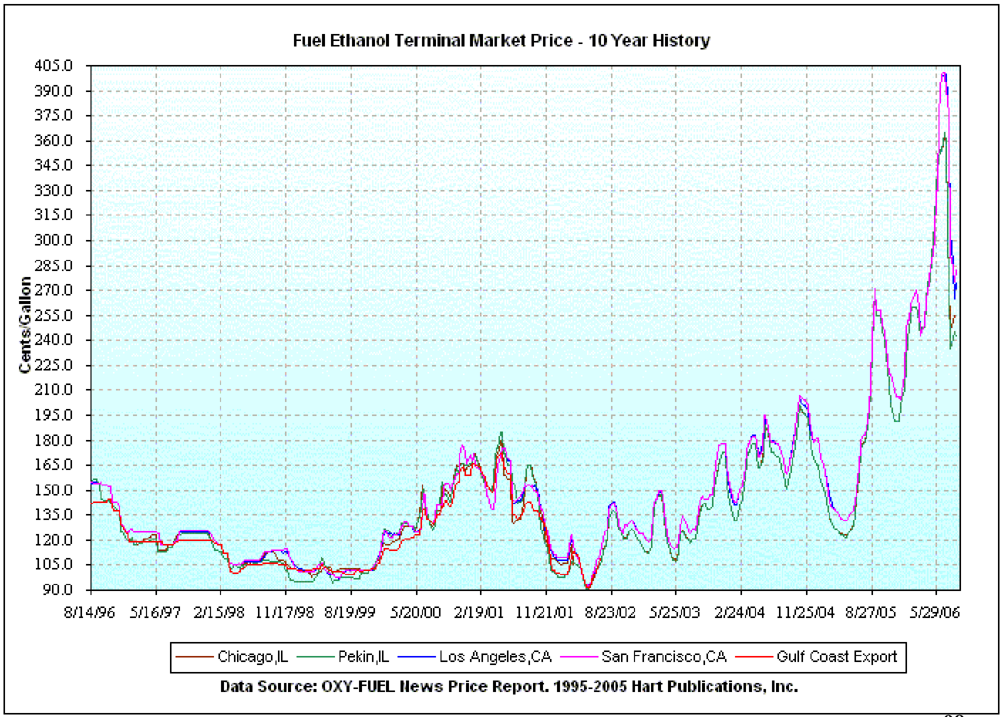
[95] "Crushing Moves to 64% from the Crop in the Center-South," Sugar and Ethanol Bi-weekly Newsletter on Market Trends, Safras & Mercado, September 2006: www.nybot.com/.../workshops/analytics/sugandethbiwkly/pdfsugar&**ethanol**biweeklyjeffjudygeneral091806.htm.

Table 4.2. Ethanol Exports to the U.S. 2002-2005 (millions of gallons).[96]

Country	2002	2003	2004	2005
Costa Rica	12	14.7	25.4	33.4
El Salvador	4.5	6.9	5.7	23.7
Jamaica	29	39.3	36.6	36.3
Trinidad & Tobago	0	0	0	10
Total	**45.5**	**60.9**	**67.7**	**103.4**

U.S. ethanol market price

The U.S. and Brazil are the two major producers and consumers of ethanol. The U.S. has the largest demand, and therefore market share, and influence on the global bio-ethanol price development. Figure 4.6 depicts the ethanol market price development at different terminals in the U.S. for the 10-year period 1995–2005. Figure 4.6 demonstrates the volatility of ethanol prices, with particularly large fluctuations in recent years. Even with these fluctuations, however, an increasing ethanol price trend is observed. The most recently available ethanol prices (from 1st quarter 2007) range between US$1.90-2.40 per US gallon, see figure 4.7[97].



Data Source: OXY-FUEL News Price Report. 1995-2005 Hart Publications, Inc.

Figure 4.6. Fuel Ethanol Terminal Market Price: 10-Year History.[98]

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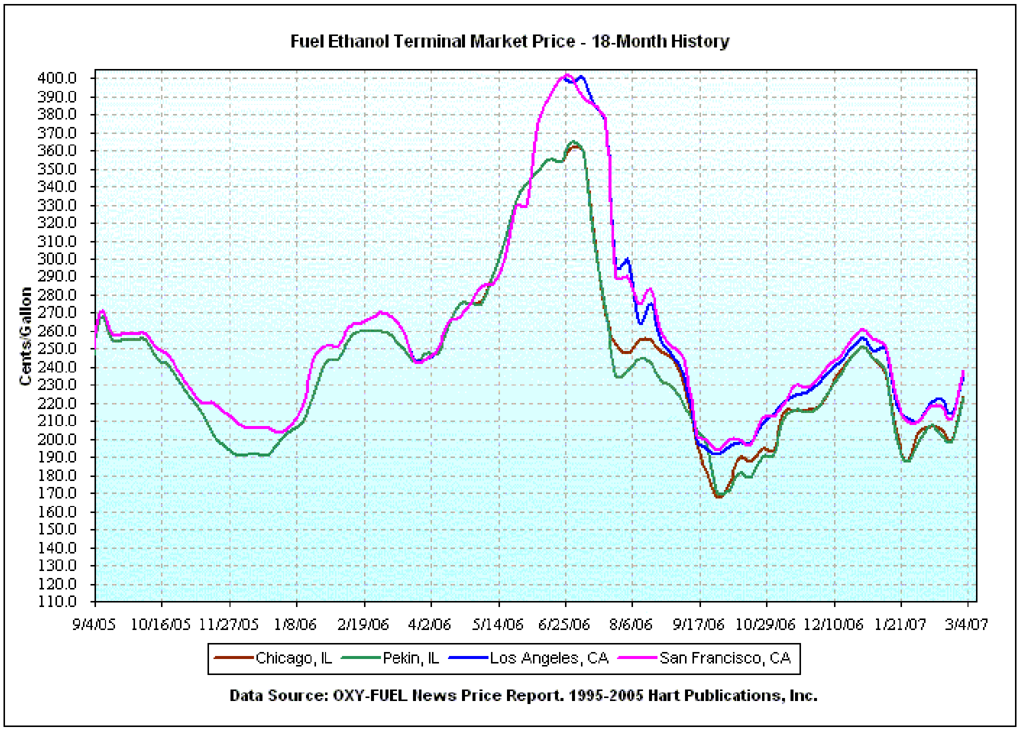
[96] Renewable Fuels Association. 'Industry Statistics' www.ethnolrfa.org/imdustry/statistics/#F.2006.

[97] California Energy Commission, see: www.energy.ca.gov/gasoline/graphs/ethanol_18-month.html

[98] California energy commission web page: http://www.energy.ca.gov/gasoline/index.html.


Fuel Ethanol Terminal Market Price - 18-Month History

Data Source: OXY-FUEL News Price Report. 1995-2005 Hart Publications, Inc.

Figure 4.7 U.S. Ethanol Market Price Over the Last 18 Months

The ethanol market price has fluctuated between US$1.70-4.00 per gallon over the last 18 months period. This indicates the very volatile price of ethanol on the U.S. market.

U.S. and Brazilian ethanol production cost

In the U.S. there are two main processes that convert corn into ethanol, the wet or dry milling. The 2003-2005 average ethanol production cost in the U.S. for wet milling was 1.03 US$/gallon, for the dry milling process the cost was 1.05 US$/gallon. In the case of Brazil, the 2003-2005 average sugarcane based ethanol production cost was 0.81 US$/gallon.[99] This production cost is much lower than the U.S. ethanol. The U.S. implements therefore a 54-cent per gallon tariff on imported Brazilian ethanol. This makes the price to increase to 1.35 US$/gallon. There are recent (March 2007) indications that this 54-cent per gallon tariff may be eliminated by 2009.[100]

To remain at the conservative end, the ethanol production cost on St. Kitts will minimally have to comply with the lowest end of the ethanol market value range, thus a value of 1.90 US$/gallon.

It would appear that in the Caribbean Basin the ethanol production potential is not being optimally utilized—there is plenty of room for future ethanol production and export.[101]

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[99] Shapouri et al., *The economic feasibility of ethanol production from sugar in the United States,* U.S. Department of Agriculture, July 2006.

[100] Speech by former governor of Florida, J. Bush at the Interamerican Development Bank (IDB) briefing on biofuels development for the Latin American and the Caribbean region, IDB Headquarters, April 02 2007.

[101] For 2005, up to 283.4 million gallons are allowed to enter the U.S. market through CIB, while the ethanol production in the Caribbean and Central America in 2005 was only 103.4 million gallons of ethanol.

In addition, because of the high volatility of the ethanol market prices it is very difficult to assess the future ethanol prices. The increasing trend in ethanol market values can provide some security for Caribbean countries to develop an ethanol export industry but has to be assessed very carefully. For St. Kitts and Nevis, the potential to take advantage of this opportunity and export ethanol to the U.S. will depend on the ethanol production capacity and the resulting production cost.

EU ethanol market

The ethanol production in 2005 for the EU was estimated to be 950 million liters (251 million gallons), this accounted for about 2.6% of the total production of 35,980 million liters (9,506 million gallons) by the top five ethanol producing countries in the world (Table 4.3).

Table 4.3. Top Five Fuel Ethanol Producers in 2005[102]

Producer	Ethanol production (Million liters)
Brazil	16,500
United States	16,230
China	2,000
European Union	950
India	300

The EU has established very aggressive targets for increasing the use of bio-fuels. The EU is motivated by multiple goals including improving domestic energy security, improving the overall CO_2 balance, complying with the Kyoto Protocol, and sustaining economic competitiveness.[103] Bio-fuels account for about 1% of overall transportation fuels in the European continent. Bio-diesel production has been dominant over ethanol (representing 80% of bio-fuels), despite that fact the EU has recognized ethanol "as a leading contender to complement and replace gasoline as an energy source."[104]

Figure 4.8 offers a comparative overview of the gross feedstock cost per liter of ethanol in the U.S., EU (France), and Brazil in 2004. The general biomass feedstock in the EU is the sugar beet. The average feedstock cost of sugar beet in France and corn in the U.S. were in the same range, at about US$0.25/liter (US$0.95/US gallon) and US$0.24/liter (US$0.91/US gallon) respectively. In comparison, Brazil's average sugarcane feedstock cost was US$0.08/liter (US$0.30/US gallon)—approximately 33% of EU and U.S. costs.

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[102] Hunt, S. and Forster, E., "Biofuels for transportation: global potential and implications for sustainable agriculture and energy in the 21st century", online at http://www.renewable-energy-world.com/display_article/271573/121/ARCHI/none/none/Biofuels-for-transportation:-Global-potential-and-implications-for-sustainable-agriculture-and-energy-in-the-21st-century/

[103] Bio-Fuels in the European Union: A Vision 2030 and Beyond. Final draft report of the Bio-Fuels Research Advisory Council. 03/14/2006.

[104] United Nations Conference on Trade and Development (UNCTAD).

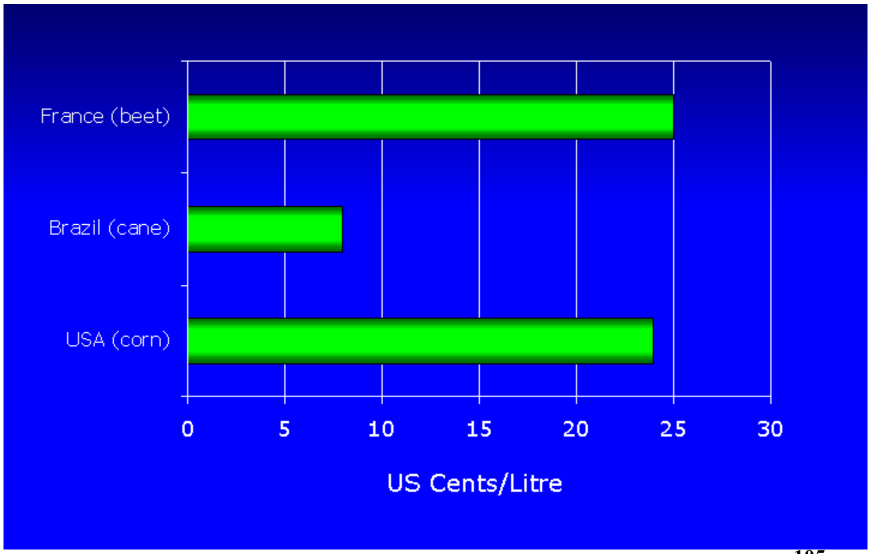

Figure 4.8. Gross Feedstock Cost per Liter of Ethanol.[105]

The policy objectives that compose the EU's bio-fuel strategy include enhancing trade opportunities and pursuing a balanced approach in trade talks with ethanol-producing countries. This bodes well for St. Kitts and Nevis. The EU exempts African, Caribbean, and Pacific (ACP) countries from import duties on ethanol (and other goods), whereas other regions have to pay US$0.10/liter. Further, for those countries in the ACP that were affected by the EU sugar reform, a special Bio-Fuels Assistance Package has been established. This package makes available financial assistance for redevelopment of domestic sugar production by enabling eligible countries to examine how best to target bio-fuel platforms.[106]

One of the EU's objectives is to displace oil consumption of member countries with bio-fuels by 5.75% in the transport by 2010, and 25% by 2030. However, objectives aside, local producers of the EU countries face high costs to produce bio-ethanol. Further, it is estimated that between 4% and 13% of the total European agricultural land would be necessary to reach the EU bio-fuels initiative goals.[107] This presents a great challenge for the EU. Even with the ability/willingness to make large-scale investments to comply with its objectives, the EU will certainly need to import ethanol.

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[105] Christoph Berg, "World Fuel Ethanol: Analysis and Outlook," April 2004.

[106] "Commission urges new drive to boost production of bio-fuels." Brussels, 8 February 2006. European Commission Web site.

[107] Bio-Fuels in the European Union: A Vision 2030 and Beyond. Final draft report of the Bio-Fuels Research Advisory Council. 03/14/2006.

5. Power, Transport and Waste Management Sector on St. Kitts

To stimulate economic growth, it is imperative for a country like St. Kitts and Nevis to provide access to reliable and affordable energy services. This section offers a brief overview of the energy and transportation sector challenges on the island. The current and future demand projections of the energy and transport sectors of St. Kitts are described to identify specific bio-fuel/energy needs. In addition, the waste management sector is reviewed. Finally, general conclusions are discussed and the rationale for a possible St. Kitts biomass-to-energy assessment is provided.

5.1 General Energy Sector Information

In St. Kitts there is one utility that manages the production, transmission, and distribution of electricity. The St. Kitts Electricity Department (SKED) is a state-owned utility with installed power production capacity of 33.5 MWe (as of 2006).

Needmust power plant

The SKED operates one power plant, the Needmust power plant, which contains seven diesel No. 2 fuel oil-fueled generators. The generators range in size from 3.5 MW to 7.9 MW in capacity. The oldest units were installed in 1971 and the most recent in 1999. Table 5.1 below provides information regarding the basic characteristics of each of the units.

Table 5.1. Generating Unit Information at St. Kitts Electricity Department.[108]

Unit	Diesel type	Capacity (MWe)	Installation year	2005 Electricity production (MWh)	Capacity factor[109]	2005 Fuel Consumption (kWh/IG[110])
#1	Mirrlees KV12	3.6	1971	6,381	0.20	15.1
#2	Mirrlees KV12	3.6	1971	7,943	0.25	14.7
#3	Mirrlees K8	3.5	1987	19,803	0.65	17.9
#4	Caterpillar 3616 (#1)	4.4	1989	13,630	0.35	13.6
#5	Caterpillar 3616 (#2)	4.4	1995	10,979	0.28	17.3
#6	Mirrlees 12MB430	7.9	1999	23,326	0.34	19.0
#7	Mirrlees 8MB430	6.1	1999	42,680	0.80	19.2
Total		**33.5**		**124,741**	**0.43**	**17.4**

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[108] Extracted and adapted from: de Cuba, K.H., "Towards a Sustainable Energy Plan for Saint Kitts and Nevis," Utrecht University, 2006.

[109] Capacity factor = electricity production [GWh] / (installed capacity [MW] * 365[days]*24 [hr])

[110] IG = Imperial Gallons or UK gallons (1 Imp. Gallon = 1.201 U.S. gallon)

Table 5.1 shows that the SKED's total electricity production in 2005 was 124,741 MWh. This electricity is transmitted via two busses, an 11.2 and an 11.4 kV, to the national grid. The average capacity factor of the power plant was 0.43 with an average fuel consumption rate of 17.4 kWh/imperial gallons (IG) (14.5 kWh/US gallon). The capacity factor is the ratio of the actual energy produced in a given period to the hypothetical maximum possible, e.g. running full-time at rated power.[111]

The total fuel consumption at the Needmust power plant in 2005 was 7,156,452 IG[112] (204,632 US barrels[113]). The fuel that is used for electricity production is Diesel 45 Cetane 0.5% Sulfur fuel oil No. 2—also referred to as "Gasoil."[114] The diesel fuel in 2005 was supplied by TEXACO West Indies Limited (Texaco) located in Trinidad and Tobago and had an average price of EC$5.91/Imp (US$1.82/US gallon) in 2005. There is no clear view on the current supply chain and what the impacts are of the PetroCaribe treaty that Federation of St. Kitts and Nevis has signed in 2005. (See Appendix C for more detail.

Based on the 2005 power plant performance information, the overall load factor is calculated to be 0.71[115] and the overall energy efficiency 0.35.[116] The generated electricity is distributed among three categories: Domestic, Commercial/Industrial, and General Supplies. Figure 5.1 provides the relative consumption per sector.

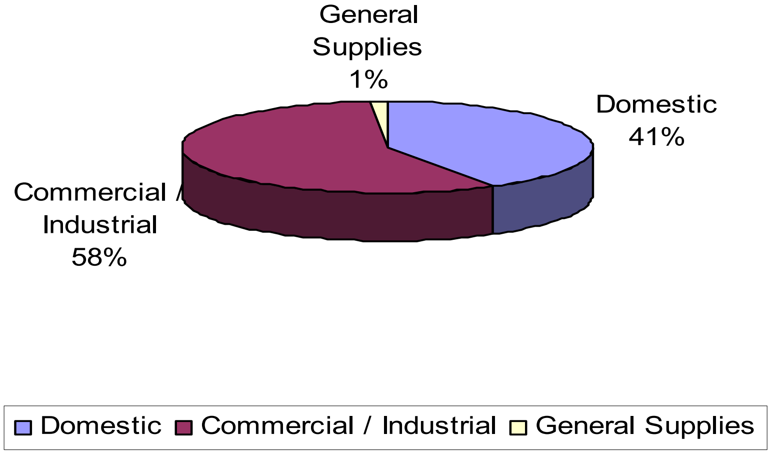

Figure 5.1. Relative Electricity Consumption per Consumer Category on St. Kitts in 2004 (St. Kitts Electricity Department, 2005).

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[111] Renewable Energy Research Laboratory, University of Massachusetts, *Wind Power: Capacity factor, Intermittency, and what happens when the wind does not blow*, Amherst.

[112] "Needmust Gensets Performance Indicators 2005," St. Kitts Electricity Department (2006).

[113] 1 UK gallon = 0.02859 U.S. barrels; source: UNEP Guidelines for Calculating GHG Emissions, http://www.uneptie.org/energy/publications/files/ghgind.htm.

[114] A gas oil type distillate of lower volatility with distillation temperatures at the 90 percent boiling point between 540 and 640° F. No. 2 distillate meets the specifications for No. 2 heating or fuel oil as defined in ASTM D396 and/or specifications for No. 2 diesel fuel as defined in ASTM Specification D975; source: T. Lidderdale, EIA, 1993.

[115] Load factor = Electricity production / Peak demand = 124,741 MWh / (22.0 MW * (365 * 24 h)) = 0.71

[116] Efficiency based on (7,156,452 Imp. Gallon * 4.546 L/Imp.Gallon * 36 MJ/L= 1171.2 TJp) and a electricity production of (124,741 MWh * 3.6 GJ/MWh = 449.1 TJe)

The total cost of generation in the year 2005 amounted to EC$60.5 million[117] (US$22.4 million), including fuel costs, O&M costs, and capital charge (see Figure 5.2). The electricity generation cost was EC$0.45/kWh (US$0.17/kWh).

Electricity

The calculation of the electricity rate is complicated. Two categories, the temporary and permanent supply are identified, and a standing charge[118] is added to the cost scheme provided below:

Temporary supply:
0.181 US$/kWh (0.49 EC$/kWh), with 2.22 US$ (EC$6.00) minimum for 0 – 12 kWh units per month.

Permanent supply:
0 – 50 kWh units at 0.119 US$/kWh (EC$0.32 per kWh). Up to 125 kWh units, 5.93 US$ (EC$16.00) for first 50 units + rest at 0.130 US$/kWh (EC$0.35 per kWh). Greater than 125 kWh units, 15.65 US$ (EC$42.25) for first 125 + rest at 0.137US$/kWh (EC$0.37 per kWh).

The standing charge per month component is calculated:
1 – 120 kWh units at 2.67 US$ (EC$7.20)
121 – 240 kWh units at 4.44 US$ (EC$12.00)
241 kWh plus units at 6.67 US$ (EC$18.00).

The electricity price (0.119 US$/kWh, when adding the standing charge and additional payments for higher consumers) is clearly subsidized for the permanent supply category, knowing that the generation cost is about 0.17 US$/kWh. This average electricity cost is compared to the 2005 average electricity price of US$0.0814/kWh[119] in the United States, much higher.

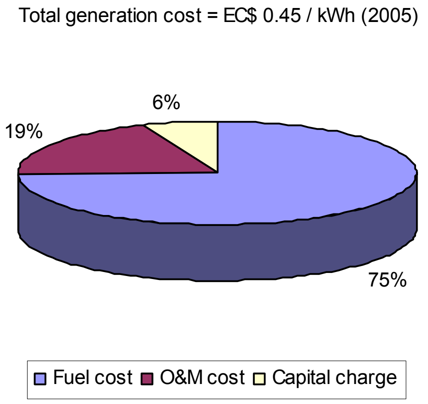

Figure 5.2. Relative Contributions of Production Cost Sources.[120]

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[117] "Generation Costs SKED & Effect of PetroCaribe 2006-2008," St. Kitts Electricity Department (2006).

[118] A standing charge is a fixed amount you pay for every day you are connected to a gas or an electricity network.

[119] U.S. Energy Information Administration. http://www.eia.doe.gov/cneaf/electricity/esr/esr_sum.html.

[120] Saint Kitts Electricity Department, "Generation Costs-SKED & Effect of PetroCaribe 2006-2008," 2006.

The electricity generation cost of EC$0.45/kWh (US$0.17/kWh) can be broken down into three main categories: the fuel cost, the O&M cost, and the capital charge. The contributions per category are 75%, 19%, and 6% respectively—see Figure 5.2. The fuel cost has a very large influence on the overall electricity generation cost.

Projected peak demand

Figure 5.3 shows the annual peak demand projection for the St. Kitts Electricity Department over the period 2005–2015. The peak demand in 2005 was 22.0 MW. Considering the baseline scenario (in dark blue), an annual peak demand of 36.9 MW is projected for 2015.

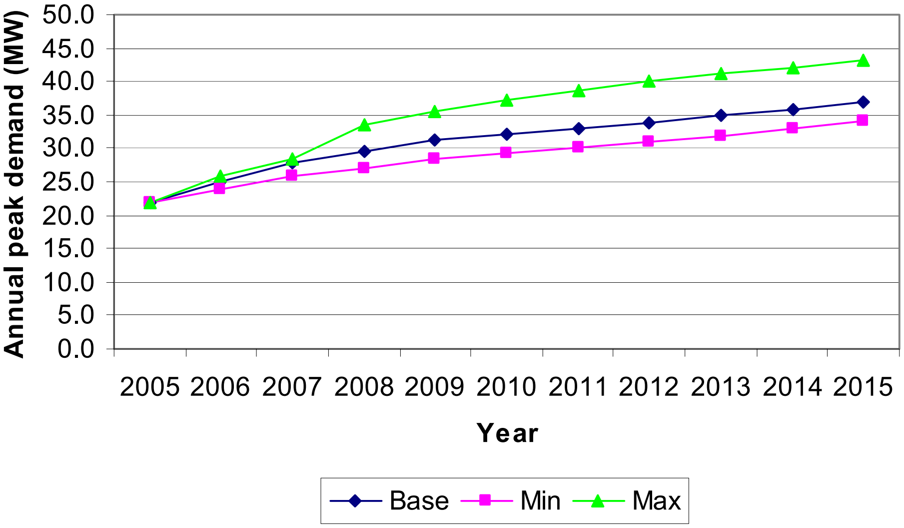

Figure 5.3. Projected Annual Peak Demand for St. Kitts, 2005-2015.[121,122]

A private consultant calculated the minimum and maximum demand projections for the above figure based on their own model. Their projection method was based on analyzing the energy demand of three sales categories (General, Domestic, and Commercial/ Industrial) and using three scenarios which vary the likelihood of implementation of future development projects.[123] The baseline is calculated based on projections made by the SKED[124]. In the above figure, through 2007, the growth in peak demand is relatively parallel for all scenarios. After 2007, the three scenarios deviate in annual peak demand growth rate, with the maximum scenario considering a large new hotel project and consequent growth of the economy.

Projected fuel consumption at SKED

Table 5.2 illustrates the SKED's expected fuel consumption for the years 2005–2008. Fuel consumption is expected to increase from 204,632 U.S. barrels to 243,869 U.S. barrels based on the baseline demand projections.

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[121] Source: Combination of St. Kitts Electricity Department (2006) extracted from de Cuba, 2006.

[122] Source: Generation Expansion Plan (2005-2015), St. Kitts Electricity.

[123] Stanley Consultants, Generation Expansion Plan for the St. Kitts Electricity Department (2005-2015), April 2005.

[124] Information from St. Kitts Electricity Department (2006) and partly extracted from, de Cuba, 2006.

Table 5.2. Projected Fuel Consumption and Electricity Production for the St. Kitts Electricity Department.[125]

Year	Fuel consumption (IG)	Fuel consumption (U.S. barrels)	Electricity production (MWh)[126]
2005	7,156,452	204,632	124,741
2006	7,745,463	221,443	161,814
2007	8,137,672	232,656	177,492
2008	8,529,881	243,869	187,883

Projecting the SKED's fuel consumption is essential in order to estimate the influence of the PetroCaribe treaty on the SKED's total fuel cost. In the summer of 2005, St. Kitts and Nevis signed the PetroCaribe treaty, which facilitates the importation of cheaper subsidized fuel oil from Venezuela to reduce fuel costs and consequently reduce electricity generation costs. Appendix C provides further details on the PetroCaribe treaty.

Fuel cost projections

Figure 5.4 projects the fuel price development of the imported fuel at SKED under variable conditions. The "reference" projection shows that in the period 2005–2009 the fuel price will decrease from US$76.6/US barrel[127] to a minimal level of US$62.5/US barrel.[128] From that point forward the projections show a steady increase in fuel oil price with an average increase of 0.8% per year. As of November 2006, the international price for No. 2 fuel oil was US$69.2/US Barrel,[129]—higher than the below projected baseline scenario—which suggests even higher prices in the future. Appendix D provides additional detail on the method used to calculate these projections.

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[125] Extracted and modified from St. Kitts Electricity Department, "SKED Information for SEP," 2006.

[126] The starting point for 2005 was 124,741 MWh; the projections to 2008 are based on the annual percentage increase calculated from the table "SKED Information for SEP,"; St. Kitts Electricity Department (2006).

[127] This value is based on the fuel price of EC$5.91/IG (2005) as registered at the St. Kitts Electricity Department.

[128] The projections are based on the international trends as projected by the EIA: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_m.htm

[129] Energy Information Administration website: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_m.htm

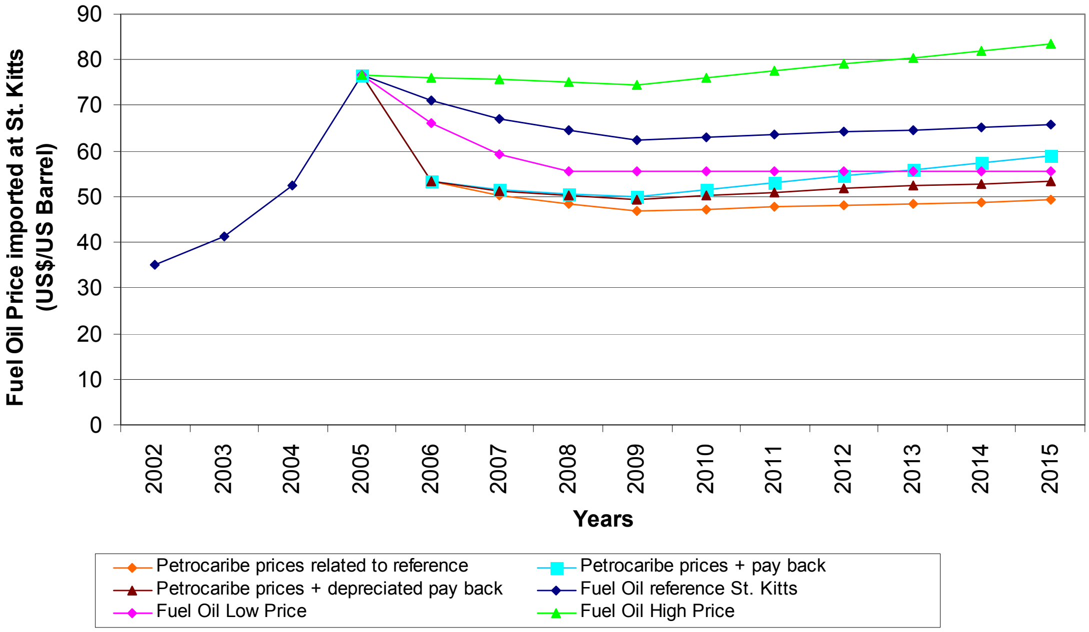

Figure 5.4. No. 2 Fuel Oil Price Forecast for St. Kitts, 2002 to 2015.[130]

The prices provided by PetroCaribe will be considerably lower in the short term due to subsidized financing. With respect to long-term financing, the payment period will stand at 17 years (which includes a two-year grace period) at 2% interest when the price is below US$40 per barrel; when the price is above US$40/barrel the payment period is extended to 25 years (with a two-year grace period) at 1% interest. Venezuela will also accept payment in the form of products or services. The question that remains is how the payback will be calculated. Figure 5.4 shows that there is a considerable difference in cost between a payback that is simply the yearly cumulative value of 1/25 of the payback (PetroCaribe + payback), and a payback that is depreciated at a rate of 10% (PetroCaribe + depreciated payback). The "PetroCaribe + payback" projection may have the long-term effect of creating higher fuel oil prices than the "reference" projection. Table 5.3 provides a summary of the projected annual fuel costs for the St. Kitts Electricity Department over the period 2005 to 2008.

Table 5.3. Fuel Oil #2 Cost Projections for SKED in Period 2005-2008

Fuel Oil #2 costs (US$)	2005	2006	2007	2008
Reference	15,664,403	15,735,032	15,593,836	15,730,918
Low Price	15,664,403	14,615,224	13,819,769	13,520,114
High Price	15,664,403	16,850,991	17,587,033	18,311,772
PetroCaribe price	15,664,403	11,801,274	11,695,377	11,798,189
PetroCaribe price + payback	15,664,403	11,801,274	11,955,274	12,332,794
PetroCaribe price + depreciated payback	15,664,403	11,801,274	11,931,647	12,240,011

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[130] Extracted and adapted from: De Cuba, K.H., "Towards a Sustainable Energy Plan for St. Kitts and Nevis," Copernicus Institute, Utrecht University, 2006.

As can be seen in table 5.3, the annual fuel costs could range between 11.8-16.9 MUS$ (2006), 11.9-17.6 MUS$ (2007), and 12.3-18.3 MUS$ (2008), thus indicating an overall increasing tendency in fuel costs.

Generation cost development

The cost of electricity generation at the St. Kitts Electricity Department for the year 2005 was approximately EC$0.45/kWh (US$0.17/kWh). As mentioned previously, the generation cost is composed of three main components: the cost of the fuel and its importation; operation and maintenance costs; and the capital charge. As illustrated in Figure 5.2, the cost distribution in 2005 was 75% for the fuel, 19% for the O&M, and 6% for the capital charge. An assessment of the future development of generation costs and the potential influence of the PetroCaribe prices on these costs must also take into account possible changes in each of the components of the generation cost. Several factors influence this cost distribution, such as expansion in capacity to meet increasing demand. Despite the reduction in oil prices realized by the PetroCaribe agreement, the increase in fuel costs during 2006 largely off-set the savings that may be projected. It is expected that the cost of generation, based on the existing diesel generation technologies used in St. Kitts and Nevis, will not fall—rather it will continue to rise in the coming years.

An accurate projection of generation costs is made difficult in part because the cost distribution (see Figure 5.2) among fuel, O&M, and capital charge costs does not remain constant every year. This is because as the fuel cost fluctuates, the O&M costs remain relatively unchanged, and the capital charge should decrease over time.

5.2 Transport Sector Baseline Information for St. Kitts

The transportation sector is the second largest energy-intensive sector in St. Kitts. This section provides an overview of the quantity and characteristics of the current car fleet present on the island of St. Kitts, the overall gasoline and/or diesel consumption amount, and prices. Table 5.4 shows that the total number of registered vehicles on the island of St. Kitts in the year 2005 was 12,217 vehicles.

Table 5.4. Registered Vehicles on St. Kitts (2005).[131]

Type of vehicle	Amount	Type of vehicle	Amount
Fire Appliances	11	Rental Cars	833
Herses	4	Rental Cycles	126
Lorries	243	Rental Jeeps	201
Motor Cycles	267	Rental Pick-ups	12
Motor Omnibuses	201	Taxi Buses	243
Motor Scooters	125	Taxi Cars	127
Others	131	Taxi Jeeps	28
Pick-ups	1,026	Taxi Pick-ups	11
Private Cars	5,645	Tractors	172
Private Jeeps	2,190	Vans	576
Rental Buses	45	**Total Vehicles**	**12,217**

There is a large variation in vehicle type in St. Kitts, each with different fuel requirements and tank capacities. The vehicle fleet consists primarily of cars manufactured during the 1970s and 1980s, and studies show that there is a possibility of mixing ethanol in up to 10% of the tank capacity for these vehicles without any negative impact on the vehicle engine's lifetime.[132]

The total imported amount of gasoline and diesel to the island of St. Kitts in 2005 was 3.3 million (MM) gallons and 9.1 MM gallons respectively (see Table 5.5). There is no significant use of the imported gasoline other than for transportation. Thus, an assumption can be made that 90-95% of this imported gasoline is available at the gasoline pump stations for transportation fuel, equaling about 3.0 – 3.2 MM gallons. The diesel amounts represent transport, power production and other consumption sources. The focus of this study is ethanol production from sugarcane sources that can be blended with gasoline. Therefore diesel is not taken further into consideration.

Table 5.5. Total Imported Fossil Fuels for St. Kitts (2005)[133].

Imported Fossil Fuel	Value	Unit
Gasoline	12,614	m3
	3,332,619	U.S. gallons
	8.57	EC$/gallon (at pump)
	3.17	US$/gallon[134]
	10.6	MUS$
Diesel (Gas oils)	34,257	m3
	9,050,699	U.S. gallons
	11.00	EC$/gallon (at pump)
	4.07	US$/gallon
	36.8	MUS$

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[131] Traffic Department, Government of Saint Kitts and Nevis (2006)

[132] Renewable Fuels Association. 'Ethanol Facts' http://www.ethanolrfa.org/resource/facts/engine/ 2006

[133] Statistics Department, Department of Sustainable Development, Government of St. Kitts and Nevis, 2006/2007.

[134] Weighted average of the gasoline price over year 2005.

Table 5.5 shows that in the year 2005, about 10.6 million US$ was spend on importation of gasoline. For diesel, this import expenditure summed up to US$36.8 million. The cost of living in St. Kitts-Nevis as measured by the consumer price index was 3.38% in 2005 and increased to 8.48% in 2006.[135] The national expenditure for importing of fossil fuels for electricity generation and transport fuel contributes to a large extent to this development.

As indicated before, ethanol can be blended at up to 10% of the total gasoline tank capacity without requiring special engine and negatively affect the engine life-time. If this 10% is set as a target, a minimum a total of 299,936 U.S. gallons[136] of ethanol would be required, given data for the year 2005. The ethanol production costs will determine if there is a potential for cost savings.

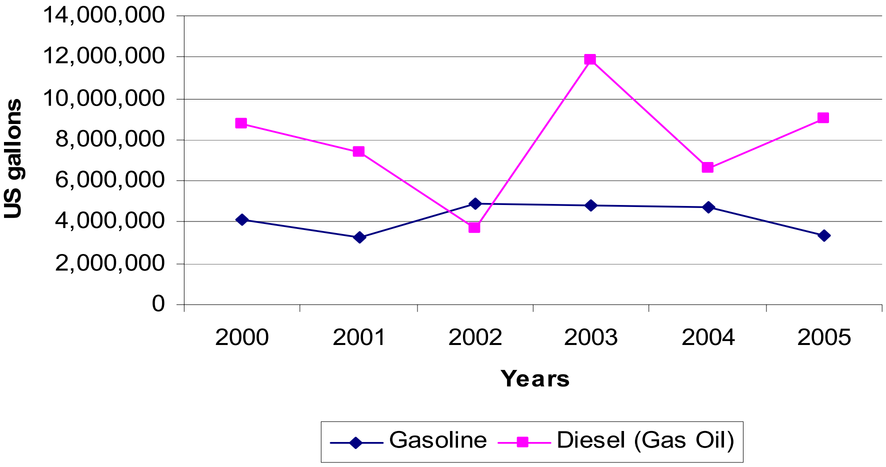

Figure 5.5. Total Imported Fossil Fuels from 2000 to 2005.

The supply and demand for gasoline on St. Kitts varied over 2000 to 2005, with importation amounts between 3.27 and 4.86 MM gallons (see Figure 5.5). In relation to the gasoline, the small but gradual decline is attributed primarily to the attempts by households and businesses alike to reduce their transportation costs in light of rising oil prices and the increase in general of the cost of living/production. The annual growth in demand over these five years was about 0.4% per annum. When extrapolating this growth rate, by 2010, the gasoline demand would be 3.4 million gallons.

To add to this, the spike in diesel in 2003 can be explain by the significant increase in activities in the construction sector, including the use of heavy-duty equipment, and by tourism sector tour operations.

Gasoline prices

Limited data on the gasoline prices indicate that it has been fluctuating from EC$6.90/gallon in the first quarter of 2005 to EC$8.30/gallon in March 2005, rising to EC$10.50/gallon in November 2005. There is no data available on 2006 figures. But

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[135] Statistics Department, Department of Sustainable Development, Government of St. Kitts and Nevis, 2006/2007.

[136] 3,332,619 U.S. gallon * 0.9 * 0.1 = 299,936 U.S. gallons

based on a recent mission to St. Kitts the price of gasoline at the pump was EC$13.5 per gallon (US$ 5.0/gallon)[137] Assuming that the price may fluctuate ±25%, the future range may be between 3.75 - 6.25 US$/gallon, and for the purpose of this study the cost of US$ 5.0 per gallon is used.

The ethanol production cost will have to be lower than 5.0 US$/gallon to become an interesting option for blending it with the gasoline. Note that the energy content of ethanol is about 73% of the energy content of gasoline. Thus more ethanol volume is necessary to have the same level of heat rate for the vehicles.

5.3 Waste Management

The Caribbean region faces unique and growing pressures within the waste management sector. Final disposal of solid waste usually consists of dumping or burning.[138] Therefore, where public health and safety and the environment are key objectives, waste management is an important sector. Because of limited landfill space and having no integrated waste treatment system in place, there is a critical need on St. Kitts to address the treatment and disposal of municipal solid waste (MSW).

Waste collection

Waste management on St. Kitts is the responsibility of the Solid Waste Management Corporation (SWMC). There is a door-to-door waste collection system, with bulk bin services provided at selected locations. The collection areas are divided into five zones consisting of zones 1, 2, and 3 covering the rural areas, and zones 4 and 5 covering the Basseterre and urban areas. Private contractors also provide collection services primarily to the industrial and commercial sectors.[139]

Waste treatment and disposal

There is no integrated waste treatment facility on the island. The collected solid waste and waste coming from other sources is brought to the Conaree Landfill, situated approximately five miles northeast of Basseterre. The Conaree Landfill is the sole authorized disposal site on the island.[140]

To date, there have been attempts to institute a system of waste disposal diversion in the landfill, to concentrate wastes such as tires, vehicles, and construction and demolition waste (inert waste) in selected areas, while municipal waste is concentrated in other parts of the landfill. There are currently two landfill cells constructed and in use, of which the cell closest to the coastline has reached its maximum landfill capacity. (See Figure 5.6.) Accordingly, there is in urgent need for environmental quality control measures.[141]

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[137] Based on travel report M. Matteini (UNIDO) to St. Kitts and Nevis, June 2007

[138] Caribbean CDM Forum website: http://www.gcsi.ca/cdmforum/problem

[139] Garraway, E., St. Kitts Solid Waste Characterization Study, Organization of Eastern Caribbean States (OECS), 2002

[140] Garraway, E., St. Kitts Solid Waste Characterization Study, Organization of Eastern Caribbean States (OECS), 2002

[141] Observations from site visit in June 2006

Figure 5.6. Pictures of the Older Landfill Cells at the Conaree Landfill

In the right picture one can see that the waste dumped contains fractions of green branches, leaves and other biodegradable fractions.

Biodegradable fraction of MSW

For this study it is of interest to look at the biodegradable portion of the municipal solid waste. This is another main source of biomass on St. Kitts, to augment sugarcane. The organic fraction of the MSW is also known as Bio-Municipal Waste (BMW). This BMW, as in the case of sugarcane, can be used to produce energy in the form of bio-fuels (e.g. bio-gas) and/or electricity (waste-to-energy systems). Additionally, there is the possibility of incorporating the BMW into the sugarcane-based biomass feedstock stream to increase the total capacity of bio-energy conversion systems. The technical and economic feasibility of incorporating the BMW source depends on the waste production capacity and cost of collection, its characteristics, and available conversion and/or treatment technologies.

5.4 Preliminary Conclusions and Rationale for Biomass-to-Energy Assessment

As discussed in previous sections, the cost of sugar production on St. Kitts is very high compared to the global market and the Sugar Protocol prices. Because of this, St. Kitts and Nevis has seen deficits in revenue and several set-backs during the past decade that resulted in the closing of the St. Kitts Sugar Manufacturing Company in the summer of 2005.

Preliminary conclusions

Sugar production

Section 4.1, “Sugar production in the Caribbean,” provides a comparison of the costs of sugar production for different countries in the Caribbean. In 2004 St. Kitts and Nevis had, after Barbados, the highest sugar production cost at US$871.3 per ton. The field production costs (sugarcane feedstock price) represented the largest component (64%) of the overall sugar production cost.

Sugar market

As regards the sugar market, this study has shown (Section 4.2) that the 2004 cost of sugar production on St. Kitts (US$871.3 per ton) was much higher than the U.S. sugar price of US$462.6 per ton and the world market price of US$187.4 per ton, as well as the guaranteed ACP-EU Sugar Protocol price of US$595 per ton. As a result of the difference between sugar production costs and global market prices, the SSMC from 2002 to mid-2005 accumulated a debt of about US$133 million[142] through the St. Kitts and Nevis National Bank. This indicates that it would have been a challenge to run the St. Kitts sugarcane industry profitably under the prevailing operational conditions.

Ethanol market

The U.S. ethanol market development shows a positive trend in terms of market value and access to this market via the CBI and DR-CAFTA agreements. In addition, the EU has committed to the EU Bio-Fuels initiative, which suggests interesting prospects for ethanol-exporting ACP countries to enter the EU ethanol market.

The most recently available ethanol prices (from 1st quarter 2007) range between US$1.90-2.40 per US gallon, see figure 4.7.[143]

For St. Kitts and Nevis, these ethanol-exporting opportunities will depend primarily on the financial feasibility of producing ethanol. Even if this appears promising, export potential will depend on the ethanol production capacity and a cost comparison between targeting local consumption to offset imported gasoline, and promoting exportation of a money-generating commodity.

In comparing between ethanol for export or local consumption, the trade-offs based on susceptibility to price volatility, socio-economic benefits, and energy security must be considered. Priorities are to be established by government.

Electricity production sector

- The total installed capacity at the St. Kitts Electricity Department was 33.5 MWe in 2006.
- The electricity sector on St. Kitts faces high generation costs 0.17US$/kWh (EC$0.45/kWh). Of the total generation costs, fuel costs in 2005 had the largest impact, accounting for about 75% of this.
- The imported No. 2 fuel oil used in the generator sets at SKED had an average cost of EC$5.91/IG (US$1.82/US gallon) in the year 2005.

Transport sector

- The total amount of gasoline imported to the island of St. Kitts over 2000 to 2005 was between 3.27 and 4.86 MM gallons per year.
- If a 10% ethanol blend is set as a target, a minimum a total of 299,936 U.S. gallons[144] of ethanol would be required under conditions for the year 2005. Estimations indicate that by 2010 the gasoline demand would be 3.4 million

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[142] Personal communication with representatives of the St. Kitts Sugar Manufacturing Corporation (SSMC), July 2005.

[143] www.energy.ca.gov/gasoline/graphs/ethanol_18-month.html

[144] 3,332,619 U.S. gallon * 0.9 * 0.1 = 299,936 U.S. gallons

gallons. Depending on the ethanol production cost there may be a cost saving potential.

Waste management sector

- BMW, as with sugarcane, can be used to produce energy in the form of bio-fuels (e.g. bio-gas) and/or electricity (waste-to-energy systems).
- The technical and economic feasibility of utilizing this biomass source depends on the waste recovery capacity, which conversion and/or treatment technologies are commercially available, cost of collection and recovery, and the characteristics of the BMW.

Rationale for biomass-to-energy assessment

The Government of St. Kitts and Nevis does not consider the permanent closure of the sugarcane industry acceptable and has identified a number of critical public sector needs associated with the industry, including:

- Providing labor opportunities.
- Preventing environmental degradation—the sugarcane crop is essential for preventing erosion on hillsides, and diverting the Municipal Solid Waste from the landfill.
- Attracting foreign investment.
- Addressing energy and transport sector requirements.

As a result it is imperative to investigate alternative business opportunities for the use of sugarcane.

6. Biomass-to-Energy Technology Overview

This chapter provides an overview of relevant commercially available biomass-to-energy conversion technologies. In order to narrow the field of viable energy conversion technologies for the case St. Kitts and Nevis, it is necessary to first acquire an understanding of its technical limitations and commercial availability.

First a brief description of the conversion processes is provided. Second, the technical limitations and socio-environmental impact of these technologies are discussed. The results of a survey on the number of available commercial biomass-to-energy conversion technologies with installed capacities in the range to be expected for St. Kitts and Nevis is provided. Additionally three case studies of islands using biomass for energy production are presented.

6.1 General Biomass-to-Energy Conversion Routes

In general, biomass-to-energy conversion processes can be divided into thermo-chemical and biochemical conversion routes. Within the thermo-chemical conversion options, a distinction can be made between combustion, gasification, and pyrolysis (a gasification alternative). Biochemical conversion options can be sub-divided into anaerobic digestion and fermentation. A graphical depiction of the general conversion processes and technologies is provided in Figure 6.1.

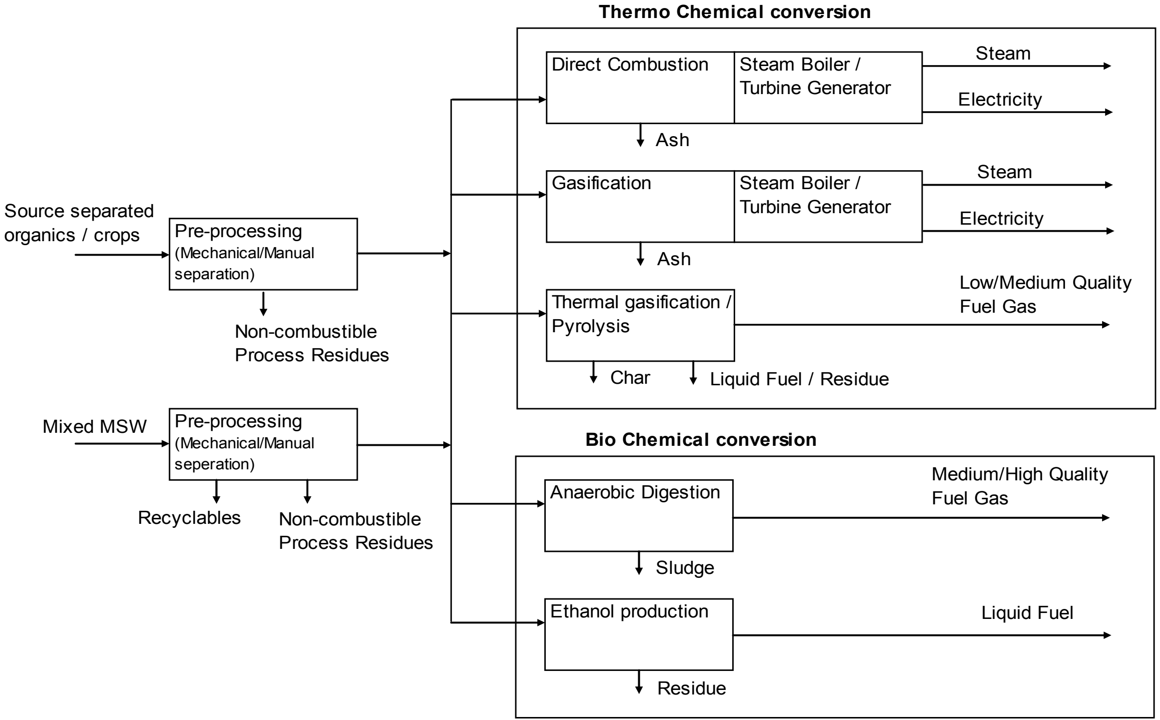

Figure 6.1. Main Biomass-to-Energy Conversion Routes.[145,146]

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[145] Extracted and modified from: Faaij, A.P.C., PhD thesis: "Energy from biomass and waste," 1997, Utrecht University.

[146] Extracted and modified from presentation: Alternative treatment technologies for organic waste, website: www.stopwaste.org/docs/composting_alameda%20county,%20ca_12%2020%2006-7.pdf.

The end-use products or energy carriers produced from these biomass conversion options are mainly electricity, heat, and bio-fuels. Each sub-technology produces its own by-products that, when garnering a market value, can be an additional source of income.
Direct biomass combustion (Thermo-chemical process)

Process
Direct combustion is a widely used process where a large variety of biomass sources can be converted to heat and/or electricity by exposing them to high temperatures and obtaining heat. The heat can then be used to produce steam and have this steam drive an electricity generating turbine (boilers and turbines); this process is known as the Rankine-Cycle (Figure 6.2). The application of this process ranges from small domestic-scale to large-scale systems with capacities of more than 100 MWe. The net electrical efficiencies for biomass combustion power plants range from 20 to 40%.[147]

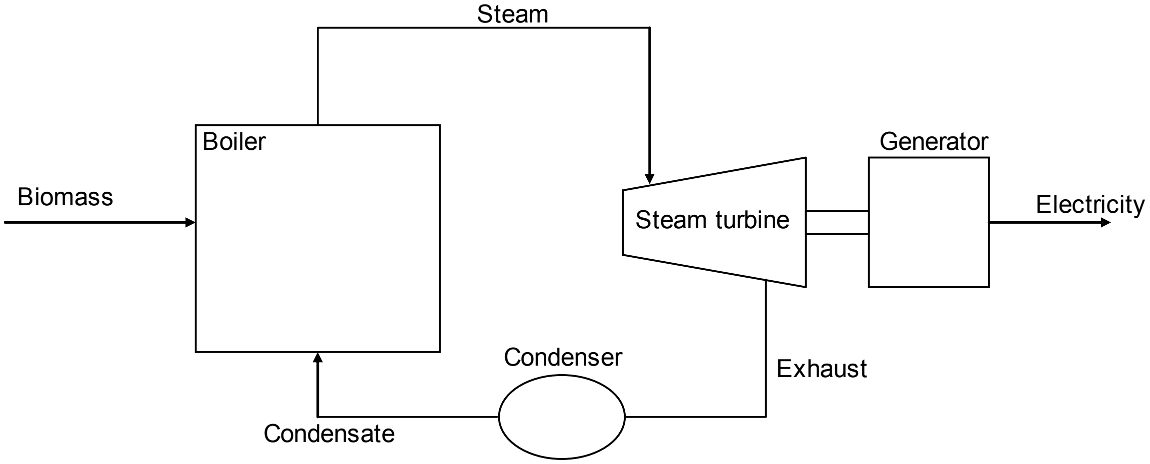

Figure 6.2. Simplistic Scheme of a Typical Rankine Cycle Combustion Process

Combustion temperatures can vary between 800–2000˚C and are influenced by moisture and excess air ratios. The excess air ratio can typically be controlled by the design of the combustion equipment, e.g., with various air feeding steps and boiler or furnace geometry. The higher the air ratio, the lower the maximum temperature—but the more complete the combustion as more oxygen is available to react with the fuel.

To find the optimal biomass combustion performance a variety of technical variables must be in balance. These include design of the equipment, materials used, air and fuel feeding methods, and other control strategies. In addition, a number of process variables must also be balanced, such as heat transfer, residence times, excess air, and insulation. Finally, fuel characteristics—moisture and mineral composition—must be taken into consideration.

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[147] Ibid.

Pre-treatment requirements
Depending on the combustion process technology chosen, various pre-treatment steps such as sizing (shredding, crushing, chipping) and drying are needed to meet process requirements. The heating value and moisture content of the biomass heavily affect the net energy efficiency of the combustion process. At moisture contents higher than 60%, it is generally impossible to maintain the combustion process.[148] Complete combustion (where all gases are converted to CO_2 and H_2O as well as a range of contaminants) depends on fuel composition and partly on the conditions of the combustion process. Drying prior to the combustion process (e.g., with waste heat) helps to lower the moisture content and consequently raise the heating value to acceptable levels; this is sometimes deployed in practice.

Gasification (Thermo-chemical process)[149]

Process
In the gasification process, biomass is thermo-chemically converted into gaseous fuel by means of partial oxidation of the biomass at high temperatures (less oxygen is allowed than during combustion, thus it is considered incomplete combustion). Next to the gaseous fuel, gasifiers produce heat and ash. To operate as an efficient system, beneficial uses need to be developed for all three products.

The main processes of a gasification plant process are fuel feeding, gasification, and gas clean-up. The fuel feeding prepares and introduces the fuel or feedstock into the gasifier. The gasifier converts the feedstock into a fuel gas (syngas) containing carbon monoxide (CO), hydrogen (H_2), and methane (CH_4) as main combustible components. In the gas clean-up process, harmful impurities are removed from the fuel gas so that it can be used safely in the gas engines/turbines. Figure 6.3 provides a simplistic scheme of this process.

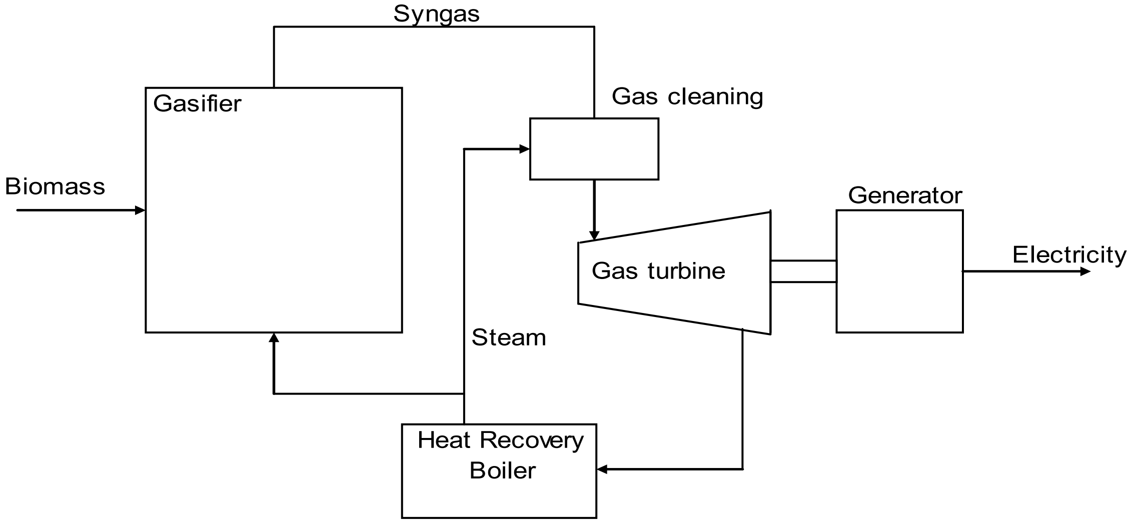

Figure 6.3. Simplistic Scheme of a Gasification Process

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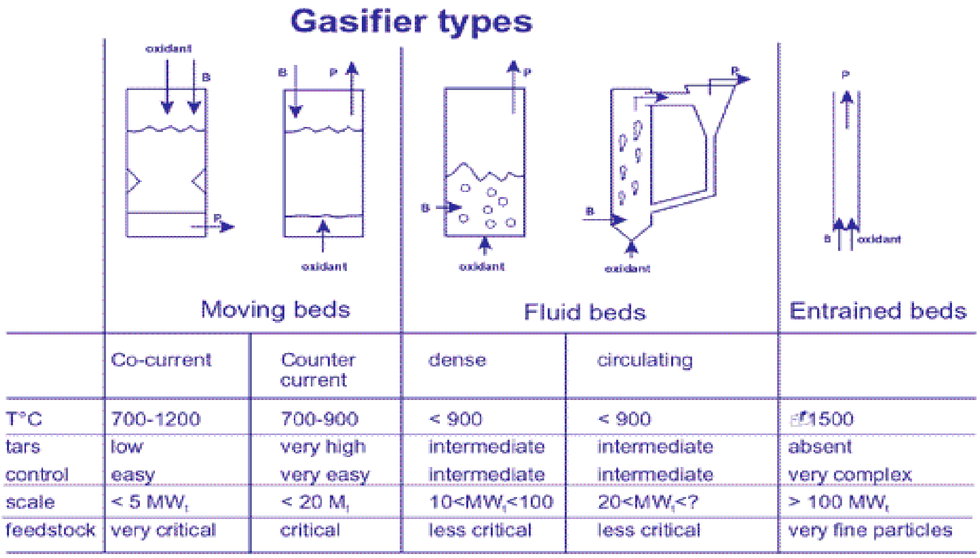
[148] Faaij, A.P.C., "Biomass combustion," Chapter for the Encyclopedia of Energy, Copernicus Institute, Utrecht University.
[149] Foster and Wheeler publications, website: http://www.fwc.com/publications/tech_papers/powgen/bagasse3.cfm.

The gaseous fuel or low calorific gas, also known as syngas, (typically between 4-6 MJ/Nm3[150]), can be used to produce power directly, or can be used to develop further refined fuels and products.[151] Figure 6.4 summarizes the main types of gasifiers, their typical operating window, and the wide range of technical requirements for each gasification sub-technology. The biomass characteristics and quantity assessment is imperative to select the best suitable biomass-to-energy technology.



	Moving beds		Fluid beds		Entrained beds
	Co-current	Counter current	dense	circulating	
T°C	700-1200	700-900	< 900	< 900	[illegible]1500
tars	low	very high	intermediate	intermediate	absent
control	easy	very easy	intermediate	intermediate	very complex
scale	$< 5\ MW_t$	$< 20\ M_t$	$10 < MW_t < 100$	$20 < MW_t < ?$	$> 100\ MW_t$
feedstock	very critical	critical	less critical	less critical	very fine particles

Figure 6.4. Types of Gasifiers and Their Characteristics.[152]

Pyrolysis (Thermo-chemical process)

Process

Pyrolysis is also a thermo-chemical conversion process that converts biomass to liquid (bio-oil), solid, and gaseous substances by heating the biomass to about 500°C in the absence of air. The pyrolysis process includes the biomass feedstock preparation phase, the pyrolysis conversion process, and the application of the bio-oil and char for heat and/or energy production.

Depending on the feedstock used, the process produces by weight, 60–75% liquid bio-oil, 15–25% solid char, and 10–20% non-condensable gas. No waste is generated, since liquid bio-oil and solid char can be used as fuels and the gas is recycled back into the process.

Alternative technologies for pyrolysis are rapid thermal processing (RTP) or fast pyrolysis and the vacuum pyrolysis process known as Pyrocycling^{TM}. The latter process involves the thermal decomposition of matter under reduced pressure, for conversion into fuels and chemicals. Vacuum pyrolysis is generally conducted at a temperature of 450°C

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[150] Faaij, A.P.C., PhD thesis: “Energy from biomass and waste,” 1997, Utrecht University, page 10.

[151] The BioTown, USA Sourcebook of Biomass Energy, Indiana State Department of Agriculture, & Reynolds, Indiana, Prepared by Mark Jenner.

[152] Biomass Technology Group website : http://www.btgworld.com/

and a total pressure of 15 Kilopascal (kPa). These operating conditions are not as extreme as those used in atmospheric pyrolysis and incineration, which makes it possible to obtain large quantities of pyrolytic oils as well as useful solids such as charcoal.[153] The fast pyrolysis refers to the rapid heating of biomass in the absence of oxygen. The feedstock for the pyrolysis process can include forestry residue (sawdust, chips, and bark) and by-products from the agricultural industry (bagasse, wheat straw, and rice hulls).

Early applications in power generation, heating, and slow speed diesel engines have been identified for bio-oil. The char is a solid fuel of high heating value that can be used in kilns, boilers, and the briquette industry. The non-condensable gases are recycled and produce approximately 75% of the energy required for the pyrolysis process itself.

The large scale process patented by DynaMotive takes less than two seconds to produce bio-oil (dark brown, free-flowing liquid comprised of highly oxygenated compounds), char, and non-condensable gases.

Pre-treatment requirements
Preparation of biomass feedstock for the pyrolysis process includes sizing and drying—to a moisture content of 10% or less—and then grinding the feed to small particles to ensure rapid heat transfer rates in the reactor.

Anaerobic Digestion (Bio-chemical process)[154]

Process
Anaerobic digestion is a type of fermentation that bio-chemically converts organic material into bio-gas, which consists mainly of methane and carbon dioxide and is comparable to landfill gas. The biomass is converted by bacteria under anaerobic conditions-without oxygen present.

The biological anaerobic degradation of residues can be divided into four steps:
- Hydrolysis: High-weight organic molecules (like proteins, carbohydrates, fat, and celluloses) are broken down into smaller molecules like sugars, amino acids, fatty acids, and water.
- Acidogenesis: Accomplishes further breakdown of these smaller molecules into organic acids, carbon dioxide, hydrogen sulfide, and ammonia.
- Acetagenesis: The products from the acidogenesis process are used for the production of acetates, carbon dioxide, and hydrogen.
- Methanogenesis: Methane, carbon dioxide, and water are produced from the acetates, carbon dioxide, and hydrogen (products of acidogenesis and acetagenesis).

There are several groups of bacteria that perform each step; in total, dozens of different species are needed to degrade a heterogeneous stream completely. The anaerobic digestion process can be carried out under many different conditions. All of these

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[153] See http://www.vdq023.org/ssc/annx_039.htm for source info.
[154] California Energy Commission website: http://www.energy.ca.gov/pier/renewable/biomass/index.html.

conditions have specific influences on the bio-gas production. Additionally, from a technological viewpoint, the biological process can also be carried out in more than one reactor, which has some implications—mainly economic.

There is a temperature range for bacteria used in digestion in which the bacteria are most productive in terms of output rates, growth rates, and substrate degradation performance. The several groups of bacteria involved in anaerobic digestion all have slightly different optimum temperatures. This results in two main temperature ranges in which digestion can be performed under optimum conditions and most economically. These ranges are: 25–38°C, called the mesophilic range, and 50–70°C, called the thermophilic range. The energy of the bio-gas typically amounts to 20–40% of the lower heating value (LHV) of the feedstock.

Bio-gas plants consist of two components: a digester (or fermentation tank) and a gas holder. The digester is a cube- or cylindrical-shaped waterproof container with an inlet into which the fermentable mixture is introduced in the form of liquid slurry. The gas holder is normally an airproof steel container that, by floating like a ball on the surface of the fermentation mixture, cuts off air to the digester (anaerobiosis) and collects the gas generated. In one of the most widely used designs, the gas holder is equipped with a gas outlet, while the digester is provided with an overflow pipe to lead the sludge out into a drainage pit.

The construction, design, and economics of bio-gas plants have been well covered in existing literature. For bio-gas plant construction, important criteria are:[155]

(a) the amount of gas required for a specific use or uses; and
(b) the amount of waste material available for processing.

Anaerobic digestion is a commercially proven technology and is widely used for recycling and treating wet organic waste[156] and waste waters. Bio-gas can be used for firing engines (typical overall electrical conversion efficiency is about 10-16%) to produce electricity. Kompogas AG of Switzerland is using this technology to generate 3 MW of electricity based on organic waste. Bagasse has not yet been used alone as fuel, but is usually combined with other organic residues.[157]

Pre-treatment requirements

In digestion processes water is an important parameter. Water is needed for life in general and so too, not surprisingly, for digestion bacteria. It is the transport medium for nutrients and for (half) products, and is a very good reaction medium for digestion. Digestion is carried out in two different ranges of water content: dry digestion, with typical dry solids content of 25-30%; and wet digestion, with dry solids content of less than 15%. These ranges have technological and economic implications: higher solid

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[155] Further considerations about the construction of bio-gas plants are given in http://www.unu.edu/unupress/unupbooks/80434e/80434E0k.htm.

[156] EUREC Agency, "The future for renewable energy, prospects and directions," James & James Science Publishers Ltd., London, 1996.

[157] Kompogas website: http://www.kompogas.ch/en/index.html.

contents lead to smaller (and thus typically cheaper) reactors; lower solid contents (containing more water) lead to much better mixing possibilities but on the downside, require a higher energy input (more water to be heated) and a bigger reactor. Natural wastes from plants, such as from greenhouse cultivation, have an estimated dry solids content of 25%. This dry solids content allows for the possibility of performing digestion without adding water.

Fermentation/Ethanol production (Bio-chemical process)[158]

Process

Fermentation of sugars is a bio-chemical process that entails the production of ethanol (alcohols) from sugar crops (sugarcane, beet) and/or starch crops (maize, wheat). The biomass is ground down and the starch is converted by enzymes and bacteria into sugars. Yeast then converts the sugars into ethanol. Pure ethanol can be obtained by distillation, which is an energy-intensive step. The remaining solids can be used as cattle feed. In the case of sugarcane, the remaining bagasse can also be used as fuel for boilers or electricity generation processes.

Sugarcane is harvested manually or mechanically and then transported to a processing plant, which is typically owned and operated by big farms or farm consortia, and located near the producing fields. At the processing plant the cane is pressed or crushed to extract the juice, leaving behind a fibrous residue (bagasse). The juice is fermented by yeasts which break down the sucrose into CO_2 and ethanol. The resulting "wine" is distilled, yielding hydrated ethanol (5% water by volume) and "fusel oil." The acidic residue of the distillation is neutralized with lime and sold as fertilizer. The hydrated ethanol may be sold as is (for ethanol-friendly cars) or dehydrated and used as a gasoline additive (for gasohol-friendly cars).

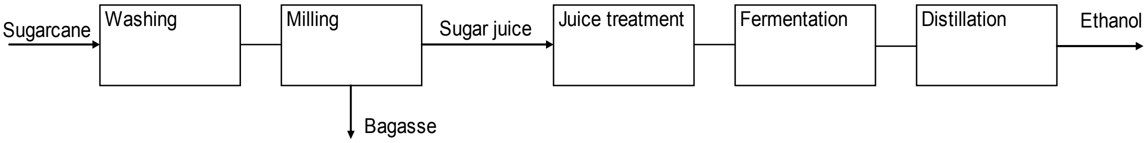

Figure 6.5. Simplistic Scheme of a Typical Ethanol Production Process

Burning the bagasse produces heat for distillation and drying. These multiple applications allow ethanol plants to be energetically self-sufficient and even to sell surplus electricity to utilities. Estimates of potential power generation from bagasse range from 1,000 to 9,000 kW per system, depending on technology. Higher estimates assume gasification of the biomass, replacement of commonly used low-pressure steam boilers and turbines by high-pressure ones, and use of harvest residues currently left behind in the fields.

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[158] Wikipedia online encyclopedia, website: http://en.wikipedia.org/wiki/Ethanol_fuel_in_Brazil.

Pre-treatment requirements
To optimize the ethanol production via the fermentation process from sugarcane bagasse, there are several methods of pre-treatment of the bagasse. The pre-treatment can have a considerable impact on the fermentation efficiency; this is because the bio-digestibility of the bagasse can be improved and the access for microbial attack can be facilitated. There are several physical and chemical methods that can be implemented to pre-treat the bagasse.[159]

Appendix E provides an overview of the companies and or facilities that currently have commercially available biomass-to-energy conversion technologies installed or that are in operation.

Box 6.1. Cellulosic Ethanol

Ethanol is produced from the fermentation of sugar by enzymes produced from specific varieties of yeast. The five major sugars are the five-carbon xylose and arabinose and the six-carbon glucose, galactose, and mannose. Traditional fermentation processes rely on yeasts that convert six-carbon sugars to ethanol. Glucose, the preferred form of sugar for fermentation, is contained in both carbohydrates and cellulose. Because carbohydrates are easier than cellulose to convert to glucose, the majority of ethanol currently produced in the United States is made from corn, which produces large quantities of carbohydrates. Also, the organisms and enzymes for carbohydrate conversion and glucose fermentation on a commercial scale are readily available.

The conversion of cellulosic biomass to ethanol parallels the corn conversion process. The cellulose must first be converted to sugars by hydrolysis and then fermented to produce ethanol. Cellulosic feedstocks (composed of cellulose and hemicellulose) are more difficult to convert to sugar than are carbohydrates. Two common methods for converting cellulose to sugar are dilute acid hydrolysis and concentrated acid hydrolysis, both of which use sulfuric acid. Dilute acid hydrolysis occurs in two stages to take advantage of the differences between hemicellulose and cellulose. The first stage is performed at low temperature to maximize the yield from the hemicellulose, and the second, higher temperature stage is optimized for hydrolysis of the cellulose portion of the feedstock. Concentrated acid hydrolysis uses a dilute acid pretreatment to separate the hemicellulose and cellulose. The biomass is then dried before the addition of the concentrated sulfuric acid. Water is added to dilute the acid and then heated to release the sugars, producing a gel that can be separated from residual solids. Column chromatographic is used to separate the acid from the sugars.

Source: http://www.eia.doe.gov/oiaf/analysispaper/biomass.html

6.2 Environmental Impacts of Biomass-to-energy conversion processes

Air Emissions[160]
When considering sugarcane bagasse and/or BMW as combustion fuels, a wide range of emissions are expected. In the case of combusting sugarcane bagasse, the most significant pollutant emitted by bagasse-fired boilers is particulate matter, caused by the turbulent movement of combustion gases with respect to the burning bagasse and resultant ash. Emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are lower than conventional fossil fuels due to the characteristically low levels of sulfur and nitrogen associated with bagasse.

Since biomass in general has significantly less sulfur than coal, there is an SO_2 benefit; and early test results suggest that there is also an NO_x reduction potential of up to 20% with woody biomass. Auxiliary fuels (typically fuel oil or natural gas) may be used during startup of the boiler or when the moisture content of the bagasse is too high to support combustion; if fuel oil is used during these periods, SO_2 and NO_x emissions will increase. Soil characteristics such as particle size can affect the magnitude of particulate matter (PM) emissions from the boiler. Cane that is improperly washed or incorrectly

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[159] See website: http://energy.seekingalpha.com/article/13457
[160] Environmental Protection Agency (EPA), www.epa.gov/ttn/chief/ap42/ch01/final/c01s08.pdf.

prepared can also influence the bagasse ash content. Upsets in combustion conditions can cause increased emissions of carbon monoxide (CO) and unburned organics, typically measured as volatile organic compounds (VOCs) and total organic compounds (TOCs).

Impacts to Soil / Water[161, 162]

In general, crops grown for biomass fuel require fewer pesticides and fertilizers than crops grown for food, which means that less pesticide and fertilizer runoff will reach local streams and ponds than if food crops are grown. If sugarcane cultivation is stopped, several environmental impacts could result. Erosion could occur, due to the agricultural lands being located on slopes, and with rainfall and no sugarcane roots this water could erode the soil.[163]

Location of ethanol/power plant facility

As is the case with fossil fuel power plants, biomass power plants have pollutant build-up in the water used in the boiler and cooling system. The water used for cooling is much warmer when it is returned to the lake or river than when it was removed. Pollutants in the water and the higher temperature of the water can harm fish and plants in the lake or river where the power plant water is discharged. This discharge usually requires a permit and is monitored. The need for cooling water for the combustion of biomass can be a determining factor for the location of a future ethanol/power plant. The location can have an impact on the logistical cost of delivering sugarcane. Currently the St. Kitts Electricity Department (SKED) uses large diesel engines for electricity production and therefore a location near large amounts of surface water for use as a cooling medium is not a priority. The sugar production plant at the SSMC was using groundwater as a source for cooling and process water for sugar production. The quality of the water needs to be high and readily available, and therefore groundwater is adequate. However, this groundwater extraction puts pressure on the limited available water contained in the aquifers that is also the source for potable or drinking water provision in St. Kitts. In addition, although the cost for the purchase of water is included in the cost of operation, the water consumption rate is not known, and may be a large contributor to the cost of plant operation.

Climatologically influence

From studies performed in Brazil[164] it was concluded that sugarcane production is very water-intensive and that the climatologically conditions have a great impact on the production yields and moisture content that consequently will have an influence on the sugarcane supply costs to the sugar mill.

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[161] Environmental Protection Agency (EPA) website: http://www.epa.gov/cleanenergy/water_discharge.htm.

[162] Union of Concerned Scientists website: http://www.ucsusa.org/clean_energy/renewable_energy_basics/environmental-impacts-of-renewable-energy-technologies.html.

[163] Caribbean Environmental and Health Institute (CEHI), information brief 4, website: http://www.cehi.org.lc/agrochemical.htm.

[164] Damen, K., “Future prospects for bio-fuel production in Brazil”, A chain analysis of ethanol from sugar cane and methanol from eucalyptus in Sao Paulo, Copernicus Institute, Utrecht University, 2001.

In St. Kitts the weighted annual average rainfall between 1993 and 2003 was compared with the sugarcane yield—see figure 6.6.

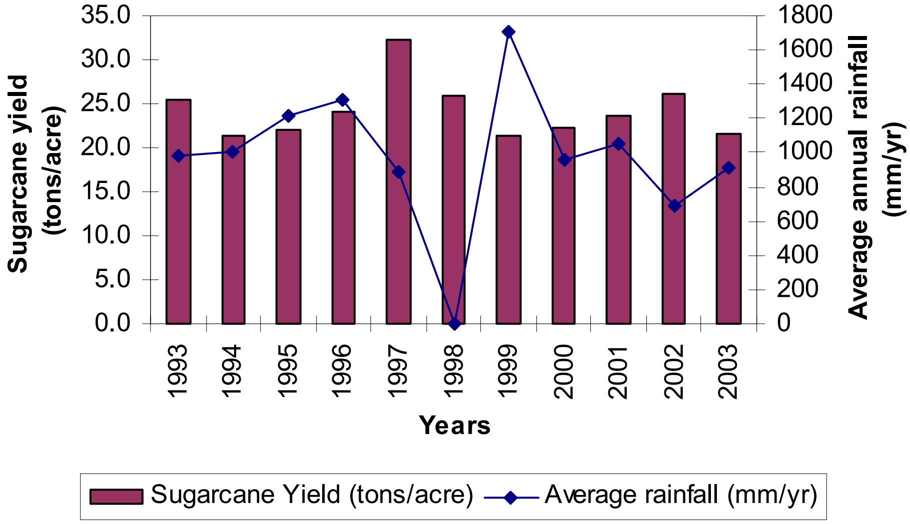

Figure 6.6 Rainfall Compared to Sugarcane Yields on St. Kitts (1993-2003)[165]

Note that in Figure 6.6 in 1998, there was no measurement of rainfall performed due to a hurricane. From this figure no direct interdependence between rainfall and sugarcane yield is noticeable. The average annual rainfall in St. Kitts can be assumed to be about 1072 mm/yr[166] and has no clear or high influence on the sugarcane yields. Reasons for this can be that the annual rainfall is, even at its lowest point, enough for sugarcane production; the type or variation of sugarcane used (moisture requirement is low); or the quantity planted in each season and the decreasing yield due to annual harvesting within a 5-6 year cycle may explain the cycles in yield decrease as depicted in the graph.

Aesthetical impacts

Aesthetically there is a visual impact. A biomass-to-energy processing plant can be a prominent feature in any landscape. They are however designed to be as tidy and visually unobtrusive as the process and space requirement will allow. When it comes to a choice between another landfill, loss of agricultural lands as tourism attraction, and a self contained biomass-to-energy plant, most residents would likely prefer this where noise, smell, and litter are contained. It should be considered however that when it comes to the planning stage, the construction of a new plant is likely to receive opposition.[167]

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[165] Source: Sugarcane yield data (SSMC, 2006) and Climatological data for 1993 to 2003 (Statistics Department, Ministry of Sustainable Development, St. Kitts & Nevis Government, 2005)

[166] St. Kitts Statistics Department, Ministry of Sustainable Development, climatological data for 1993 to 2003

[167] Cardiff University, Waste Research Station, website: http://www.wasteresearch.co.uk/ade/efw/mswcombustion.htm.

6.3 Case Studies of Biomass-to-Energy Conversion Technologies

Several case studies of biomass-to-energy conversion systems in operation on other islands are outlined in this section.

Case studies[168]

The objective of the following case studies is to highlight the experience of biomass-to-energy systems on other comparable island states in the world. Important issues to focus on are the biomass feedstock quantities, the installed capacities, and techniques used for electricity and or ethanol production. Also, where possible, the cost of feedstock and investment should be considered.

Guadeloupe

About 563,600 tons of cane is produced annually on Guadeloupe. The SIDEC (Subsidiary of Charbonnages de France) and Electricite de France (EDF) have developed a cogeneration power plant combusting bagasse and coal imported from Colombia, known as the Le Moule project. The bagasse fired power plant has 2x32MWe turbines installed for steam and electricity production, with a base load output of 50 MWe to sell on the national grid.

At Le Moule, the cogeneration plant is operated by Compagnie Thermique du Moule (CTM) and is situated next door to the Gardel sugar factory. The sugar factory no longer has boilers and generators; they get their low pressure steam from CTM at 130 tons per hour, 150°C and 3 bar pressure. About 90% of the steam is returned to CTM as condensate. Electricity is fed into the grid by CTM and Gardel takes what it needs from the grid under terms agreed upon between the companies and the grid operating party.

La Réunion

On the island of La Reunion, two bagasse to power plants have been installed, the Bois-Rouge and the Le Gol plants. Together they provide about 44% of the total electricity produced on the island, with an average availability of 90%. Reunion produces about 2 million tones of sugarcane per year which produces 640,000 ton of bagasse per year. Thus the wet bagasse recovery is about 32%.

The Bois-Rouge bagasse based power plant was built next to a sugar mill to save transport costs to the plant. This power plant supplies the mill with process heat and exports and sells electricity to the national grid. Because the bagasse cannot be stored over an extended time and due to limited space, this is burned as it is produced at the sugar mill. In the intercrop season (when no sugarcane is harvested), the plant uses an alternative fuel source (coal), to improve the reliability (load factor), and operate as a conventional power plant for electricity production to the grid. This plant was commissioned in August 1992. Table 6.1 provides technical information of the plant.

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[168] Headley, O., Barbados Renewable Energy Scenario, Current Status and Projections to 2010, Centre for Resource Management and Environmental Studies, University of West Indies, Barbados, website: http://www.terryally.com/library/oheadleyrenewable.html.

Table 6.1. Technical Information of the Bois-Rouge Plant

Technology	Parameter	Value	Unit
Bagasse Storage	Capacity	1000	ton
2x Boiler (mid-high pressure steam)	Efficiency (thermal)	90	%
	Feedstock	Bagasse and Coal	
	Steam	130	ton/hr
		80	bar
		520	Degrees (Celsius)
2x Turbine (30MWe HP steam turbines)	Type	Steam extraction system	

Mauritius[169]

In the year 2000, there were 14 sugar mills in operation in Mauritius. Ten of these mills exported electricity to the grid and three were firm capacity power plants (combusting bagasse and coal). There is a continuing process of centralization ongoing, whereby only six sugar mills are projected to be in operation by 2008.

Mauritius produces between 5.0-5.5 million tons of cane per year which yields 550,000-625,000 tons of sugar. Their first bagasse/coal plant was commissioned in 1985 and fed some 90 gigawatt-hours (GWh) per year into the grid, about 50% of which was derived from bagasse. With the addition of a new turbo-alternator in 1998, about 20% of the national electrical energy was derived from bagasse in 2000.

Table 6.2. Overview of Bagasse Based Power Plants in Other Island States

	Mauritius	Reunion	Guadeloupe
Installed electricity generation (MW)	480	437	483
Sugarcane production (tons)	5,800,000	2,000,000	564,000
Bagasse produced	1,800,000	640,000	180,000
Bagasse/Coal generation capacity (MW)	132	118	64
Percentage energy generated from bagasse	20	16.5	7

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[169] Deepchand, K., Sugar Cane Bagasse Energy Cogeneration – Lessons from Mauritius, Mauritius Sugar Authority, 2005

As can be seen in Table 6.2, the installed co-generation plant capacities range from 437 to 483 MW with bagasse inputs ranging between 180,000 – 1,800,000 tons of bagasse annually.

6.4 Performance parameters

As a result of a literature survey and summarizing the previous sections, Table 6.3 provides an overview of the technical performance parameters and the qualitative assessment of the environmental impacts of the main biomass-to-energy conversion technologies in the context of St. Kitts.

Survey of commercially available biomass-to-energy conversion technologies and/or facilities

The available biomass feed stocks on St. Kitts are outlined in Table 6.4. This table provides the range of available feed stocks based on the most recent production numbers and the assumed amount of land that would be available for sugar cultivation (6,000 acres). If additional lands were made available or if the production efficiency were to increase dramatically, the available biomass feed stocks may be improve.

Table 6.3. Biomass Supply to Facility on St. Kitts

Source	Biomass supply (tons/ year)	Biomass supply (TPD[170])
Sugarcane (directly fired)	112,750 – 209,950	1,174 – 2,187
Bagasse	20,295 – 41,990	169 – 350
BMW	8,500	29
Bagasse + BMW	29,923 – 48,391	281 – 379
Sugarcane + BMW	121,250 – 218,450	1,203 – 2,216

In this section, the range of potential applications for use in St. Kitts is narrowed. Among the bio-energy conversion alternatives outlined above, pyrolisis and digestion are excluded because the minimum range of feedstock at which point these become economically viable far exceeds the quantities that are available in St. Kitts (See Appendix F for additional considerations.) The three basic technology groups that appear most applicable to the market conditions/feedstock characteristics of St. Kitts meet the following basic facts in that they are: 1) commercially available; 2) have processing capacities based on the available biomass feedstock types and quantities in St. Kitts; and 3) there are companies that have experience in commercial implementation of these projects/technologies.

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[170] TPD is the tons per day of feedstock supplied to a biomass-to-energy conversion system.

Table 6.4. Summary of Results of the Comparative Analysis of Biomass-to-Energy Conversion Systems for St. Kitts

		Thermo-chemical conversion			**Bio-chemical conversion**	
Technology	**Unit**	**Combustion**[171,172]	**Gasification**[173,174,175]	**Pyrolysis**[176,177,178,179,180,181]	**Digestion**[182,183,184]	**Fermentation**[185,186,187,188,189,190]
Pre-treatment requirement		pre-heating/drying, shredding, crushing/chipping	depending on sub-technology, shredding, minimization	Sizing, drying	Sizing (water addition)	Crushing, milling
Feedstock type		Wood, MSW, bagasse	Wood residues, saw dust, BMW, REF[191]	Forestry residues, agricultural waste, bagasse	Waste water sludge, manure	Sugarcane

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[171] Damen and Faaij, A life Cycle Inventory of Existing biomass import chains for 'green' electricity production, Copernicus Institute, Utrecht University, January 2003.

[172] U.S. Climate Change Technology Program, *Technology Options for the Near and Long Term*, section 2.3.6 Thermo-chemical conversion of Biomass, 2005, www.climatetechnology.gov/library/2005/tech-options/tor2005-236.pdf.

[173] Foster and Wheeler website: http://www.fwc.com/publications/tech_papers/powgen/bagasse3.cfm.

[174] Office of Technology Assessment at the German Parliament (TAB) website: http://www.tab.fzk.de/en/projekt/zusammenfassung/AB49.htm.

[175] OPET, Micro and Small-scale CHP from Biomass (<300kWe), Technology Paper 2, NNE5/3/2002

[176] Dynamotive website: http://www.dynamotive.com/biooil/technology.html (visited 04 March 2007).

[177] Presentation by Energie de Developement Durable, WET Summit, February 2004, slide 8.

[178] Renewables, Anaerobic Digestion, European Commission website: http://ec.europa.eu/comm/energy_transport/atlas/htmlu/adenv.html

[179] Friends of the Earth, 2002, see: http://www.foe.co.uk/resource/briefings/gasification_pyrolysis.pdf

[180] Friends of the Earth, 2002, see: http://www.foe.co.uk/resource/briefings/gasification_pyrolysis.pdf

[181] Friends of the Earth, 2002, see: http://www.foe.co.uk/resource/briefings/gasification_pyrolysis.pdf

[182] Wikipedia online encyclopedia, website: http://en.wikipedia.org/wiki/Ethanol_fuel_in_Brazil.

[183] Seeking alpha, Energy Stocks, See website: http://energy.seekingalpha.com/article/13457

[184] Renewables, Anaerobic Digestion, European Commission website: http://ec.europa.eu/comm/energy_transport/atlas/htmlu/adenv.html

[185] Copersucar website: http://www.copersucar.com.br/institucional/ing/academia/alcool.asp.

[186] Environmental Protection Agency (EPA) website: www.epa.gov/ttn/chief/ap42/ch01/final/c01s08.pdf.

[187] Wright et al., Biomass Energy Data Book, U.S. Department of Energy, Energy Efficiency and Renewable Energy, 2006, website: http://www.eere.energy.gov/afdc/progs/vwbs2.cgi?9745.

[188] Macedo, I.C., Unicamp, Campinas, Brazil, website: http://www.carensa.net/Brazil.htm

[189] Website: http://cat.inist.fr/?aModele=afficheN&cpsidt=821530

[190] Wikipedia website: http://en.wikipedia.org/wiki/Industrial_fermentation.

[191] REF (Recycled fuel), is composed of 5-15% plastic, 20-40% paper, 10-30% cardboard and 30-60% wood by weight, with a heating value 2.2 MJ/kg (50% m.c.)

		Thermo-chemical conversion			**Bio-chemical conversion**	
Technology	**Unit**	**Combustion**[171,172]	**Gasification**[173,174,175]	**Pyrolysis**[176,177,178,179,180,181]	**Digestion**[182,183,184]	**Fermentation**[185,186,187,188,189,190]
Moisture content	% m.c.	< 60	10 - 55	≤ 10	65 - 85	65 - 75
Conversion type		Full oxidation or combustion (Rankine Cycle)	Partial oxidation	Anaerobic combustion	Anaerobic fermentation	Fermentation/Distillation
Operating temperature	°C	800 - 2000	700 - 2700	500	25 - 38 (mesophilic), 50 - 70 (thermophilic)	35 - 45
Main output product		Heat & Electricity	Syngas -> Electricity via gas engine/turbine	Liquid bio-oil -> diesel engines	Biogas -> Electricity	Hydrated Ethanol -> E-flex cars, Dehydrated Ethanol -> Gasohol cars
Net conversion efficiency	%	20 - 30 % (depending on scale)	22 – 38%	14%	10 - 16 %	163 gallons/ton sucrose
Product quality	Heating Value	Electricity (kWh)	4.0 - 6.0 MJ/Nm3	19.8 MJ/kg (LHV)	20 - 40% of LHV of feedstock	23.4 MJ/L
	Composition	-	CO, H_2, CH_4	H_2,CO,CH_4,C_2H_2,C_2H_4	CH_4, CO_2	5% volume H_2O (hydrated ethanol)
By-products		Heat	Heat	Solid char, non-condensable gas	Digestate	Bagasse, Fertilizer
Possible use / market value		Process heat	Process heat	Solid char -> Electricity (via Rankine Cycle), non-condensable gas re-used in process	Digestate -> Fertilizer	Bagasse -> Heat/Electricity, Fertilizer -> Soil Treatment

		Thermo-chemical conversion			**Bio-chemical conversion**	
Technology	**Unit**	**Combustion**[171,172]	**Gasification**[173,174,175]	**Pyrolysis**[176,177,178,179,180,181]	**Digestion**[182,183,184]	**Fermentation**[185,186,187,188,189,190]
Environmental Impacts						
Emissions (Air)		CO_2, SO_2, NO_x	fuel gas impurities, ash, low SO_2 emissions	Acid gases, dioxins and furans, nitrogen oxides, sulphur dioxide, particulates, cadmium, mercury, lead and hydrogen sulphide	Nitrogen oxides, sulphur oxides and particulates are the main pollutants to be considered here.	CO_2, SO_2, NO_x
Water consumption/ contamination		Polluted process water effluent	Toxics in combustion ash contaminate surface water and groundwater[192]	Treated water – used to wash the waste in the pre-treatment stage, and clean the gas.	N.A.	N.A.
Soil quality		Fly ash used as fertilizer (depending on heavy metals contamination)	N.A.	Inert mineral ash, inorganic compounds, and any remaining unreformed carbon (which is also inert) – these can be between 8 and 15 per cent of the original volume of waste	Allows nutrients to be returned to the land through application of the digestate maintaining or improving soil structure due to the application of organic matter	Sludge used as fertilizer

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[192] *Waste gasification: impact on the environment and public health.* A Blue Ridge Environmental Defense League report (April, 2001). Retrieved on March 21st, 2007 from *http://www.bredl.org/pdf/wastegasification.pdf*

The initial set of bio-energy conversion technologies that will be analyzed in detail for the purposes of this assessment include electricity production via **direct combustion,** and ethanol production through **fermentation/distillation.** The analysis that follows will assess the viability of these options on a standalone basis and in combination with each other. (See appendix E for a review of data provided by a select number of system manufacturers and investors.)

7. Biomass to Energy Conversion Scenarios

In this chapter the bio-energy resources – including their characteristics, quantities, and costs – are fed into economic models according to the available conversion technologies, in an effort to identify one or more scenarios that would likely be economically viable. A techno-economic and sensitivity analysis is performed for key scenarios, the results of which are projected and discussed.

7.1 Scenario Overview

Ethanol production

This scenario assumes that the harvested sugarcane is crushed and milled whereby the produced cane juice is further processed to dehydrated ethanol via a fermentation and dehydration or distillation process. The ethanol can be flash blended with gasoline up to 10% in tank volume, substituting costly and imported gasoline. The bagasse produced as a by-product after the crushing and milling process is stored and combusted in a boiler/turbine system to produce process heat and electricity. Depending on the electricity consumption of the ethanol plant, a limited amount of the excess electricity generated may become available to the grid.

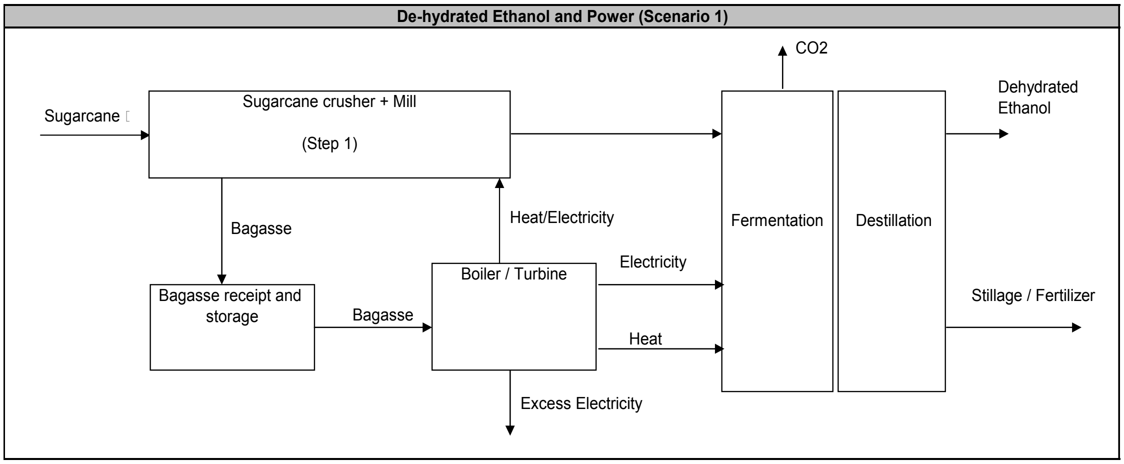

Figure 7.1 Schematic Overview of the Ethanol Production Scenario (Scenario 1)

As by-product of the fermentation/distillation process, stillage is produced. With treatment, stillage can be used as fertilizer on the sugarcane lands. This scenario assumes a baseline condition where local sugarcane is used as a feedstock to produce ethanol and electricity.

Electricity production

The second scenario assumes the combustion of sugarcane, as delivered at the processing facility, via direct combustion system to produce electricity. Figure 7.2 provides a schematic overview of this scenario.

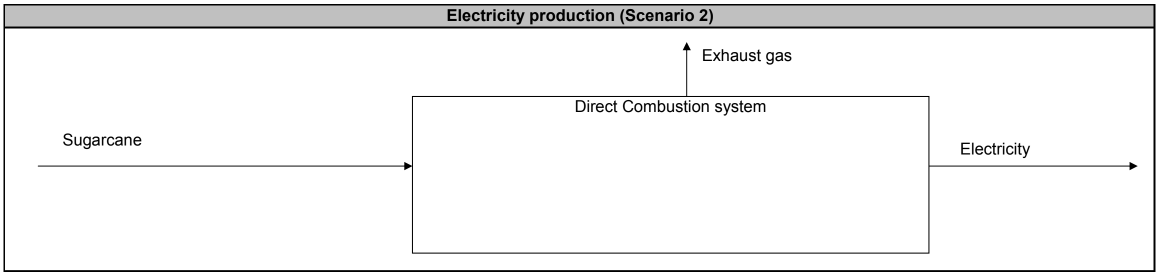

Figure 7.2. Schematic Overview of the Electricity Production Scenario (Scenario 2)

Electricity is a very costly commodity on the island of St. Kitts. The current generation cost at the St. Kitts Electricity Department is about 0.17 US$/kWh, which is among the highest in the world. This scenario aims to maximize the electricity production for export to the national grid.

7.2 General Costing and Technical Input Parameters

This section outlines the assumptions regarding input parameters and the costing data assessment for the many components that are common for each of the scenarios. The costing factors that are anticipated to have the greatest impact on the production cost of the end-use application products or energy carriers will be assessed in more detail.

7.2.1 Sugarcane feedstock cost

To have an idea of sugarcane supply cost ranges, some sources from literature indicate a price range on Brazilian fields between 18-22 US$/ton of biomass feedstock price (in the form of sugarcane trash[193]), under varying transport distances.[194] Data collected over two years in a sugarcane growing area for a study in India show that the delivered, sized, and dried cost of sugarcane leaves is between 38.3-47.6 US$ per ton of biomass, if the material is procured from within a 20-30 km distance[195]. In the case of a eucalyptus plantation in Thailand, the biomass feedstock price varied between 16.3-19.6 US$/ton.[196] In the U.S., based on a 2002 survey on 21 dry-mill ethanol plants, the net feedstock costs for the surveyed plants ranged from 39 to 68 cents per gallon for plant capacities divided in two groups, small ethanol plants (< 40 million gallon per year) and large ethanol plants (40 – 100 million gallon per year). [197]

This wide range indicates that the biomass feedstock cost depends primarily on site specific conditions, to include climatological factors; soil quality; cultivation, harvesting methods (e.g. labor), and equipment used; and biomass type and quality (yields, resistance, etc.).

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[193] This is 15% of dry matter of the produced sugar cane

[194] Rodrigues, M. et al., Techno-economic analysis of co-fired biomass integrated gasification/combined cycle systems with inclusion of economies of scale, 2003, page 1248

[195] Jorapur, R. and Rajvanshi, A.K., Sugarcane leaf-bagasse gasifiers for industrial heating applications, Nimbkar Agricultural Research Institute (NARI), 1997, India, page 145

[196] Junginger et al., Fuel supply strategies for large scale bio-energy projects in developing countries. Electricity generation from agricultural and forests residues in Northeastern Thailand, 2001, page 267

[197] Shapouri et al., USDA's 2002 Ethanol Cost-of-Production Survey, USDA, July 2005.

In 2004, the sugar production cost at the St. Kitts Sugar Manufacturing Company was US$871.3 per ton of sugar. Knowing that the typical field cost per ton of sugar produced was US$557.8 per ton sugar and that the conversion efficiency from delivered sugarcane to sugar was around 8.4%, the cost for delivered sugarcane should be about 46.9 $US\$_{2004}$/ton of sugarcane. When correcting this value for the baseline scenario whereby we assume the conditions in the year 2006, this cost will be 49.5 $US\$_{2006}$/ton. To verify this value, the specific cost per each process step in the production of sugarcane is assessed.

Figure 7.3 shows a breakdown of the sugarcane feedstock costs as delivered to the mill for the year 2004. The total cost results to be 49.5$US\$_{2006}$/ton based on weighted averages of cost for the *growing cost*, *harvesting cost*, *transport cost,* and the *field overheads*. The growing cost (10.2$US\$_{2006}$/ton) is the sum of the cost for land preparation, planting, plant cane maintenance, and ratoon cane maintenance. The harvesting cost (19.1$US\$_{2006}$/ton) is the sum of the cost of manual and mechanical harvesting, whereby the cost contribution is 62% and 38% respectively.[198] The costs for transport and field overheads are 10.4 $US\$_{2006}$/ton and 9.9 $US\$_{2006}$/ton respectively.

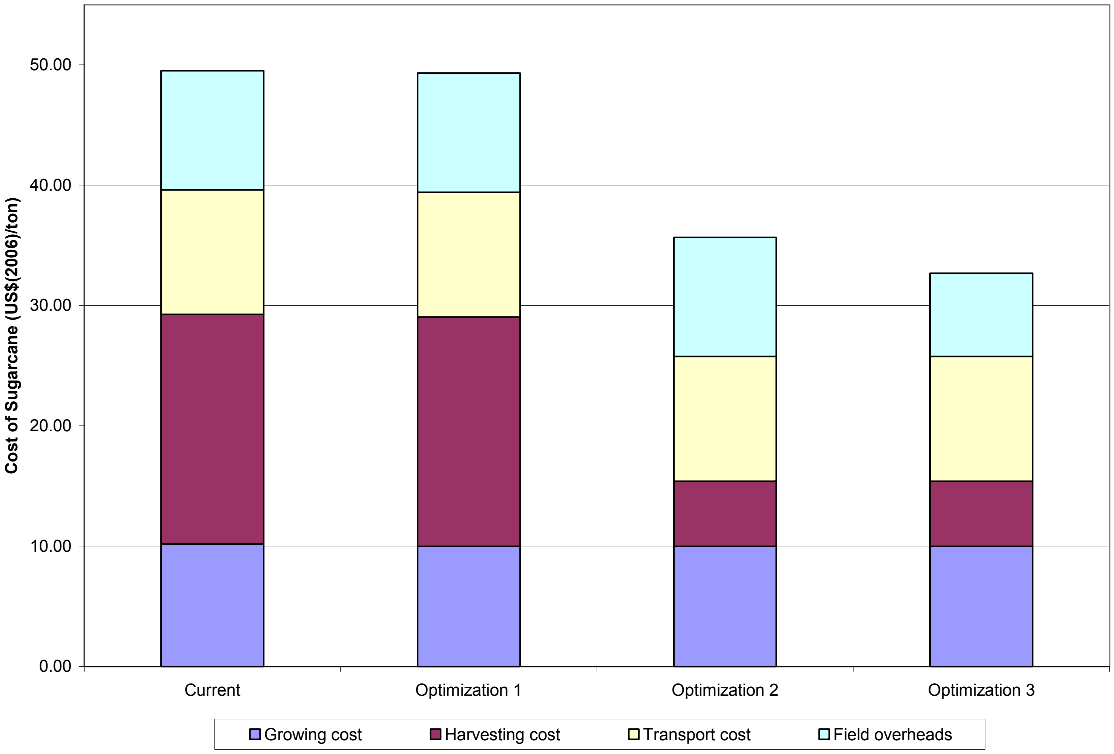

Figure 7.3. Cost Break Down of the Sugarcane Feedstock Cost on St. Kitts Based on Optimization Options (2006)[199]

To assess a possible cost range, two extremes are assumed. The current sugarcane feedstock cost of 49.5$US\$_{2006}$/ton, is considered the worst case scenario under normal

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[198] Cost Statistics 2004, Field Cost per hectare, Sugar Association of the Caribbean (SAC).

[199] Source: Costs Statistics 2004, Sugar Association of the Caribbean (SAC).

operating conditions (note that in case of a natural disaster the whole cane harvest is considered unavailable). From this perspective, it is envisioned that this cost can only be reduced via implementation of optimization alternatives.

In the best case, it is assumed that the fertilizer used for the plant cane and ratoon cane maintenance is replaced by the stillage produced from the fermentation/distillation process, thus making fertilization possible at no cost (Optimization 1). This results in a cost of 49.3US$_{2006}$/ton. For the harvesting cost, the manual labor is replaced by mechanical harvesting up to a cost distribution of 30% for manual labor and 70% mechanical harvesting (Optimization 2). This results in a cost of 35.7US$_{2006}$/ton. For the transport cost, it is assumed replacing the existing rail train with a modern, efficient transport system, and improving collection wagons and other logistical issues, results in a potential decrease of 30% in transport costs (Optimization 3). This yields a cost of 32.7US$_{2006}$/ton.

The cost range will therefore be assumed to range between 32.7 – 49.5US$_{2006}$/ton for this study. In the section on optimization potentials, other alternatives are discussed for reducing the costs of the sugarcane feedstock.

7.2.2 Investment costs

It is difficult to provide a detailed assessment of potential investment costs as much of this information is proprietary and not released by project developers and manufacturers. The assessments that follow are drawn from a limited number of quotes and extensive literature/internet research to provide the investment cost ranges for systems included in the scenarios. Tables 7.1, 7.2 and 7.3 show the overview of collected investment cost data for larger capacity ethanol plants and direct combustion systems.

Ethanol plant investments

The investment costs provided in Table 7.1 are drawn from multiple sources including data related to costing for corn-based and sugarcane-based ethanol plants. The investment costs vary along with the capacities of the ethanol plants. The costing values are corrected for inflation to 2006 US$ values to create a common baseline to be able to compare.

Table 7.1. Investment Costs for Ethanol Plants with Varying Capacities

Technology	Investment cost[200] (Million US$$_{2006}$)	Capacity	Unit
Ethanol (wet mill, corn-based)[201]	91.0	30	Mgallon/yr
Ethanol (wet mill, corn-based)[idem]	108.0	40	Mgallon/yr
Ethanol (wet mill, corn-based)[idem]	188.0	100	Mgallon/yr
Ethanol (dry mill, corn-based)[idem]	43	30	Mgallon/yr
Ethanol plant[202]	38.5 – 41.0	0.5	M tons/yr sugarcane
Ethanol plant[203]	20.0	~3	Mgallon/yr
Ethanol (dry mill, corn-based)[204]	27.0 - 94.5	9 - 90	Mgallon/yr

The capital investment ranges between 20 MUS$ (for a 3 Mgallon/yr plant) to 188 MUS$ (for a 100 Mgallon/yr plant). Note that there is limited or no information on small scale ethanol plants (< 10 Mgallons/year), due to limited commercial experience and application.

Direct Combustion Investment Costs

Table 7.2 provides an overview of combustion systems based on steam boilers and turbines (the Rankine Cycle process). A range of costs and capacities are provided with capital investments occurring from 1,013 US$/kW (0.2 MW) to 338 US$/kW (800 MW).

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[200] Inflation correction: X US$*$(1+i)^{yr}$, with inflation rate of 3% per annum.

[201] Whims, J., Corn based ethanol costs and margins, Department of Agricultural Economics, Kansas State University and Sparks Companies Inc, May 2002.

[202] Lucon, O. and Goldemberg, J., *A 10% ethanol blend in the Caribbean*, September 2006, page 3.

[203] Quote from an expert source. For further information please contact the author.

[204] Modified from, Shapouri et al., USDA's 2002 Ethanol Cost-of-Production Survey, USDA, July 2005, page 7 and 8

Table 7.2. Investment Costs of Direct Combustion Systems with Varying Capacities

Technology	Investment cost[205] (US$$_{2006}$/kW)	Capacity (MW)
Direct combustion[206]	1,529	70
Direct Combustion[207]	2,500 - 980	1 - 110
Direct combustion[208]	2,804	30
Direct Combustion[209]	1,000	-
Direct combustion[210]	1,013 - 338	0.2 - 800

When considering the biomass to electricity scenario, the expected range based on the energy content of the sugarcane (as combustion fuel) is estimated to be in the range of 30 to 50 MW. Equation 7.1 shows how the rated capacity is estimated.

$$\frac{cane * heating_value * (1 - m.c.) * \eta_e * 0.2778}{harvest_days * 24hrs * load_factor} = rated_capacity \qquad (7.1)$$

Cane : sugarcane production [ton/yr]
Heating Value : calorific value of the cane [GJ/ton]
m.c. : Moisture Content [%-mass]
η_e : Electrical efficiency [%]
0.2778: Conversion factor GJ to MWh
Harvest days : harvesting period [days/yr]
Load factor : 0.7 (default for biomass fueled systems)
Rated Capacity : Installed capacity [MW]

$$\frac{147{,}000 * 17.0 * (1 - 0.5) * 0.2 * 0.2778}{120 * 24hrs * 0.7} = 34.4MW$$

The investment costs are very inconsistent and therefore based on consultations with industry representatives, the capital investment is assumed at 1,500 US$/kW for Direct Combustion Plants with capacities ranging between 30-50 MW as the baseline condition. With the sensitivity analysis the uncertainty and influence of this cost factor is further assessed.

7.2.3 Energy Demand projections

The energy demand on the island of St. Kitts is a determining factor for the scale and design of a biomass power plant. From the demand forecasts for the St. Kitts Electricity

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[205] Inflation correction: X US$*$(1+i)^{yr}$, with inflation rate of 3% per annum.

[206] Deepchand, K., Sugar Cane Bagasse Energy Cogeneration – Lessons from Mauritius, Mauritius Sugar Authority, 2005.

[207] Scahill, J., National Bioenergy Center, NREL, Biomass to Energy: Present Commercial Strategies and Future Options, see: files.harc.edu/Sites/GulfCoastCHP/Presentations/**Biomass**ToEnergy.pdf.

[208] Deepchand, K., Sugar Cane Bagasse Energy Cogeneration – Lessons from Mauritius, Mauritius Sugar Authority, 2005.

[209] IEA Energy Technology Essentials, *Biomass for Power Generation and CHP,* January 2007.

[210] Environmental Protection Agency (EPA), Catalogue of CHP Technologies, Combined Heat and Power Partnership, 2002, page 7 of 14.

Department can be concluded that by 2010 the peak demand will be around 32 MWe. Several currently installed units with a total installed capacity of 33.5 MWe are reaching the end of their technical lifetime and are being phased out. To prevent a capacity shortage and to be able to provide a base load electricity supply at SKED, an additional 19.6 MWe will need to be installed by 2010; this is over and above the planned diesel generation capacity expansion of 11.5 MWe at the SKED.[211] Therefore it is recommended to envision at least a capacity of 10 MWe supplied by a bio-energy system.

7.3 Techno-Economic Analysis – Ethanol Production Scenario (Scenario 1)

7.3.1 Assumptions and input data

The primary end use application in this scenario is dehydrated ethanol[212], or simply ethanol, a finished product which can be blended with gasoline (functioning as a replacement for methyl tertiary butyl ether (MTBE) for transportation use. The MTBE is used as an oxygenating component to increase the oxygen content of the gasoline to increase complete combustion efficiency and also help prevent engine knocking. Ethanol can be mixed up to 10% of tank-volume with gasoline without the need for adaptations in existing transport vehicles. It is also possible that the process will result in excess electricity that may be sold to the national grid; this is will depend on the amount of heat and electricity that is required to produce ethanol. Figure 7.4 below illustrates the process steps for ethanol production.

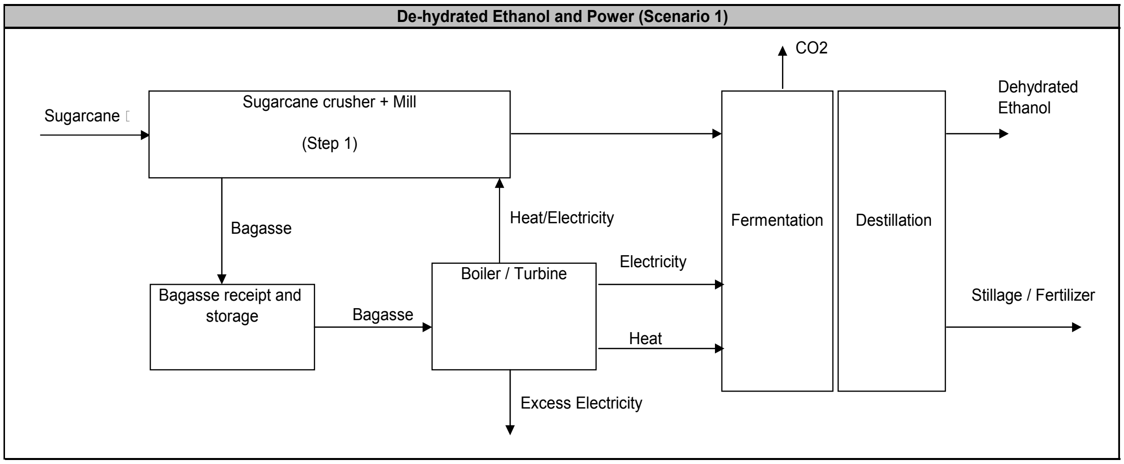

Figure 7.4. Schematic Overview of the Dehydrated Ethanol Production Scenario (Scenario 1)

Sugarcane availability depends on the harvesting period, which runs between 3 – 5 months per year. Based on the available 6,000 acres of land at the time of this study, and a yield of 24.5 tons per acre (the 10-year average during full operation of the SSMC), this results in a sugarcane production of 147,000 tons per year, over a period of 3 – 5 months.

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[211] De Cuba, K.H., Towards a Sustainable Energy Plan for St. Kitts and Nevis, March 2006, table 6.2, page 84.

[212] See for more details on the composition of ethanol the following source: http://www.ucc.ie/academic/chem/dolchem/html/comp/ethanol.html

It is assumed that the sugarcane will be chopped, crushed, and juice extracted for ethanol production. The sucrose content of the sugarcane juice is estimated to be around 16%-volume.[213] Approximately 138 to 163 gallons of ethanol per ton of sucrose [214, 215] can be produced. In this scenario, the lowest ethanol yield from sucrose is used. The remaining bagasse from the crushing process is combusted to produce electricity and heat. There is a parasitic load stemming from the production of ethanol, which reduces the amount of electricity available for sale every year. The electric energy consumption of the ethanol production process is set at 2.0 kWh/gallon of ethanol, this is the higher end of a range between 0.9 – 2.0 kWh/gallon of ethanol (see Appendix G). The sensitivity analysis will demonstrate the effects of changes in internal energy consumption on the potential to export and sell excess electricity to the grid, based on their effect on cost.

The energy model indicates that the ethanol production could be about 2.7 Mgallons per year, and a 7.0 MWe power plant could be installed. The rated capacity of the power plant is based on the assumption that the sugarcane cannot be stored over a period longer than the harvesting period, thus 120 days per year and a load factor of 0.7 for maintenance and other miscellaneous occurrences. The bagasse combustion system in this first scenario is assumed to be a direct combustion (Rankine Cycle) system where mid/low pressure steam is produced to run steam turbines for electricity generation. This is common practice for the energy production element of an ethanol plant. The overall electric efficiency of the power plant is set to be 20%; this is the average efficiency for small scale (~5MWe) direct combustion units.[216]

In order to calculate the overall costs of an ethanol production system in St. Kitts the initial investment costs for a 3 million gallon/year ethanol facility has been estimated. Table 7.2 above provided investment cost information for various sized ethanol production facilities. A scaled down investment cost estimate was calculated (see Appendix H), and the results of this represent the estimated investment cost extremes for this analysis. These ranged from US$14.3 million to US$23.8 million. The baseline investment cost estimate used for this calculation is US$19.0 million (US$6.96/gallon). This estimate has been reviewed by several industry experts and is considered realistic for this scale facility. (This figure also incorporates the investments required for the power plant, to produce heat and electricity.)

Table 7.3 presents the costs, expenses, and factors used for the calculation of the levelized cost of electricity (COE) and the dehydrated ethanol production cost.

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[213] Minussi, R.C. et al., Sugar-cane Juice induces pectin lyase and polygalacturonase in Penicillium Griseoroseum, December 1998, source : http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0001-37141998000400002

[214] U.S. Department of Agriculture, *The Economic feasibility of Ethanol production from sugar in the United States*, July 2006

[215] Macedo, I.C., Unicamp, Campinas, Brazil, website: http://www.carensa.net/Brazil.htm

[216] U.S. Climate Change Technology Program, *Technology Options for the Near and Long Term*, section 2.3.6 Thermo-chemical conversion of Biomass, 2005, www.climatetechnology.gov/library/2005/tech-options/tor2005-236.pdf.

Table 7.3. Input Data for the Dehydrated Ethanol Production Scenario 1

Sugarcane production	**Typical**	**Unit**	**Input Range**
Land Available	6,000	acres	5,500 – 6,500
Yield	24.5	ton/acre	20.5 – 32.3
Harvesting Period	120	days/yr	100 – 150
Sugarcane Production	147,000	ton/yr	
Sugarcane Feed	1,225	tons per day (TPD)	
Operation	**Typical**	**Unit**	**Input Range**
Heating Value Cane	17	GJ/ton (HHV)	17.0 – 18.1
Moisture Content Cane	50	%	40 – 60%
Sugarcane Cost	32.7	$\text{US\$}_{2006}$/ton (wet)	32.7 – 49.5
Ethanol System			
Sucrose Content Cane	13.5	% by weight	12 – 15
Efficiency for Ethanol Conversion	138	Gallons/ton sucrose	138 – 163
Ethanol Production Heat Requirement	56.0	MJ_{th}/gallon of ethanol	56.0 – 79.1
Ethanol Production Electrical Requirement	2.0	kWh/gallon of ethanol	0.9 – 2.0
Power System			
Overall Energy Efficiency	20	%	20 – 30%
Bagasse Recovery from Cane	19	%	18 – 20%
Bagasse Moisture Content	45	%	40 – 50%
Bagasse Heating Value	16.5	GJ/ton(HHV)	16.5 – 19.0
Electricity production	50,693	GJe/yr	
	14,083	MWh/yr	
Available Electricity to Grid	30,992	GJe/yr	
	8,609	MWh/yr	
Load Factor	0.7		0.6 – 0.8
Annual Operating Hours	2,016	hrs	
Power Plant Capacity	7.0	MWe	
Financial data	**Typical**	**Unit**	**Input Range**
Capital Investment	19.0	MUS$	14.3 – 23.8
Fuel Cost*	4,806,900	US$/yr	
O&M Costs* (5.5% of Tot. Investment)	1,048,245	US$/yr	1 – 6%
Miscellaneous Expenses* (3% of Tot. Investment)	571,770	US$/yr	1 – 10%
Inflation Rate	8.7	%	1 – 15%
Equity/Debt ratio	0/100		
Economic Life	20	yr	
Interest Rate	10	%	1 – 20%

*Values for year one

7.3.2 Results

Given the cane and bagasse characteristics, operational factors, cost and expenses showed in the above sections, as well as the income and the financing requirements for such a facility, the following results are obtained for an ethanol production facility if located on St. Kitts and Nevis.

The annual outputs for this scenario result in 2.7 million gallons of ethanol and 8,609MWh electricity for sale to the national grid. The costs of production derived by this analysis suggests an electricity generation cost of US$0.086 / kWh and an ethanol production cost of US$2.12 US$ per gallon. Table 7.4 presents a summary of these results.

Table 7.4. Summary of the Results for Scenario 1 –Dehydrated Ethanol Production

Output	Value	Unit	Sensitivity results
Ethanol Produced	2.7	MGallons/yr	
Cost of Ethanol Production	2.12	US$/gallon	1.86 – 2.87
Electricity Available to the Grid	8,609	MWh/yr	
Cost of Electricity Production (Constant $)	0.086	US$/kWh	0.075 – 0.117
Set Electricity Sales	0.13	US$/kWh	0.086 – 0.17
Cost of Ethanol (incl. electr. Sales)	1.78	US$/gallon	

This analysis suggests that the electricity generation cost of this scenario of 0.087 US$/kWh is lower than the current 0.17 US$/kWh generation cost on St. Kitts. Such a margin may provide an electricity rate with an acceptable rate of return (depending on the electricity sales), while still providing cheaper electricity to the consumer. For this base case scenario an electricity sales rate of 0.13 US$/kWh (thus a revenue margin of 0.044 US$/kWh) is assumed to assess the effect of this revenue on the ethanol production cost.[217]

In the case of ethanol (without considering electricity sales), the production cost is US$2.12/gallon. With the inclusion of electricity sales at a rate of 0.13 US$/kWh, the ethanol production cost is reduced to 1.78 US$/gallon. Therefore it is important that the electricity price sold to the national grid is assessed carefully in order to reach the balance between increasing the reliability of return of investments while simultaneously reducing the electricity rates to the consumers.

Local gasoline

To compare the ethanol production cost with the current gasoline price of US$5.0/gallon on St. Kitts (see section 5.2), one has to compare them based on the energy content of both fuels[218], this is also known as the substitution value. It shows that the cost for

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[217] Note that the buy-in rate is dependant on the Power Purchase Agreements (PPA) that are subject to future plans for energy development on St. Kitts and Nevis.

[218] The energy content of ethanol is 23.4 MJ/L or 0.0886 GJ/gallon and gasoline has a heating value of 32.0 MJ/L or 0.121 GJ/gallon, therefore the 23.4/32.0=0.73, thus 1 gallon of ethanol contains 73% of 1 gallon of gasoline.

ethanol will increase to US$2.26/gallon[219] if it should replace 1 gallon of gasoline. Even with this cost increase, the ethanol production cost is still US$2.8/gallon cheaper than the gasoline per gallon at the pump. This US$2.8/gallon margin should then cover the costs for infrastructure and logistical transport and distribution related costs to supply the ethanol at the pump. In addition environmental taxes charged to gasoline or other fiscal mechanisms can be used to promote the local ethanol market.

Knowing that the ethanol can be blended with gasoline by up to 10% of tank volume, and the gasoline demand in 2005 was 4.86 million gallons, leads to a gasoline replacement of 299,936 gallons. This represents an energy content of 36,292 GJ_{gas}/year. To replace the energy content of 299,936 gallons of gasoline, 409,619 gallons/year of ethanol are required. The ethanol production is about 2.7 million gallons per year and is more than enough to supply the nation with ethanol (on the short term), in addition providing about 2.3 million gallons for export. The local ethanol consumption could be increased by investing in adequate infrastructure and modifying import regulations to promote the introduction of flex-fuel vehicles that can run on higher tank volume-% of ethanol. Unfortunately this process takes considerable time and effort, and therefore cannot be considered as a starting-point condition or a value-added solution as first-hand optimization option for the biomass-to-ethanol scenario.

U.S. Ethanol Market

When considering U.S. ethanol market value of US$1.90/gallon (see Chapter 5), this is the lower end of a very volatile market value range between 1.90-2.40 US$/gallon (over 1st quarter of 2007), the wholesale cost of St. Kitts and Nevis ethanol of US$1.78/gallon (incl. electricity sales at 0.13 US$/kWh) results to be less expensive. On short to mid-term future it is very difficult to assess the ethanol market development, it will need some time for the market to stabilize and experience less value fluctuations. Also no prediction can be made on the results of the power purchase agreements (PPAs) that should conclude in a set electricity sales rate, this may vary in the extremes between 0.086 – 0.17 US$/kWh.

EU Ethanol Market

When considering the European Union, the ethanol market has been mainly driven by ethanol made of sugar beet and at current stage forms only a small fraction (<0.5%) of the total fuels market for transport and sums to a production of 0.5 Mton (2006). But there is a serious commitment towards the rapid development of the ethanol market (see section 4.3). The current (2006) import fraction is about 12% of total consumed ethanol, in the future St. Kitts and Nevis could consider this market for export.[220] Being a Caribbean nation and part of the ACP-countries, St. Kitts and Nevis is exempted from the US$0.10/liter (0.39 US$/gallon) import duty. Thus, a similar advantage to market entrance to the U.S. market. Unfortunately at this point there is not sufficient information

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[219] 1.78 + 1.78*(1-0.73) = 2.26 US$/gallon

[220] European Union of Ethanol Producers, source: www.minagricultura.pt/.../extcnt/docs/FOLDER/PROT_TEMAS/F_BIOCOMBUSTIVEIS/3-Bioetanol-UE_Valerir-Corre.pdf

available on the market conditions, prices or forecasts to assess the competitiveness of local produced ethanol to the EU ethanol market price.

Based on the arguments described above, the financial feasibility of ethanol production depends on the possibility of exporting the ethanol with a cost lower than the U.S. ethanol market price. The baseline ethanol production cost on St. Kitts of 2.12 US$/gallon (without incl. electricity sales) is higher than the lowest end of the range of 1.90 – 2.40 US$/gallon (U.S. market value in the 1st quarter of 2007). The subsidized ethanol cost of 1.79 US$ per gallon (with an electricity sales rate of 0.13 US$/kWh) is below the U.S. market value range. Note, however, that this U.S. market price is very volatile (see Figures 4.6 and 4.7). Therefore under the baseline conditions (assuming conservative conversion efficiencies and higher end costing data), and considering the current U.S. market value range, it would not seem advisable to invest in an ethanol plant on St. Kitts and Nevis. This is especially the case when taking in account the substitution value of ethanol to gasoline of US$ 2.26 per gallon.

7.3.3 Sensitivity analysis

As previously discussed, the fuel cost is a significant component of the biomass energy system's production costs. In the sensitivity analysis, the impact of a change in this feedstock cost on the biomass-to-energy conversion process and costing results can be investigated. Also alternatives or factors can be identified to optimize the production of ethanol to produce a more cost-competitive ethanol. Factors such as capital cost, operation and maintenance costs, miscellaneous expenses, interest rate, efficiencies for ethanol and for electricity conversion, bagasse fuel heating value, sugarcane yield, cane availability, and sucrose content are therefore varied to observe their effect on the cost of production of ethanol and electricity.

Ethanol production cost

Figure 7.5 below shows how a percentage change in the factor considered (see the x axis), will affect the cost of **ethanol production** (y axis). The zero value on the x axis constitutes no change in the factors considered, and corresponds to a cost of ethanol production of $1.79 per gallon, including electricity sales at a rate of 0.13 US$/kWh. Fuel cost, electricity sales rate, capital investment costs, cane yields, efficiency for ethanol conversion, and sucrose content are the most noteworthy factors affecting cost of production of ethanol. Miscellaneous costs, operation and maintenance costs, and interest rate also have an impact on the cost of ethanol production, but they are not as significant as the other factors (less steep graph).

The ethanol production cost on St. Kitts could range from 1.38 – 2.52 US$/gallon, assuming the input ranges of 0 - 0.17US$/kWh for electricity sales (where 0 represents the baseline cost of 2.12 US$/gallon) and other input ranges as provided in Table 7.3. Figure 7.5 also depicts the gasoline price (based on energy content of ethanol), with a value of 3.65 US$/gallon. Also the U.S. ethanol market value range of 1.90 – 2.40 US$/gallon is depicted.

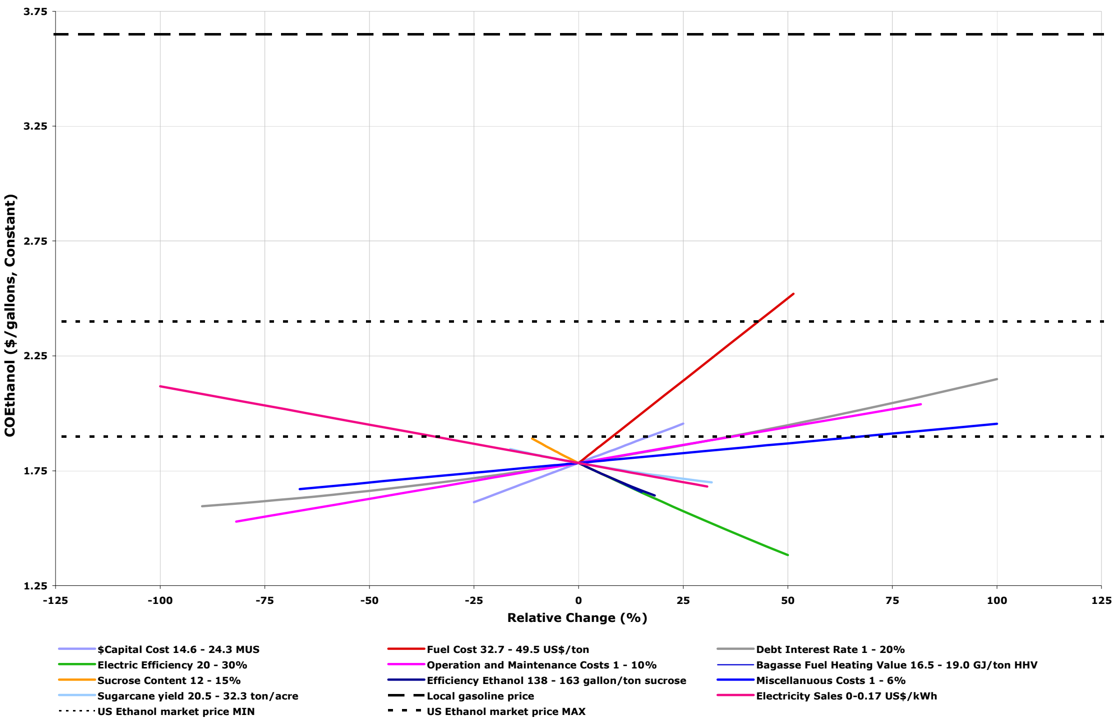

Figure 7.5. Sensitivity Results for Ethanol Production Cost (Scenario 1 –Ethanol and Electricity Production)

Sugarcane feedstock cost (fuel cost)

The fuel cost is varied from 32.7 – 49.5 US$/ton. As discussed in Section 7.2.1, the decrease in fuel cost is based on the optimization potentials for bringing the cost down. A decrease of for instance 10% of the fuel cost from 32.7 to 29.4 US$/ton decreases the cost of ethanol production from 1.78 to 1.64 US$/gallon. The decrease in the fuel cost has a high sensitivity on or will cause a significant decrease in the cost of production of ethanol and reduction potential of this cost should therefore be further investigated.

Electric efficiency, sucrose, and energy content

An increase in the efficiency for ethanol conversion or in the sucrose content and energy content (bagasse fuel heating value) can decrease the cost of production of ethanol very rapidly (see the slopes of the lines in the graph). The potential for improving the efficiency of these factors is bound in this study to a theoretical range based on literature review. As an example, the literature shows that the energy content of bagasse can only range between 16.5 – 19.0 GJ/ton (HHV). If it were possible to achieve higher heating values the cost of ethanol production could be drastically lowered. But to remain on the conservative side, this study sets the ranges based on extensive literature review related to existing and or proven studies.

Capital investment cost

As in the case of the fuel cost, energy, and sucrose content, the capital investment cost also has a large impact on the ethanol production cost. Although derived from vendor quotes and subjected to review by industry experts, there is uncertainty in the capital investment cost. To examine sensitivity, this cost was scaled based on investment cost data for corn-based ethanol plants under varying processing capacities. Other factors, as the transport and installation of the plant on this remote island and individual negotiations with vendors will impact the final capital investment cost. The annual operation and maintenance costs and miscellaneous expenses are estimated based on percentage of the total investment cost. More detailed assessment is required in these costing parameters during implementation.

The lowest capital investment cost value used in this analysis was 14.3 MUS$$_{2006}$. This value is based on the lowest found capital investment data for a similar ethanol plant, corrected for inflation and scale. This resulted in an ethanol production cost of 1.61 US$/gallon dehydrated ethanol. But when applying the economies of scale rule of thumb, one would envision higher costs, and it is therefore recommended to consider the higher end of the provided capital investment range. When running the analysis with a total capital investment of 23.8 MUS$, this results in an ethanol production cost of 1.95 US$/gallon.

O&M, miscellaneous expenses, and debt interest rate
The slope of the operation and maintenance costs, miscellaneous expenses, and debt interest rate lines in the graph are smaller than all others. This means that change in any one of these parameters will not be as significant as the other factors discussed above.

Ethanol production cost – local gasoline price
The baseline cost of 2.12 US$/gallon and the 1.78 (incl. electricity sales) are based on energy content, much lower than the local consumed gasoline with a value of 3.65 US$/gallon (ethanol). Based on the results of the sensitivity analysis, there is a large margin for ethanol cost competitiveness, even under worst case conditions. There are a wide range of optimization alternatives that can have an effect on the cost reduction to drop even further under the value of the local consumed gasoline.

Ethanol production cost – U.S. ethanol market value
The conditions for the financial feasibility of **ethanol** production can clearly change if the U.S. ethanol market price continuous its growing trend (even with high volatility), if simultaneous optimization options are implemented, and if cost reductions are achieved to the level of 1.78 US$/gallon for St. Kitts. Note that this study does not assess infrastructure and logistical issues for ethanol exportation from St. Kitts to the U.S. The cost of ethanol will increase once these components are considered.

Electricity generation cost
Figure 7.6 shows how a percentage change in the factor considered (x axis) will affect the cost of electricity production under baseline conditions (not including revenue from sales). In this figure, as in the case for the ethanol production, the fuel cost decrease potential has the largest impact on the electricity generation cost. The current electricity generation cost on St. Kitts is 0.17 US$/kWh and is much higher than the cost value of 0.086 US$/kWh for the excess electricity produced by this ethanol plant. Based on the

results of the sensitivity analysis the cost of electricity production can range from 0.077 – 0.116 US$/kWh.

As can be seen in Figure 7.6, the fuel cost, efficiency of ethanol conversion, and sucrose content have a more significant effect on the cost of electricity production than the same factors for the electricity only scenario (Scenario 2, see section 7.4) because the majority of the energy output from the system is in the form of ethanol. A decrease in ethanol production due to changes in any of these three factors will result in higher cost of electricity production. As seen in the below graph, the impact of change on any of these three factors is more significant than that of any other factor considered.

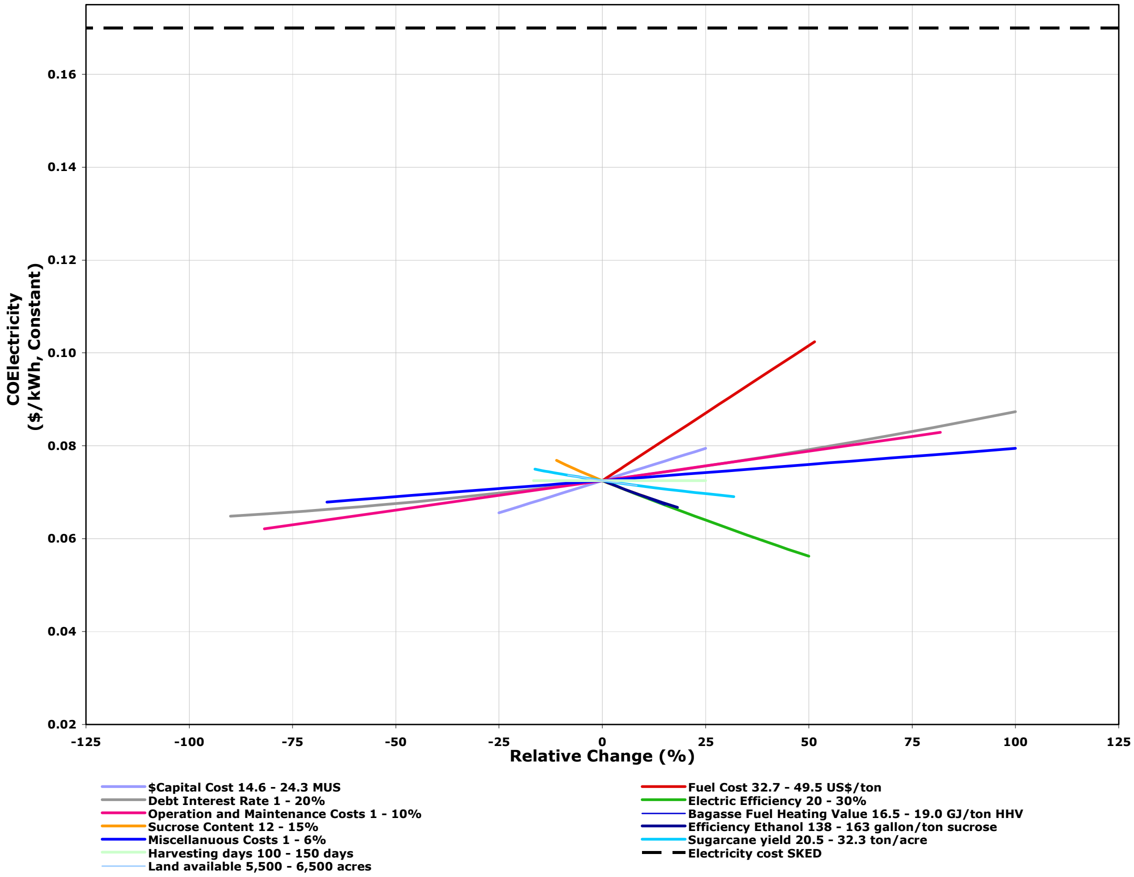

Figure 7.6. Sensitivity Results for Electricity Production Cost (Scenario 1 –Ethanol and Electricity Production)

An increase in operation and maintenance costs, land availability, miscellaneous expenses, interest rate, or capital cost will result in an increased cost of electricity production, but this increase will not be as significant as the other factors discussed above do.

Electricity cost – St. Kitts Electricity Department generation cost

It should be noted that based on the ranges of input provided in Table 7.3, the cost of electricity does not trespass the current electricity generation cost at the St. Kitts Electricity Department. This creates a margin for revenue generation to subsidize the ethanol production that may lead to a cost competitive ethanol value. The amount of electricity sales will determine the annual revenues. It is envisioned that the electricity sales compared to ethanol production is limited and therefore not enough to compensate or subsidize.

7.4 Techno-Economic analysis – Electricity Production Scenario (Scenario 2)

Assumptions and Input Data

In this scenario it is assumed that the sugarcane (as delivered to plant)[221] will be used directly as fuel for a direct combustion system. Sugarcane availability depends on the harvesting period; this is between 3 – 5 months per year. Based on the available 6,000 acres of land at the time of this study, and a yield of 24.5 tons per acre (that represents 10-year average of full operation of the SSMC), there is a sugarcane production of 147,000 tons per year. The rated capacity of the power plant is estimated based on the assumption that the sugarcane cannot be stored over a longer period than the harvesting period, thus between 100 – 150 days per year, and a load factor of 0.7 for maintenance and other miscellaneous occurrences.

As pre-condition, the energy demand forms a determining factor to match production to demand and ascertain the commercial viability of biomass electricity production. This energy demand is estimated to be 10 MW (see section 7.2.3). Also the current electricity production cost of 0.17 US$/kWh at the St. Kitts Electricity Department is used as a reference point, whereby the biomass energy system electricity production cost should at least remain below 0.16 US/kWh.

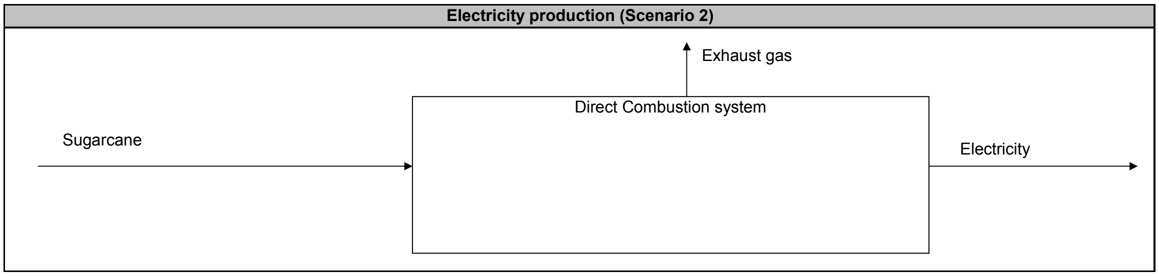

Figure 7.7. Schematic Overview of the Electricity Production Process (Scenario 2)

Figure 7.7 shows a very simplistic overview of a biomass-to-electricity system. In practice the fuel (biomass) has to be prepared before it can be incinerated in the boiler. This preparation process, whether it is chopping, grinding or milling, is done to minimize the particulate size, decrease the moisture content, create a more homogenous condition of the fuel and increase the biomass surface that is subjected to heat exchange. The general aim of this process step is to make the fuel workable and controllable and its specific characteristics when entering the boiler are based on practical choices made by the operator of the system.

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[221] The sugarcane (delivered as is) still needs to be prepared (grinded) before inserting in a boiler, here the assumption is made that the quality (energy content) of the cane will remain constant before incinerated.

The moisture content is an important determining factor for the heating value of the fuel. The higher the moisture content the lower the heating value. But if the fuel is too dry this may burn out to rapidly, and therefore the retention time in the boiler will be too short and producing not much energy. On the other hand, having a higher moisture content in the fuel, thus lower heating value, the fuel will burn slower and the heat exchange can occur more steady and improves the operational conditions and stability of the boiler and increases therefore the boilers efficiency. At the end it is a balancing act to define the optimal conditions for the fuel and is dependant on the operator's experience.

In this scenario the assumption is made that the fuel (sugarcane) is grinded (fractionated) and inserted to the boiler after open-air drying of 2/3 days, with an average moisture content of 50%. The remaining liquid or juice as a result of the grinding can be collected and sold to local or regional alcohol/beverage distillers for further processing.

There is a series of costs and expenses associated with the installation and operation of this kind of facility. The total investment cost for the power plant is dependent on the rated capacity, this is set at 1,500 US$ per kW for a 10-20 MWe Direct Combustion plant.

Based on the energy model there is an available primary energy (sugarcane as delivered) sufficient to supply a plant with a rated capacity of 44.8 MWe, with an overall electric efficiency of the power plant set to be 26%.[222] This is clearly more than the power demand on St. Kitts. Therefore the model is used to find the optimal conditions to yield energy for a rated capacity of 10 MWe. This may result in less required sugarcane quantities, which may mean less need of lands, under the assumption that there is no possibility to store the sugarcane over a longer time frame than 100-150 days a year. Take note that this is the baseline condition, in a later phase optimization options are discussed, where cane storage among other alternatives are discussed.

The annual operation and maintenance costs and other non-fuel expenses are estimated based on percentage of the total investment cost. The present value of the total annual costs is divided by the total electricity exported to the national grid to come to the cost of production of electricity. Table 7.5 presents the costs, expenses, and factors used for the calculation of the cost of electricity (COE).

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[222] Weighted average of electric conversion efficiencies between 20 – 30% of larger size plants ranging between 30-70 MWe.

Table 7.5. Input Data for the Electricity Production Scenario 2

Sugarcane production	Typical	Unit	Range
Yield	24.5	ton/acre	20.5 – 32.3
Harvesting period	120	days/yr	100 – 150
Power Plant (Direct Combustion)	**Typical**	**Unit**	**Range**
Moisture Content Cane	50	%	40 – 60%
Heating Value Cane	17	GJ/ton (HHV)	17.0 – 18.1
Sugarcane Cost	32.7	US$/ton (wet)	32.7 – 49.5
Overall Energy Efficiency	26	%	20 – 30%
Load Factor	0.7		0.6 – 0.8
Financial data			
Capital Investment	1,500	US$/kW	
Tot. Capital Investment	15,000,000	US$	+/- 25%
Fuel Cost*	1,073,541	US$/yr	
O&M Costs* (5.5% of Tot. Investment)	825,000	US$/yr	1 – 6%
Miscellaneous Expenses* (3% of Tot. Investment)	450,000	US$/yr	1 – 10%
Inflation Rate	8.7	%	1 – 15%
Equity/Debt ratio	0/100		
Economic Life	20	yr	
Interest Rate	10	%	1 – 20%

*Values for year one

Results

Given the cost and expenses showed in the above sections, the following results are obtained for an Electricity Generation-only facility.

The annual available electricity to the grid for sale amounts to 20,156 MWh per year. The cost of electricity generation is $ 0.13 per kilowatt hour. Table 7.6 provides a summary of these results.

Table 7.6. Summary of the Results for Scenario 2 Electricity Production

Output	Value	Unit
Needed land	1,340	Acres
Sugarcane production	32,830	ton/yr
Power Plant capacity	10	MW
Electricity to grid	20,156	MWh/yr
COE	0.131	US$/kWh

Under the baseline conditions, results that in order to produce cane to supply a 10 MW power plant, there is a need of at least 1,340 acres of land. There is potential to decrease the COE even further if the feedstock from 6,000 acres (147,000 tons) availability is extended over a longer period of time (not limited to 100 – 150 days/year), which leads to smaller scale power plant design (~10MW) and longer operating hours. Under the baseline condition the power plant can only run about 2,304 hours. This decreases income due to less available electric units to be sold and in the availability and reliability of this energy service. Later in this study optimization options are discussed to increase the fuel supply availability.

Sensitivity analysis

As previously done for Scenario 1, the influence of a wide range of parameters on the cost of production of electricity (COE) are assessed. As noted above, the COE was 0.131 US$/kWh, it is the combination of six main techno-economic factors that contribute to this cost, which are the *O&M costs, interest rate, capital investment cost, fuel cost, cane yield* and the *electric efficiency*. The COE can fluctuate based on the input ranges be between 0.101 – 0.171 US$/kWh.

Capital costs

Figure 7.8 shows that the capital cost has an impact on the cost of production of electricity. There could be a large uncertainty in the electricity production cost because only a limited amount of references were used for assessing the investment cost for a direct combustion system. The range is set to simply deviate from this baseline investment cost data by ±25%. In reality the cost range is estimated to be smaller, whereby the potential to decrease the cost of electricity is limited. In practice the conversion factors, costing data, etc are interdependent and the potential for overall performance improvement is higher.

Efficiency and heating value

An increase in the efficiency or in the heating value can lead to bringing the cost of production of electricity down. The reason for the overlap in the graph is because they both relate to the conversion of fuel into the desired output. This increase in output translates to an increase in plant capacity and total capital cost. The exponential relationship comes as the operation and maintenance cost and miscellaneous expenses are both functions of the total capital cost. Combining all of these costs leads to the exponential increase in cost of electricity production with a decrease in efficiency or fuel heating value. The electric efficiency has a higher influence on the cost of electricity than the heating value of the fuel.

Land availability

The more lands available the larger the cane production and power plant size, this creates an economy of scale, that leads to reduction of costs. The limitation in place is that the demand is only 10 MWe, and this forms a challenge to produce electricity cheap electricity. As can be seen in figure 7.8 there is a large potential to reduce the COE if the combination of land/cane production and the power plant capacity/demand is balanced.

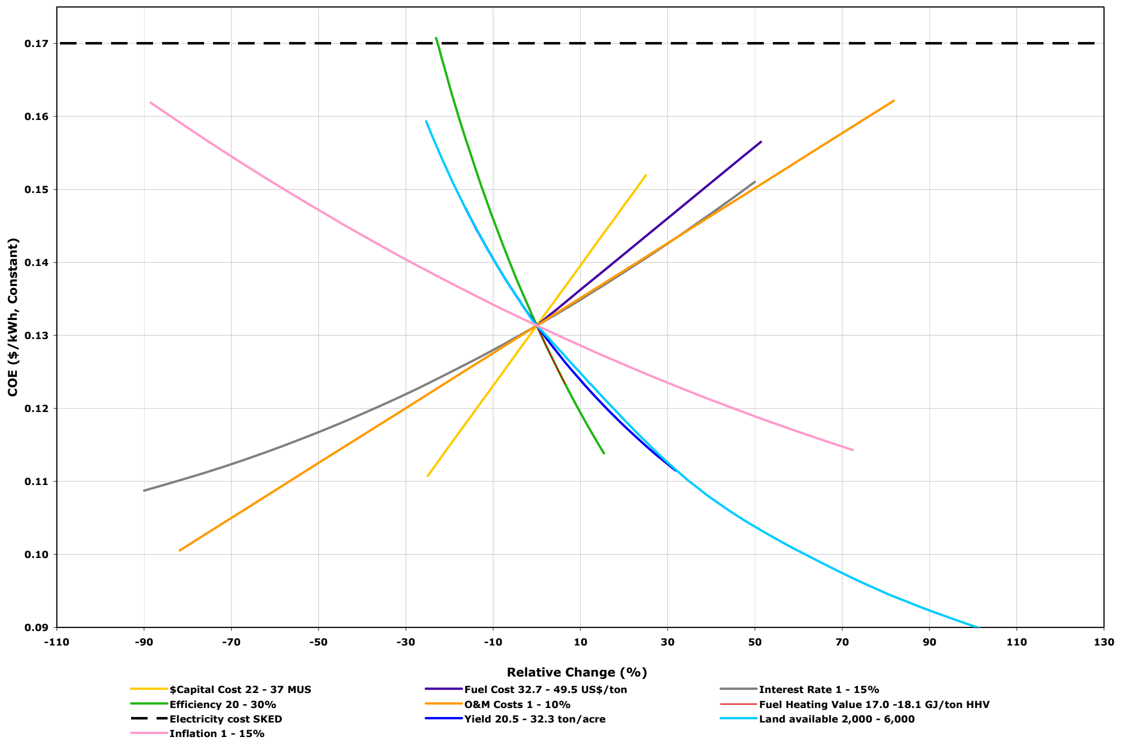

Figure 7.8. Sensitivity Results for Scenario 2 Power Production

Compared to the sensitivity results of Scenario 1, the land availability, capital, interest rate, and O&M costs in this scenario have the largest influence on the cost of electricity production. The reason for this is that it is arbitrary chosen to set rough ranges of 1-15%, 1-15% and 1-10% for the debt interest rate and O&M costs respectively. In practice O&M costs are in the lower end of the range applied in this scenario. And the inflation and interest rates could be set lower.

7.5 Optimization Alternatives

In this section a focus is set on optimization alternatives to improve the economic performance of each of the two biomass-to-energy conversion scenarios. A summary is provided of the results of the optimization alternatives at the end of this section.

7.5.1 Biomass feedstock treatment and storage

For both scenarios, the biomass feedstock-fuel-cost had a large impact on the production cost of ethanol and/or electricity. Depending on the end-product that you want to produce, and the associated conversion system, one can think of treating and storing the biomass feedstock. Storage is a determining factor for the feasibility of an electricity production plant. The aim is to have a continuous operation to provide a base load that reduces costs, in particular for O&M.

Drying

Because of the organic composition of the sugarcane it decomposes rapidly and makes storage a challenge. However, there exist alternatives to treat and store the sugarcane to extend the feedstock availability over the year. One such alternative is drying, whereby the moisture content of the sugarcane can, depending on heating temperature, be lowered to a moisture content level of about 28% w.b. This results in stagnating the decomposing activity.[223, 224]

Pelletizing is based on a similar principle, but is an energy intensive process, as it includes a densification process that uses electric driven extruders and roller press with an energy consumption rate between 22 – 130 $\text{kWh/ton}_{\text{cane}}$ and 60 – 70 $\text{kWh/ton}_{\text{cane}}$ respectively. The sugarcane is dried to moisture content levels around 8-15%[225], which makes it possible to store over a longer period without an extensive bio-conversion of this biomass or fuel. Because this process is very energy intensive it requires economies of scale to be a feasible option for St. Kitts.

Cane juice storage

Cane juice will be produced in both scenarios as a by-product or intermediate product. Therefore it is of interest to investigate the potential to store and transport this juice for conversion in other end applications (i.e. food industry or distillation plants). The practice in the sugar cane juice industry today, is that harvested cane is stored in a shed at ambient temperatures before it is further processed. Once extracted the cane juice is immediately chilled and stored before distribution. The delay in extraction of juice from harvested sugarcanes is reported to cause some changes in the juice quality. Low temperature (~10°C) storage has been observed to be able to prolong the shelf-life of the juice for about 3 days, without any change in juice quality, and up to 9 days to still maintain good quality juice.[226] One has to further analyze the energy requirements for the cooling system, and other storage and transportation implications to assess its feasibility for exporting sugarcane juice from St. Kitts.

7.5.2 Increasing overall system efficiency

An alternative for improving the overall efficiency of a biomass-to-energy conversion system is to improve the quality of the sugarcane/bagasse presented to the boilers. It is important when considering cane quality to look at the total non-combustibles – ash and moisture – combined. Thus, there are two possibilities, improving the moisture content and reducing the ash. Neither is particularly easy but the effect, predicted by the following formula, can be important:

$$\text{GCV}^{227} = 196.05\,(100 - (\text{moisture\%} + \text{ash\%}))\ \text{kJ/kg}$$

[The equation shown is a simplified version of the full formula which also compensates for the difference in the calorific values of sucrose and fiber][228]

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[223] Avant-Garde Engineers and Consultants Ltd, Bagasse Drying Methods, website: www.avantgarde-india.com/techpapers/**Bagasse**%20**Drying**%20Methods.pdf.

[224] Sosa-Arnao et al., Sugarcane Bagasse Drying – A review, International Drying Symposium (IDS), Brazil, 2004.

[225] Suurs, R., Long distance bio-energy logistics, An assessment of costs and energy consumption for various biomass energy transport chains, Copernicus Institute, Utrecht University, 2002.

[226] Yusof et al., Changes in quality of sugar-cane juice upon delayed extraction and storage, Faculty of Food Science and Biotechnology, University Putra Malaysia, 1999

[227] GCV is the Gross Calorific Value of the sugarcane/bagasse matter.

[228] Inkson, M., Co-generation for export: a review, Biotherm Ltd, England, 2000, website: http://sucrose.com/bsst/2000agm1.html.

Sugarcane varieties that contain either higher levels of sucrose for ethanol production or higher fiber content can be created by using genetic manipulation techniques. This involves increasing the heating value of the cane to be used as fuel for direct electricity generation. Table 7.7 presents an overview of a variation of sugarcane types investigated on Barbados.[229]

Table 7.7. Sugarcane Varieties on Barbados[230]

Variety	Ton cane/acre (stalk only)	Fiber % stalk cane	Ton biomass per acre	Ton Fiber per acre	Brix[231]	Purity
WI79460	45.6	26.08	61.8	19.3	13.13	68
WI79461	51.4	24.28	65.4	18.8	15.4	81.9
WI80534	42.5	24.25	57.8	17.1	12.22	71.5
B69689	35.9	26.29	54	17.5	13.85	79.1
IS76163	36.2	33.46	54.7	19.5	9.82	50.4
Average of five varieties	42.3	26.9	58.7	18.4	12.9	70.2
Values used in study	42.5	25	55.9	16.3	11.8	71.4
Current sugar cane harvest	21	16	.	3.4	18	83

Yield

Barbados is located in the same geographical and climatologically region as St. Kitts. Table 7.7 shows that sugarcane yields on St. Kitts could be improved if these sugarcane varieties are planted. Currently the yields on St. Kitts are 24.5 ton/acre, and could theoretically increase to levels around 35.9-51.4 ton/acre (stalk only) or 54- 65.4 ton/acre (with tops and leaves) as was shown in the case of Barbados. Other sources, as in the case of Hawaii, indicate that with the introduction of fertilizers and improved mechanization even higher yields of 100 ton/acre are attainable.[232] Moreover, in the centre southern region of Brazil, sugarcane yield per acre increased from 55 tons per acre in 1975 to over 90 ton per acre in 2003 with a sucrose content of 14.5% by weight.[233] The yield improvement potential depends on factors such as the climatological conditions, soil quality, cultivation method used, etc. For St. Kitts the theoretical yield improvement potential is set at 51.4 ton/acre (stalk only). Soil fertility and quality can be adversely affected upon removal of these crops. Reincorporation of stillage produced by the energy system into the soil, may compensate for this. Testing on smaller plots within the island is recommended before proceeding with this step.

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[229] Copersucar website: http://www.copersucar.com.br/institucional/ing/academia/cana_acucar.asp

[230] Summary of tests done at the ARVTU & STRU Barbados (May 2004)

[231] Brix is a system for measuring the sugar content of grape/sugarcane juice by its density. Each degree is equivalent to 1 percent of sugar in the juice. For example, grape juice which measures 15.5 degrees on the Balling or Brix scale contains about 15.5% sugar.

[232] Gibson, A.C., Course: Plants and Civilization, University of California Los Angeles (UCLA), website: http://www.botgard.ucla.edu/html/botanytextbooks/economicbotany/Saccharum/index.html.

[233] Shapouri et al., *The economic feasibility of ethanol production from sugar in the United States,* U.S. Department of Agriculture, July 2006.

Sucrose content

The sucrose level of the sugar cane on St. Kitts varied between 12 – 15 % by weight; the theoretical potential is between 10 – 20%[234, 235] by changing cane varieties or adapting the cultivation and harvesting procedure. Therefore specific agronomical studies have to be performed to assess the improvement potential in cane quality for St. Kitts. In this study the theoretical potential increase to 20% sucrose content is used.

Fiber content

In case of using sugarcane for the production of electricity, the power production capacity can be enhanced by using "fuel cane"[236] instead of sugar cane. Fuel cane is harvested with tops and leaves and after-drying using solar radiation; crushing this cane can have a higher heating value. To harvest fuel cane, some adaptations have to be made in the harvesting method, whereby mechanical harvesting of green fuel cane is the most recommended. Based on the values in Table 7.10 a yield of 65.4 ton/acre (with tops and leaves) and a fiber content of 18.8% can be achieved. This value is further used in the optimization analysis. The same considerations taken for increased yields apply.

Year-based cultivation

Next to genomics research (increase fiber and sucrose content), one can also consider the possibility of cultivating sugarcane year through. This will require additional research in weather patterns, and also may result in the need for irrigation systems. The irrigation alternative needs to be assessed carefully, since this may put burden on the aquifers available, that are primarily used for drinking water extraction. Waste Water could be used as alternative source for irrigation but one has to take in mind that large fractions of the cane lands are located on higher elevations and are therefore not in the proximity of ground or waste water sources that creates logistical/technical challenges (e.g. pumping costs and required pipelines).

7.5.3 Internal factory energy efficiency improvement[237]

From the sensitivity analysis for the electricity production scenario (Scenario 2), it is discussed that a continuous or firm capacity for power production is preferred from a technical and financial perspective. Acknowledging the limitation of increasing cane as feedstock, other energy efficiency improvement options are considered.

The following are alternatives to achieve continuous power export:

- Release energy by improving efficiencies in individual processes within the system.
- Secure the power for export to the grid by including bagasse storage.
- Ensure firm power by arranging auxiliary fuel (co-firing).

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[234] Gibson, A.C., Course: Plants and Civilization, University of California Los Angeles (UCLA), website: http://www.botgard.ucla.edu/html/botanytextbooks/economicbotany/Saccharum/index.html

[235] Shapouri et al., *The economic feasibility of ethanol production from sugar in the United States,* U.S. Department of Agriculture, July 2006.

[236] *Fuel Cane* is a special variety of very high fiber sugar cane that would be grown for the primary production of fuel for the generation of consumer electricity

[237] Inkson, M., Co-generation for export: a review, Biotherm Ltd, England, 2000, website: http://sucrose.com/bsst/2000agm1.html

- Change in end-use application or product.

Release energy by improving efficiencies in individual processes within the system
To be able to assess the greatest efficiency improvements potential, an exergy analysis is required. This will allow identifying the quality of the energy type (heat or electricity), while simultaneously identifying the equipment or processes that are energy intensive. As an example, traditional steam driven milling wheels are large steam consumers in the overall process. One can increase the overall efficiency of the plant by replacing these steam-driven milling wheels with electrically driven wheels to save quality heat for other process uses. Other process steps with significant parasitic loads include crushing and distillation.

Secure the power export by including bagasse storage
By installing exhaust heat recovery equipment or replacing/modifying, the saved heat can be used to dry the bagasse or sugarcane and store it over a longer period to increase both fuel availability and power plant availability. The outputs of Scenario 2 show that the energy demand on the island of St. Kitts is very important. Based on 6,000 acres and a yield of 24.5 ton/acre, sufficient sugarcane can be produced that could supply a capacity of 44.8 MWe. From the demand forecasts for the St. Kitts Electricity Department, the peak demand by 2010 will be around 32 MWe. Several currently installed units with total installed capacity of 33.5 MWe are reaching the end of their technical lifetime and are being phased out. To prevent a capacity shortage and provide base load power at SKED, at least an additional 10 MWe has to be installed by 2010, next to the already planned diesel generation capacity expansion of 11.5 MWe.[238] The results show that 44.8 MWe (operating only 120 days per year) is more than enough, and ways need to be found to dry and store the sugarcane to extend the fuel availability over a longer period while scaling down the power plant to required levels. This type of analysis requires a detailed energy and exergy analysis and is out of the scope of this study, but is certainly recommended to execute.

Ensure firm power by arranging auxiliary fuel (co-firing)
By importing an auxiliary fuel (e.g. coal), co-firing can be done to increase the power or ethanol production capacity, create economies of scale, and increase the availability and reliability of the power plant. In the case of ethanol production, it is envisioned that by importing an auxiliary fuel, more heat can be generated for the distillation unit, leaving the local imported hydrated ethanol to be processed into de-hydrated ethanol. For a co-firing power plant, as in Guadeloupe, low sulfur quality coal can be imported from Colombia to co-fire in the combined heat and power plant (CHP). When designing the power plant, one has to take in account the energy demand and its potential future increase on the island. When importing coal, the power plant capacity size can be adjusted to the demand.

Change in end-application or product
Another alternative to increase the overall energy efficiency is to switch to an end use application or a product that requires less energy to be produced. In the case of the

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[238] De Cuba, K.H., Towards a Sustainable Energy Plan for St. Kitts and Nevis, March 2006, table 6.2, page 84.

ethanol production process, instead of producing dehydrated ethanol, hydrated ethanol could be produced. When producing hydrated ethanol, the distillation process is excluded; this is the highest source of internal energy consumption with 45-70% thermal-energy requirements (see Section 7.2.3). The costs of producing hydrated ethanol may decrease by 20% of total ethanol plant investment cost, while producing about the same amount of ethanol. The purity of the hydrated ethanol is 95%, thus it contains 5% water. This hydrated ethanol is suitable to blend with an ignition improver, or as a 15% emulsion in diesel that is known as diesohol.[239] There is no clearity whether this blend is commercially available, but it makes sense to create this blend only as long as the ethanol is cheaper than diesel and taking in mind that it can in general only be consumed in heavy-duty diesel engines and may form problems when applying to diesel car engines. Alternatively the hydrated ethanol can be exported to a regional centralized dehydration unit (e.g. Jamaica) for further processing.

The decrease in energy requirement (heat) from excluding the distillation unit is useful to assess. The more heat available, the larger the boiler capacity can be, thereby producing high pressure steam that can be exhausted on high pressure steam turbines. The exhaust heat will be still hot enough to exhaust on a back pressure steam turbine. This is a Combined Heat and Power system, allowing more electricity to be produced. In addition, heat may also be used for drying and maintaining a steady supply of fuel throughout the year. The steam quality assessment (exergy analysis) is out of the scope of this study but is recommended to be further analyzed.

7.5.4 Bio Municipal Waste use

As an alternative biomass resource the BMW was identified, this amounts about 8,500 tons per year. This waste feedstock, depending on the waste management system in place and the application of waste tipping fees, can potentially create a base to reach a low-cost feedstock stream. Also demographic and economic projections indicate a rapid growth in waste production that contributes to a long term availability of this potentially low-cost feedstock for biomass-to-energy conversion system.

Currently on St. Kitts no tipping fee is required for household waste (residential waste). Tipping fees to dump the waste in the landfill are only applied to industrial and commercial waste and demolition waste, where the tipping fee is set on EC$ 54 /ton (20 US$/ton) and EC$ 15/ton (5.6 US$/ton), respectively. The investments required to set up an integrated waste management system will determine the cost per ton of the BMW as feedstock for a biomass-to-energy conversion system. This assessment is out of the scope of this study, but is seriously recommended to be looked into.

If we estimate the energy potential, assuming a conventional Rankine Cycle power plant with an overall electric efficiency of 25%, a load factor of 0.8 and an all-year round BMW availability, the electricity production and power plant capacity would be:

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[239] Australian Government, Comparison of Transport Fuels-Part 2 Details of Fuels, website: www.greenhouse.gov.au/transport/comparison/pubs/2ch13.pdf.

Energy potential from BMW: 11.2 MJ/kg * 8,500 *10^3 kg/yr = 95,200 GJ/yr * 0.25 =23,800 GJe/yr * 0.2778 = 6,612 MWh/yr. 6,612 MWh/yr / (**365days***24hrs*0.8) = 0.9 MWe

In the case of St. Kitts the BMW delivery will require investments in an improved MSW collection, separation, and treatment system. Under current conditions, small scale waste production compared to high investment requirements for the collection, treatment and disposal of waste, the costs of investment for these systems is envisioned to be high. Even including tipping fees, the cost of delivered BMW to the facility as a co-firing fuel will remain high. The rate of waste production depends on the GDP per capita, economic activities as tourism/services, the spectrum of appliances or products available on the market, and other socio-economic factors. One has to keep in mind that the waste quantity will continue to increase to larger quantities and may then become financially attractive to include in a biomass-to-energy conversion system.

Because of lack of detailed information on the composition, separation quality and costs, this option is not further scrutinized in this study.

7.5.5 Carbon credits

Via the Kyoto Protocol, several financing mechanism were created to combat Global Climate Change. The Clean Development Mechanism (CDM) is of particular interest for St. Kitts. By mitigating or avoiding greenhouse gases, in particular CO_2 emissions, a credit can be allocated to the amount of avoided CO_2 emissions, thus helping to reduce upfront investment cost of a bio-energy project.

To be able to assess the CO_2 mitigation level of each scenario, the baseline, or current CO_2 emissions is established. The current electricity generation system installed on St. Kitts is a diesel fueled power plant with a total installed capacity of 33.5 MWe and the average annual electricity production is 124,741 MWh/year. The fuel consumption is about 8.6 Mgallons or 32.5 million liters per year. The fuel type used is fuel#2 diesel with a heating value of 36 MJ/L or 137 MJ/gallon (LHV). As a result, the total annual primary energy entering the power plant is about 1,171 TJp.

The CO_2 emission factor related to this fuel type is 165 lb/MMBtu or 0.0709 metric ton CO_2/GJ (fuel input)[240]. Thus, Needsmust power plant at the St. Kitts Electricity Department emits about 83,241 metric tons of CO_2/year.

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[240] U.S. Environmental Protection Agency (EPA), Stationary Internal Combustion Sources, Emission Factors, section 3.4-5.

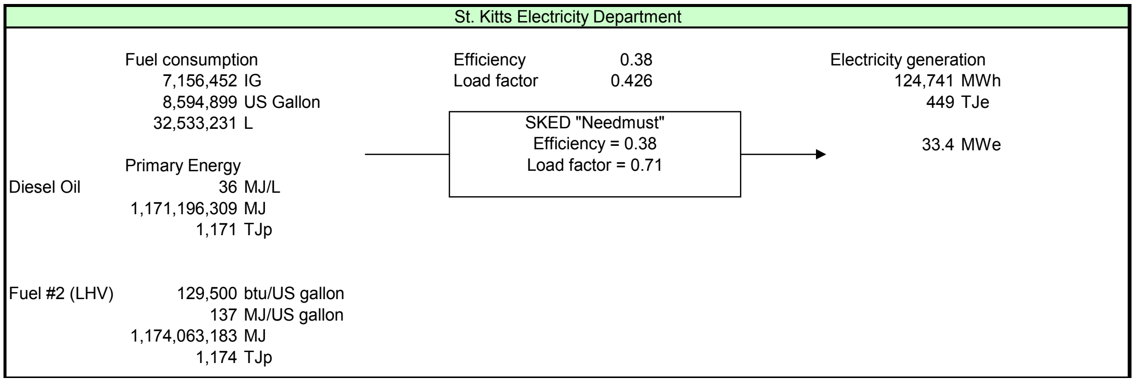

Figure 7.9. Schematic Overview of the Diesel Power Plant on St. Kitts

For the transport sector, the gasoline emission factor has to be used to assess the CO_2 mitigation by replacing gasoline by ethanol. The emission factor for gasoline is 154 lb/MBtu or 0.0698 metric ton CO_2/GJ. 3.3Mgallons of gasoline were imported in 2005, with the energy content of this amount of fuel was 399,300 GJp. The total CO_2 emissions from the combustion of gasoline in transport vehicles was 27,871 metric tons CO_2 in 2005 for St. Kitts.

To estimate the CO_2 mitigation level for each scenario, the difference in primary energy consumption is required. This means that when a scenario produces two different energy carriers, e.g. electricity and ethanol, the primary energy input should be allocated to energy content of each energy carrier. The difference between the primary energy input for the diesel system and the primary input for the energy carrier is the amount of primary energy mitigated. In other words, one has to calculate the carbon credits by assessing the gasoline replacement by the ethanol, and the fossil fuel based electricity production by the co-generated electricity. To quantify the CO_2 amount mitigated, this primary energy saving has to be converted into heat/electricity. It is here where the CO_2 emission factor is used. Recent CO_2 market price values include EUR15.5 per ton (US$20.7) for the EU (March 2007)[241] and US$12.0 per ton CO_2 in the U.S. (December 2006)[242].

Optimization of Scenario 1 – Ethanol and Electricity production

The objective here is to highlight the improvement potentials for each scenario. More detailed financial and energy analysis is required to assess the absolute cost reduction of each optimization option. Therefore one should consider the projected values as indicative and not as absolute reductions.

Optimization alternatives:

1. By selling the excessive electricity produced to the national grid, an additional revenue is gained to subsidize the whole biomass-to-energy system and lower the ethanol production cost. As done previously in section 7.3.2, a rate of **0.13 US$/kWh** is set, creating a margin of 0.04 US$/kWh.

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[241] Climate Corporation, website: http://www.renewable-energy-world.com/articles/article_display.cfm?Section=ARCHI&C=PoMaF&ARTICLE_ID=271583&KEYWORDS=%7Bcarbon%7D%26%7Bmarket%7D.

[242] Lavelle, M., U.S. News *The Market to Clear the Air: The growing trade in carbon emissions offers hope as a pollution solution*, website: http://www.usnews.com/usnews/biztech/articles/061210/18carbon.htm.

2. By genetically manipulating the fiber and sucrose content of the sugarcane, higher ethanol and/or power yields can be achieved. As mentioned previously the theoretical potential is between 0.10 – 0.20[243],[244] by changing genetically the composition of the cane or adapting the cultivation and harvesting procedure. In this case we assume that this is achievable for St. Kitts. Thus the sucrose content increases from **13.5% to 20%**.
3. The sugarcane production yield could, with more intensive energy saving measures in the cultivation, harvesting, transport, and storage/handling, lead to considerable reduction in biomass feedstock costs. The yield improvement potential depends on factors as climatologically conditions, soil quality, cultivation method used, etc. For St. Kitts the theoretical yield improvement potential is set at **51.4 ton/acre** (stalk only).
4. The power production capacity in this plant can be optimized by adding BMW to the fuel feedstock, the BMW can be used in the period that no bagasse is available. This means that the operating hours can be increased. Note that the amount of energy in BMW is only 5.8% of the sugarcane amount. The assumption is made that the 8,500 tons of BMW (**95,200 GJ/year**) is co-fired with the same cost value as the bagasse in the power plant of the ethanol facility and the same installed power plant capacity is maintained.
5. The amount of mitigated carbon dioxide is assessed for this scenario and the potential credit is estimated and deducted from the Total Capital Investment cost for the ethanol plant. The amount of CO_2 mitigated by replacing fossil fuel based electricity with bagasse based electricity is 848 metric ton CO_2 per year.[245] 3.3Mgallons of gasoline were imported in 2005; the energy content of this amount of fuel was 399,300 GJp. The total CO_2 emissions from the combustion of gasoline in transport vehicles were 27,871 metric ton CO_2 in 2005 for St. Kitts. The total ethanol production was 2.7 Mgallons with an energy content of 242,403 GJp. Based on this information the amount of CO_2 mitigated emissions is 10,951 metric tons of CO_2 per year. In total the amount of avoided CO_2 emissions was 11,799 metric tons per year for the ethanol plant.[246] With an EU market carbon value of 20.7 US$/ton CO_2 and a project lifetime of 20 years, the estimated revenue from carbon credits is about **4,884,786 US$**[247] over the project lifetime.

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[243] Gibson, A.C., Course: Plants and Civilization, University of California Los Angeles (UCLA), website: http://www.botgard.ucla.edu/html/botanytextbooks/economicbotany/Saccharum/index.html

[244] Shapouri et al., *The economic feasibility of ethanol production from sugar in the United States,* U.S. Department of Agriculture, July 2006.

[245] Amount of excess electricity to grid from the bagasse co-generation system was 8,609 MWh/yr (Table 7.4), this converted to primary energy GJp is (8,609 MWh /3.6 and divided by 20% electric conversion efficiency of the system is 11,957 GJp). The CO_2 emission factor for fuel#2 diesel is 0.0709 metric ton CO_2/GJ. Thus amount of mitigated CO_2 emission is 11,957 GJp * 0.0709 mton CO_2/GJ is about 848 mton CO_2 per year.

[246] Note that the Carbon Mitigation Level depends on whether the ethanol (energy carrier) is consumed locally or exported, when exported the CO2 emissions related to the transportation and handling need to be taken in account. Therefore the distance of an X amount of volume of e.g. ethanol transported is an important factor whether the energy carrier is still eligible for Carbon Credits.

[247] This number is an estimation based on a simple summation of linear annual Carbon emissions, in practice the CDM application procedure is more complex and exists of basically four steps, *1) Preparation of a Project Design Document (PDD), 2) Validation and Registration of the Project Activity, 3) Monitoring, Verification and Certification and 4) Issuance of Carbon Emission Credits.* The timeframe for these steps are project specific and therefore the Issuance of CERs can take up to 2-3 years. Also the annual Carbon Credit Value should be depreciated (using e.g. a 10% discount

6. Excluding the distillation process from the ethanol production system where hydrated ethanol is produced can lead to energy savings since this process is energy intensive. The parasitic energy consumption is lowered **from 2.0 to 0.9 kWh/gallon**. In this way more heat is available for power production (using High Pressure Steam boilers instead of Mid/Low-Pressure Steam Boilers), and larger amounts of electricity could potentially be exported to the grid. The hydrated ethanol can be exported to a regional centralized dehydration unit (e.g. Jamaica) for further processing and eventual export to the U.S. market. The assumption is made that the distillation unit is excluded from the process and larger investment costs are required for the CHP plant, this means that the **net overall plant cost may increase by 10%**. The electrical conversion efficiency increases from **20 to 30%** by using a combined cycle system. The amount of ethanol produced remains about the same level (hydrated ethanol containing 5% water).

Optimization alternatives

The improvement alternatives are summarized in Table 7.8 and the accumulative impact of implementing these alternatives are projected in Figure 7.11.

Table 7.8 Summary of Improvement Options for the Ethanol Plant (Scenario 1)

Improvement option	Change
1. Electricity sales	At rate of 0.13 US$/kWh
2. Increase sucrose content	from 13.5 to 20.0 % by weight
3. Increase Sugarcane Yield	from 24.5 to 51.4 ton/acre
4. Include BMW	95,200 GJp added energy
5. Carbon credit value assessment	Reduction in Total Capital Investment
6. Excluding distillation unit, produce hydrated ethanol	Overall electric efficiency increase from 20 to 30%, increase in ethanol plant investment of 10%

Optimization results for Scenario 1

Figure 7.10 depicts the relative reduction in the ethanol production cost. The results are based on rough assumptions and should not be taken as absolute changes in cost value. The objective is to highlight the improvement potentials for each scenario. More detailed exergy and energy analysis are required to assess the absolute cost reduction of each optimization option.

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rate and taking in account a project lifetime of 20 years). The detailed assessment of the CDM application procedure is out of the scope of this study.

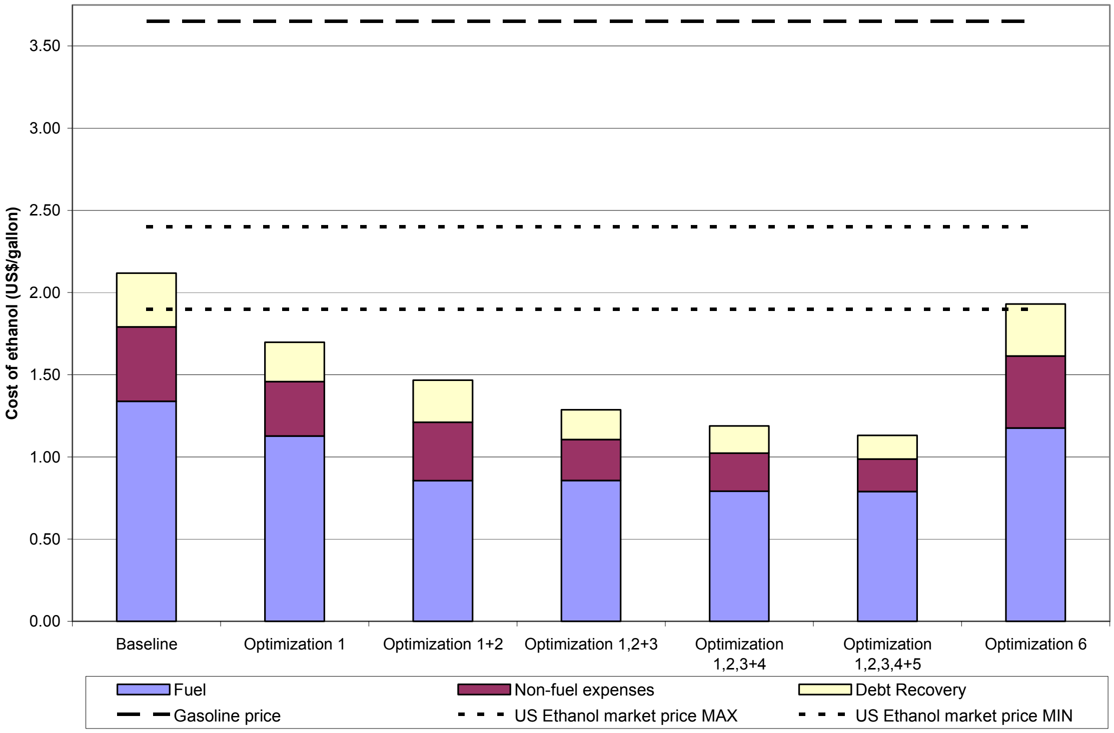

Figure 7.10 Results of the Optimization Alternatives for Ethanol Production (Scenario 1)

By selling the excessive electricity to the national grid with a rate of 0.13 US$/kWh (Optimization 1), the cost of ethanol production on St. Kitts could fall below the current U.S. ethanol market value range of 1.90 US$/gallon. Implementing the additional optimization options, in an accumulative manner, by increasing the sucrose content from 0.135 to 0.20% of the feedstock (Optimization 2), and introducing additional optimizations, 3, 4 and 5 may lead to a decrease of the ethanol production cost to 1.13 US$/gallon.

However, to be on the conservative end, one has to take in mind that no transport and other export related logistical costs are included and additional optimization combinations are required to de facto come under the lower end U.S. ethanol market value. Therefore it will remain a challenge to assure its feasibility. In case of producing hydrated ethanol (Optimization 6, excluding distillation and increasing the power output), the cost of ethanol may change marginally; a decrease from 2.12 to 1.93 US$/gallon is observed. Note that a positive U.S. ethanol market price decrease could provide a margin for St. Kitts Ethanol to be exported.

At the local level, the gasoline price (US$3.65 per gallon) is high enough that there is no need for optimization effort in the ethanol production chain to come to a competitive ethanol cost. A downside is that the local ethanol demand is limited to the 10% blending capacity of the local consumed gasoline. This amount is 409,619 gallons/year of ethanol while the ethanol production is about 2.7 million gallons per year and is more than enough to supply the nation with ethanol, however, this will create an excess of about 2.3

million gallons of ethanol that cannot be exported or used otherwise. This confirms the priority to have a competitive ethanol production cost on the global market to be able to assess ethanol opportunities in a small island state as St. Kitts and Nevis.

Optimization of Scenario 2 – Electricity production

As is the case above, the objective here is to highlight the improvement potentials for each scenario. More detailed financial, exergy and energy analysis are required to assess the absolute cost reduction of each optimization option. Therefore one should consider the projected values as indicative and not as absolute reductions.

Optimization alternatives:

1 The amount of mitigated carbon dioxide is assessed for this scenario and the potential credit is estimated and deducted from the Total Capital Investment cost for the ethanol plant. For optimization 1, a total of 21,534 GJp is consumed to produce 20,156 MWh/year by the 10 MWe biomass power plant. The amount of CO_2 mitigated by replacing fossil fuel based electricity with cane based electricity is 1,527 ton CO_2 per year.[248] With an EU market carbon value of 20.7 US$/ton CO_2 and a project lifetime of 20 years, the estimated revenue from carbon credits is about **632,071 US$**[249] over the project lifetime.

2 In case of opting to invest in drying and storage of sugarcane coming from 6,000 acres of land, an **incremental investment cost of 20%** is estimated. This will extend the fuel availability beyond the 120 days per year. The aim is to supply a 10 MWe power plant and run this plant for base load power supply.

3 Another alternative to extent the fuel availability or supply is to import coal to co-fire, as in the case of Guadeloupe, with the cane in a power plant. The cost of importing coal is assessed within the two extreme ranges of 8.55 US$/ton (8,800 Btu, 0.8 SO2, US market, EIA 2007 report) to 52.09 US$/mton – whole sale price (Australia, WB, 2007)[250], in this study the cost of coal is set at 44.6 US$/ton (higher end of the U.S. coal). The incremental capital investment cost for co-firing coal with bagasse is set between 50 – 250 US$/kW.[251] The challenge for St. Kitts is that the delivered coal needs to have a price lower or equal to the current biomass fuel cost. The estimated biomass fuel cost is 32.7 US$/ton (with heating value of 17 GJ/ton - HHV). Knowing that the energy content of coal (27 GJ/ton) is higher than the cane heating value the cost difference can be over bridged. To supply a 10 MWe, a monthly available primary energy of about 69,764 GJp is required (considering 120 days of harvest). An amount of 20,671 ton (over 8

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[248] Amount of excess electricity to grid from the bagasse co-generation system was 8,609 MWh/yr (Table 7.4), this converted to primary energy GJp is (20,156 MWh /3.6 and divided by 26% electric conversion efficiency of the system is 21,534 GJp). The CO_2 emission factor for fuel#2 diesel is 0.0709 metric ton CO_2/GJ. Thus amount of mitigated CO_2 emission is 21,534 GJp * 0.0709 mton CO_2/GJ is about 1,527 mton CO_2 per year.

[249] This number is an estimation based on a simple summation of linear annual Carbon emissions, in practice the CDM application procedure is more complex and exists of basically four steps, *1) Preparation of a Project Design Document (PDD), 2) Validation and Registration of the Project Activity, 3) Monitoring, Verification and Certification and 4) Issuance of Carbon Emission Credits.* The timeframe for these steps are project specific and therefore the Issuance of CERs can take up to 2-3 years. Also the annual Carbon Credit Value should be depreciated (using e.g. a 10% discount rate and taking in account a project lifetime of 20 years). The detailed assessment of the CDM application procedure is out of the scope of this study.

[250] http://web.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTDECPROSPECTS/0,,menuPK:476941~pagePK:51084723~piPK:51084722~theSitePK:476883,00.html

[251] EIA Energy Technology Essentials, January 2007, website: http://www.iea.org/Textbase/techno/essentials3.pdf

months) of coal is required per year to supply a co-firing power plant over the whole year.

4 Use of an alternative system to produce electricity is considered here. Although there are currently limited commercially operated gasification systems, it is expected that within five years capacities as required on St. Kitts may become feasible. Therefore, as a futuristic glance, a gasification system is assessed. Gasification systems have higher overall energy conversion efficiency. Assuming that either a reciprocating gas engine or a gas turbine is installed as part of the gasification system, the electrical efficiency can range between 22-40%.[252],[253] In this scenario the electrical efficiency is set at 35%; the sugarcane can be directly fed into the gasification system; and the investment cost is set at 19.6 MUS$ for a 2000 TPD gasifier and a scale factor of -0.65. (See Annex J). Thus, more primary energy is available to produce electricity for the grid.

Optimization alternatives

The improvement alternatives are summarized in Table 7.9 and the impact of implementing these alternatives on the COE are projected in Figure 7.12.

Table 7.9 Summary of Improvement Options for the Power Plant (Scenario 2)

Improvement option	Change
1. Carbon Credit	Reduction in Total Capital Investment
2. Cane drying and storage	20% additional investment to the total capital investment of the power plant for cane drying and storage, maintain lands at 3,700 acres, supply enough cane for a 10 MWe plant over an extended period of 330 days. Conversion efficiency set at 26%.
3. Co-firing with coal	Import coal at 44.6 US$/ton (heating value 27 GJ/ton) Incremental capital cost of 150 US$/kW Importing 20,671 ton/year of coal
4. Introducing gasification system	Overall electric efficiency increase from 26 to 35%, the plant capacity is set at 10 MWe, investment cost is set at 2,000 US$/kW.

Figure 7.11 depicts the relative reduction or changes in the electricity production cost when implementing the above described optimization options and switching from a Direct Combustion system to a Gasification system.

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[252] American Council for an Energy Efficient Economy, Small Scale Cogeneration (CADDET 1), November 1995, website: http://www.aceee.org/store/proddetail.cfm?CFID=6190&CFTOKEN=44729708&ItemID=65&CategoryID=10.

[253] OPET-RES, Micro and Small –scale CHP from Biomass (<300 kWe), Technology Paper 2, 2002, website: websrv2.tekes.fi/.../Viestinta_ja_aktivointi/Julkaisut/OPET-RES/TechnologyPaper2_chp_70404.pdf.

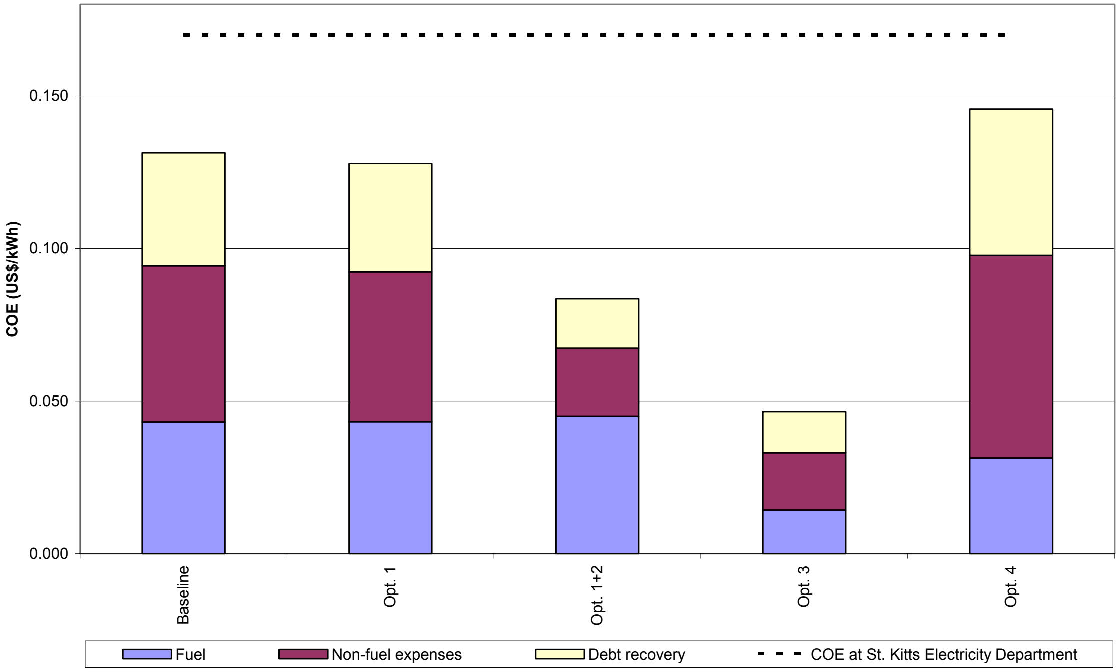

Figure 7.11. Results of the Optimization Alternatives for Electricity Production (Scenario 2)

The implementation of optimization 1, using carbon credits to reduce the initial capital investment leads to a limited reduction of cost to 0.128 US$/kWh. Optimization 2 (Cane drying and storage) results to reduce the cost to 0.084 US$/kWh, whereby the electricity could be supplied year round with an power capacity of 10 MWe. Note that this optimization alternative can also represent the case of introducing an irrigation system, whereby the 6,000 acres is cultivated in sections to provide a year-through feedstock supply. Optimization 3 (co-firing coal) will provide enough primary energy to provide a baseload power production over the year. Considerable cost reduction can be achieved, leading to a COE of 0.05 US$/kWh. Optimization 4 (switching from Direct Combustion to Gasification) resulted in a 1,000 acres of land needed, at a cost of electricity of 0.146 US$/kWh. Note that this is because an electrical efficiency of 35% was assumed. This occurs while yielding excess cane that can either be dried and stored or crushed for cane juice extraction as local beverage or other uses.

As general observation, lower costs of electricity production are achievable for St. Kitts by increasing the land availability, but the cost effectiveness is challenged due to the limited energy demand on the island. An alternative may be to export this generated electricity to the neighboring island of Nevis, whereby under water interconnection cables will have to be installed and additional studies are required for its feasibility.

7.6 Summary of Results

Two different biomass-to-energy conversion systems were identified as alternatives to convert the biomass into energy. Scenario 1, described the conversion of cane into ethanol and electricity. Scenario 2 involved converting biomass to power using a direct combustion system. Further optimization options were discussed and their impacts on the cost of ethanol and/or electricity production were estimated. This section summarizes the results of the techno-economic analysis performed for each scenario.

Table 7.10. Cost and Price Comparison of Fuels (US$ per gallon)[254],[255]

Fuel	Typical Costs (US$/gallon)	Cost range (US$/gallon)	Typical Market Value (US$/gallon)	Market Value Range (US$/gallon)
Gasoline (local)	-	-	3.65	2.72 – 4.13
U.S. Ethanol	-	-	1.90	1.90 – 2.40
Ethanol (de-hydrated, local in Constant $)	2.12	1.86 - 2.87	-	-
Ethanol (hydrated, local in Constant $)	1.93	1.71 - 2.82	-	-

The wholesale cost of ethanol for the country of St. Kitts and Nevis is considerably higher than the U.S. market value of US$1.90/gallon. The financial feasibility of ethanol production at the end depends on the possibility of exporting the ethanol with a cost lower than the U.S. ethanol market price. The baseline de-hydrated ethanol production cost on St. Kitts of 2.12 US$/gallon is higher than the lowest end of the range of 1.90 – 2.40 US$/gallon (U.S. market value in the 1st quarter of 2007). Note, however, this market price is very volatile (see Figures 4.6 and 4.7). Therefore, under the baseline conditions—assuming conservative conversion efficiencies and higher end costing data and considering the current U.S. market value range— it would not seem advisable to invest in a de-hydrated ethanol plant on St. Kitts.

At the local level, the gasoline price is high enough whereby relative small optimization efforts in the ethanol production system could lead to a competitive ethanol cost. A downside is that the local ethanol demand is limited to the 10% blending capacity of the local consumed gasoline. This amount is 409,619 gallons/year of ethanol while the ethanol production is about 2.7 million gallons per year, leaving more than enough to supply the nation with ethanol but creating an excess of about 2.3 million gallons of ethanol that cannot be exported or used otherwise. This confirms the priority to have a competitive ethanol production cost on the global export ethanol market for small island state as St. Kitts and Nevis to consider making investments in an export market for ethanol.

For the bio-energy production results, Table 7.11 summarizes the cost of electricity for the different system configurations including the results of the optimization alternatives.

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[254] Inflation correction: X US$*$(1+i)^{yr}$, with inflation rate of 3% per annum.

[255] Partly extracted from Shapouri et al., *The economic feasibility of ethanol production from sugar in the United States,* U.S. Department of Agriculture, July 2006.

Table 7.11. Cost Comparison of Electricity Generation Costs

Technology	Input	Cost (US$/kWh)[256]
Diesel generators (SKED)	Fuel oil	0.170
Direct Combustion – dehydrated ethanol plant (scenario 1)	Bagasse	0.075 – 0.117
Direct Combustion – hydrated ethanol plant (scenario 1)	Bagasse	0.070 – 0.115
Direct Combustion (scenario 2)	Sugarcane	0.050 - 0.171
Gasification system (scenario 2)	Sugarcane	0.146

The results provided in Table 7.11 for the direct combustion system related to Scenario 1, are the costs of electricity generation for the electricity available for use in the national grid. This electricity is produced as a by-product of the ethanol production; therefore, the cost of ethanol production is the key output to evaluate the system's feasibility. Since these COE are much lower than the 0.17 US$/kWh cost at SKED, there is a large margin for revenue. The limitation is that the quantities of exported electricity are low. One would have to perform additional study into the possibility of subsidizing the ethanol cost by using the revenue from electricity sales.

Under the baseline conditions for Scenario 2, the electricity production cost was 0.131 US$/kWh and is lower than the current generation cost on St. Kitts of 0.17 US$/kWh. When implementing optimization options, the COE may decrease to the level of 0.050US$/kWh. When switching from a direct combustion to a gasification system, the COE is increased to 0.146 US$/kWh, when down grading the land requirement to 1,000 acres and to the point the COE is still below 0.17 US$/kWh. Unfortunately the commercial availability is limited and can only be considered as a futuristic alternative.

As general observation, lower costs of electricity productions are achievable for St. Kitts by increasing the land availability, yields, fiber content, and other performance parameters, but the cost effectiveness is challenged due to the limited energy demand on the island.

7.7 Discussion

This discussion section will highlight general points of concern in the quality of the results of this study. Also some other requirements or conditions for the development of a sustainable biomass-to-energy conversion system for St. Kitts are discussed.

Quality of results

One important limitation of this study is that this analysis is meant to provide acceptable ranges and establish a baseline on current, not final design conditions, whereby the main characteristics are the energy and mass balance. It also quantifies the cost per each process step and uses the mass/volume or energy content as common denominator.

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[256] Including optimization options.

Additionally, an attempt was made to provide an overview of qualitative socio-environmental impacts for each biomass-to-energy conversion technology and scenario, but it is not sufficient to be considered as a complete feasibility study. Environmental Impact Assessments (EIA) need to be developed for each new renewable energy project.

For the costing data in each scenario, one has to take in account that the investment costs of the ethanol and power plant should escalate according the heat or energy ratio. In the case of an ethanol plant, the capital investment cost escalates in a linear fashion between the maximum and minimum investment cost and capacity size. The results from the optimization options are only provided to highlight the qualitative potential. The model used was limited in its potential to integrate all the parameters and assumptions to provide real costing data as there are no definite relationships among factors, only average values, and these are subject to agreements reached with equipment supplier/project developer.

8. Conclusions and Recommendations

The main cost factor related to biomass-to-energy conversion systems is the biomass feedstock cost. On the other hand the market value of the final product and by-products form the key parameters for the economical feasibility of such a system. One has to keep in mind that St. Kitts and Nevis is a small island state in a globalizing market economy, where the market value of its products are subject to international market price fluctuations and competition stems from geo-political, climatologically, and/or legal/policy development factors.

8.1 St. Kitts Ethanol vs. U.S. Ethanol Market

The wholesale cost of ethanol for the country of St. Kitts and Nevis of US$2.12/gallon is considerably higher than the lowest end of the range of 1.90 – 2.40 US$/gallon (U.S. market value in the 1st quarter of 2007). This market price however is very volatile (see Figures 4.6 and 4.7). Therefore, under the baseline conditions, assuming conservative conversion efficiencies and higher end costing data and considering the current U.S. market value range, it would not seem advisable to invest in a de-hydrated ethanol plant on St. Kitts.

8.2 St. Kitts Ethanol vs. Local/Sub-regional Gasoline

The production cost of ethanol of US$2.12/gallon is lower than the gasoline price of US$ 3.65/gallon. Based on the energy content the cost for ethanol (US$ 2.27/gallon) still remains lower than the cost of gasoline.[257]

A downside to this is that the local ethanol demand is limited to the 10% blending capacity of the locally consumed gasoline. This amount is 409,619 gallons/year of ethanol while the ethanol production is about 2.7 million gallons per year. This is more than enough to supply the nation with ethanol, but will create an excess of about 2.3 million gallons of ethanol that cannot be exported or otherwise used. This confirms the priority to have a competitive ethanol production cost on the global export ethanol market before further ethanol opportunities for export are considered by the country. Without significant reductions in the projected costs, it would seem that the export potential to the U.S., E.U. or other international markets for this fuel is limited. At the sub-regional level (e.g. OECS region), there may exist possibilities for cost competitive export, due to close proximity of islands, the high local/regional gasoline prices and common regulatory and commercial frameworks in place, this warrants further analysis.

8.3 St. Kitts Bio-Electricity vs. Local Fossil Fuel based Electricity generation

The electricity production cost was 0.131US$/kWh and is lower than the current generation cost on St. Kitts of 0.17 US$/kWh. This is the case without considering the losses in the juice created in the fuel preparation process. Alternatively this juice could be

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[257] The energy content of ethanol is 23.4 MJ/L or 0.0886 GJ/gallon and gasoline has a heating value of 32.0 MJ/L or 0.121 GJ/gallon, therefore the 23.4/32.0=0.73, thus 1 gallon of ethanol contains 73% of 1 gallon of gasoline.

sold to local or regional alcohol/beverage distilleries that require smaller scale capacities and are subject to a different beverage market. Implementing optimization options, the COE may decrease to the level of 0.050US$/kWh. By switching from direct combustion to a gasification system the COE may increase to 0.146US$/kWh. Lower costs of electricity production are achievable for St. Kitts by increasing the land availability, yields, fiber content, and other performance parameters, but the cost effectiveness is challenged due to the limited energy demand on the island.

8.4 Optimizations and Socio-Environmental Impacts

BMW

The investments required to set up an integrated waste management system will determine the cost per ton of the BMW as a feedstock for a biomass-to-energy conversion system. Because of the lack of detailed information on the composition, separation quality, and costs, this option is not further scrutinized in this study. This assessment is out of the scope of this study, but is seriously recommended to be looked into.

Hydrated ethanol

An alternative to producing ethanol is the production of partially processed, un-distilled ethanol, commonly referred to as hydrated ethanol. The cost of producing hydrated ethanol is smaller than the cost of producing ethanol, US$2.12/gallon. Furthermore, economies of scale can be gained if hydrated ethanol from Saint Kitts, in conjunction with imported hydrated ethanol from other countries, is processed in a larger facility in a neighboring island, e.g., Jamaica. Alternatively, there is sufficient biomass to provide the required heat and electricity demand for a large scale dehydration or distillation unit. Hydrated ethanol can be imported from other countries to obtain economies of scale and produce ethanol at competitive market costs.

Land

The more land available, the lower the cost of production of both power and ethanol, due to economies of scale. But for small size islands as St. Kitts, the local market demand for ethanol and electricity limits the economical feasibility of the systems. From the analysis conducted it is demonstrated that smaller size power plants can still generate competitive COE rates on St. Kitts, while using less land. The benefits of maintaining the crop for energy, avoiding soil erosion, maintaining the regeneration capacity of the aquifer and appeal for the tourist sector should be recognized with a focus on establishment of government priorities.

Feedstock production and costs

A decrease in the cost of delivered fuel to the facilities will bring down the cost of production of any output, and is the most significant cost component of any system, based on the baseline. Increases in the yield, a change in variety of sugar cane planted-to maximize for ethanol or electricity generation, depending on priorities and increased efficiencies (in cultivation, harvesting, transportation) will bring down the cost of production of outputs, even if the cost per ton does not decrease. It is important to note that while increased efficiency in harvesting through mechanization will bring down feedstock production costs, it may reduce the labor necessary, a consideration for social development.

Labor

While it was originally desired to provide employment opportunities, it was discovered during the analysis that many of those formerly employed by the sugar production industry have already switched to the tourism sector. It is understood that many of these individuals will not return to the agricultural sector, creating a labor shortage. This issue further emphasizes the need for mechanization as an alternative to bring down the cost of feedstock production and avoid labor shortages.

Climate vulnerability

The biomass supply is dependant on the climatologically conditions, where one should consider their vulnerability to natural disasters. Particularly in an island state as St. Kitts and Nevis, which is located in the hurricane route, financial insurance or other types of back up mechanisms are needed in case of disasters.

Food and energy security

The competition between agriculture for food or energy crops is not assessed in this report. However, in that the government is opting for a transition away from sugar production to alternative configurations for using the sugarcane, one can conclude that halting the sugar production compensates for the importation of sugar.

Carbon credit

A significant amount of carbon can be offset by the implementation of a biomass system over the use of conventional fossil fuel systems. In addition to mitigating global climate change, the sale of carbon credits can be an additional source of revenue for the operation. The revenues obtained will depend on the market in which those credits are sold, length of contract, and methodology utilized under the Clean Development Mechanism.

Economic development orientation

There are a series of ongoing developments that provide the basis for a drastic decrease in land use for agricultural purposes, which in the future will limit the opportunities for identifying feasible and sustainable biomass-to-energy conversion systems for St. Kitts. One main reason is the land use competition between the agricultural sector and the hotel/service sector. In other words, it is possible that all or major fractions of the agricultural land will in future be used for other purposes with many socio-environmental and economic consequences.

In the energy sector, the St. Kitts Electricity Department (SKED) will have to cope with a rapid increase in energy demand due to projected demographic and economic development (assuming that the government chooses hotel/service sector development over sugarcane cultivation for energy). Due to its dependency on an inflexible or traditional fossil fuel based power system (assuming capacity expansion based on the use of these systems is the most likely route), SKED and the national economy will remain vulnerable to international crude oil price fluctuations. Fuel oil constitutes the largest cost component of the power system. In addition, due to the lack of application of economies of scale and internal process inefficiencies, the electricity rates are, and will continue to be, among the highest in the region. These rates will put serious financial pressures on the local population and businesses and will indirectly hamper the economic activity and development of the island.

8.5 Requirements and Conditions for Sustainable Bio-energy Development

To come to a sustainable bio-energy project development, several required conditions are highlighted in this section.

Priority

Before making any decision, priorities should be established. Is it the intention of the government to minimize the local and global environmental impacts of the energy system and protect the local environment—i.e. soil erosion? Is energy sustainability and security the top priority? Does the government wish to engage in an income maximizing operation? Are other criteria such as creating employment or environmental protection a factor? Until this is clear, a final decision will be difficult.

Policy considerations

While the production of bio-energy may prove feasible based on the optimization of the presented baseline scenarios, a comprehensive policy framework is essential to support the development of this kind of project. This could address financial incentives such as preferential import tariffs for renewable energy, mainly bio-energy, equipment, and feed-in tariffs; fiscal incentives including as tax exemptions or schedules that allow for increased returns for the operation owner; development of a general energy plan; bundling of carbon emission projects with other countries, etc.

Environmental standards

Since there are no emission standards on St. Kitts and Nevis, as a responsible government it is recommended to utilize the US or EU based environmental laws and emission standards as a starting point for the development of emission regulation and air quality assurance. The Federation of St. Kitts and Nevis signed the Kyoto Protocol; the development of a clean air policy may benefit the country in facilitating the implementation of future renewable energy projects that are eligible for CDM Carbon credits.

Implementation

It is recommended to make this report available for the private sector in order to attract private investments for a possible bio-energy project for St. Kitts and Nevis. This report provides objective baseline data for further detailed feasibility analysis. It also may function as a guideline for a bio-energy policy framework or creation of a bio-energy program. In the end, the decision to focus on bio-energy will depend on the priorities set by the government of St. Kitts and Nevis and the general public.

Glossary

Annual Equity Recovery	Amount of revenue that needs to be recovered annually to make revenues recovered over the life of the investment equal to having made an alternative equity investment at the present time. Measured in U.S. dollars per year ($/y).
Capacity factor	the capacity factor is the ratio of the actual energy produced in a given period to the hypothetical maximum possible, e.g. running full time at rated power (%).
Carbon Credit Revenue	Revenue from the sale of carbon credits, based on the reduction of carbon emissions per year. Measured in U.S. dollars per year ($/year). The carbon credits revenue is calculated based on the avoided emissions from using biomass over a business as usual scenario. Fossil fuel bases systems are assumed to be the business as usual scenario.
CHP	Combined Heat and Power generation: Combustion facilities that produce both electricity (by driving a steam turbine and generator) and heat (e.g. process steam or district heat)
Constant Level Annual Revenue Requirements	Total amount of money that needs to be recovered every year by the facility operators/owners based on the specified financing described. Also known as Energy Revenue Requirements. Measured in US dollars per year ($/y).
Constant Level Annual Cost	Annualized cost of generation in constant dollars, which attempts to adjust for the effect of inflation so that economic values may be compared on an equivalent basis. Measured in U.S. dollars per kilowatt hour ($/kWh), gallons of ethanol per year (gallons/y), or tons of sucrose per year (tons/year). This value is obtained by dividing the Annual Revenue Requirements by total gigajoules available per year. This is then converted into dollars per unit energy carrier—dollars per kilowatt hour, dollars per gallon of ethanol, or dollars per ton of sucrose.
Depreciation	Loss of value for the project's assets. A straight line depreciation, where the value of the assets depreciates for an equal amount every year over the economic life of the project, is assumed for this

	analysis. The total investment cost is divided over the life and subtracted from the energy revenue requirements. Measured in dollars ($).
Distillation	this process consists of heating the ethanol-water solution and passing the vapor through a column in which the vapor condensed and re-vaporized numerous times, a process that successively concentrates the ethanol and removes the water.
Ethanol Plant capacity	Size of the ethanol processing plant, measured in millions of gallons per year (MGallons/yr). This is calculated based on the fuel heating value, sugarcane supply, sucrose content, and conversion efficiency of the process.
Fuel cost	Delivered cost of fuel. This includes growing, harvesting, transport, and field overhead costs for sugarcane. This is a recurring cost and is measured in U.S. dollars per ton ($/ton).
Fuel Heating Value	The heat content of the fuel or product, expressed in units of energy per amount of material, measured in gigajoules per ton (GJ/ton). The fuel heating value is dependent on the moisture content of the feedstock. Fuel heating value is also dependent on fiber and sucrose content. It is assumed for this assessment that the same crop will be grown. However, crop varietals may change to optimize for fiber content—increased power output, or sucrose content—to maximize sucrose or ethanol production.
General inflation	Inflation rate used to adjust current dollar result to constant dollars. It assumes that fuel production and labor costs increase at the rate of inflation. Measured as a percentage per year (%/y).
HHV	Higher heating value: the thermal energy released during the combustion of a substance, including heat associated with the condensation of water. The HHV value is independent of the moisture content of the substance
Interest rate on Debt	Interest rate applied to the debt portion of the investment. Measured as a percentage per year (%/y). A higher interest rate on debt will increase energy revenue requirements.
LHV	Lower heating value: the thermal energy released during the combustion of a substance. Heat associated with the condensation of water is not included. The LHV value depends on the moisture content of the substance

MSW	municipal solid waste: heterogeneous mixture of organic fractions, plastics, paper, etc., as collected in urban areas from households and service sector
O&M cost	Cost of operating the facility: includes labor and repairs and spares. This is a recurring cost, calculated as a percentage of the Total Investment Cost and presented in US dollars ($) It is based on a percentage of the total investment cost per year.
Other operating expenses	Any additional costs for the operation of the facility, utilities, etc. This is a recurring cost, calculated as a percentage of the Total Investment Cost and presented in US dollars ($). These are based on a percentage of the total investment cost per year.
Power Plant capacity	Size of the power plant, measured in kilowatts (kW). This is calculated based on the fuel heating value and conversion efficiency.
Total investment cost	The total installed cost of the facility, including pre-treatment equipment if required. This is a one-time cost. Measured in U.S. dollars per kilowatt ($/kW) or U.S. dollars ($).

Appendices

Appendix A

Table A-1. Production of Sugar cane for period 1990-2005[258]

Year	Sugar Cane (tons)	Reaped area (ha)	Sugarcane Yield (tons/acre)	Sugar production (tons)	Efficiency (Sugar/Sugar Cane) (%)	Available cultivable area (acres)
1990	168,476	8,223	20.5	15,178	9.01	10,397
1991	219,100	8,276	26.5	19,392	8.85	10,318
1992	205,037	8,541	24.0	20,159	9.83	10,397
1993	219,586	8,656	25.4	21,288	9.69	10,397
1994	180,494	8,445	21.4	19,980	11.07	10,356
1995	180,285	8,220	21.9	19,961	11.07	10,383
1996	203,740	8,467	24.1	20,249	9.94	10,363
1997	305,181	9,456	32.3	30,880	10.12	10,510
1998	240,077	9,268	25.9	24,582	10.24	10,380
1999	196,784	9,247	21.3	17,738	9.01	10,306
2000	188,373	8,496	22.2	18,052	9.58	10,010
2001	211,656	8,937	23.7	22,486	10.62	10,002
2002	227,650	8,704	26.2	21,398	9.40	9,993
2003	169,451	7,846	21.6	16,255	9.59	9,200
2004	171,915	6,996	24.5	14,384	8.37	8,067
2005[259]	142,693	5,198	27.5	10,729	7.52	7,770

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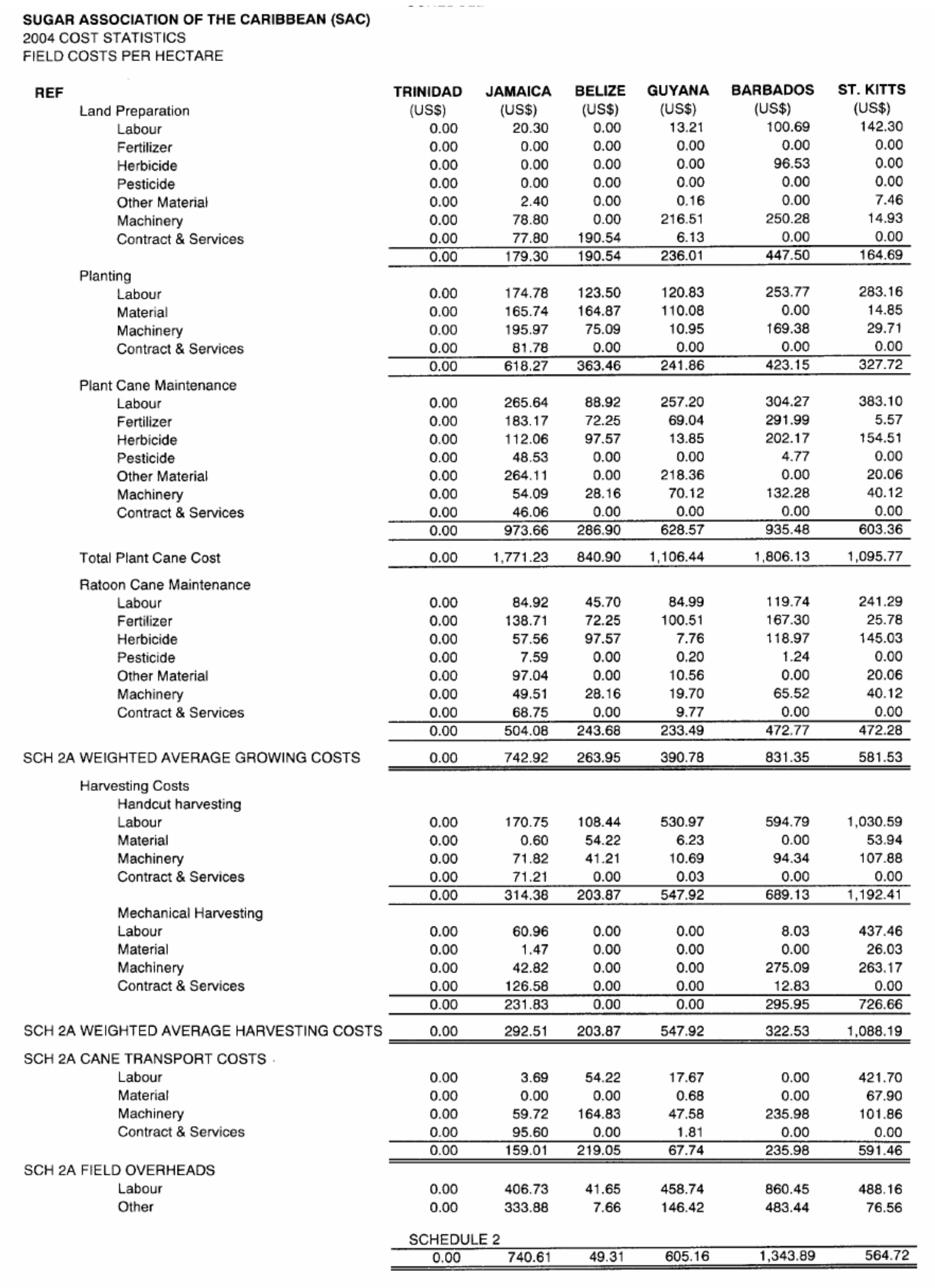
[258] Modified from SSMC statistics (2006) and extracted from "2004 Cost Statistics", Sugar Association of the Caribbean (SAC), 2004

[259] Note that the sugar cane production stopped mid 2005, thus no complete yearly production numbers.

Appendix B



SUGAR ASSOCIATION OF THE CARIBBEAN (SAC)
2004 COST STATISTICS
FIELD COSTS PER HECTARE

REF	**TRINIDAD** (US$)	**JAMAICA** (US$)	**BELIZE** (US$)	**GUYANA** (US$)	**BARBADOS** (US$)	**ST. KITTS** (US$)
Land Preparation						
Labour	0.00	20.30	0.00	13.21	100.69	142.30
Fertilizer	0.00	0.00	0.00	0.00	0.00	0.00
Herbicide	0.00	0.00	0.00	0.00	96.53	0.00
Pesticide	0.00	0.00	0.00	0.00	0.00	0.00
Other Material	0.00	2.40	0.00	0.16	0.00	7.46
Machinery	0.00	78.80	0.00	216.51	250.28	14.93
Contract & Services	0.00	77.80	190.54	6.13	0.00	0.00
	0.00	179.30	190.54	236.01	447.50	164.69
Planting						
Labour	0.00	174.78	123.50	120.83	253.77	283.16
Material	0.00	165.74	164.87	110.08	0.00	14.85
Machinery	0.00	195.97	75.09	10.95	169.38	29.71
Contract & Services	0.00	81.78	0.00	0.00	0.00	0.00
	0.00	618.27	363.46	241.86	423.15	327.72
Plant Cane Maintenance						
Labour	0.00	265.64	88.92	257.20	304.27	383.10
Fertilizer	0.00	183.17	72.25	69.04	291.99	5.57
Herbicide	0.00	112.06	97.57	13.85	202.17	154.51
Pesticide	0.00	48.53	0.00	0.00	4.77	0.00
Other Material	0.00	264.11	0.00	218.36	0.00	20.06
Machinery	0.00	54.09	28.16	70.12	132.28	40.12
Contract & Services	0.00	46.06	0.00	0.00	0.00	0.00
	0.00	973.66	286.90	628.57	935.48	603.36
Total Plant Cane Cost	0.00	1,771.23	840.90	1,106.44	1,806.13	1,095.77
Ratoon Cane Maintenance						
Labour	0.00	84.92	45.70	84.99	119.74	241.29
Fertilizer	0.00	138.71	72.25	100.51	167.30	25.78
Herbicide	0.00	57.56	97.57	7.76	118.97	145.03
Pesticide	0.00	7.59	0.00	0.20	1.24	0.00
Other Material	0.00	97.04	0.00	10.56	0.00	20.06
Machinery	0.00	49.51	28.16	19.70	65.52	40.12
Contract & Services	0.00	68.75	0.00	9.77	0.00	0.00
	0.00	504.08	243.68	233.49	472.77	472.28
SCH 2A WEIGHTED AVERAGE GROWING COSTS	0.00	742.92	263.95	390.78	831.35	581.53
Harvesting Costs						
Handcut harvesting						
Labour	0.00	170.75	108.44	530.97	594.79	1,030.59
Material	0.00	0.60	54.22	6.23	0.00	53.94
Machinery	0.00	71.82	41.21	10.69	94.34	107.88
Contract & Services	0.00	71.21	0.00	0.03	0.00	0.00
	0.00	314.38	203.87	547.92	689.13	1,192.41
Mechanical Harvesting						
Labour	0.00	60.96	0.00	0.00	8.03	437.46
Material	0.00	1.47	0.00	0.00	0.00	26.03
Machinery	0.00	42.82	0.00	0.00	275.09	263.17
Contract & Services	0.00	126.58	0.00	0.00	12.83	0.00
	0.00	231.83	0.00	0.00	295.95	726.66
SCH 2A WEIGHTED AVERAGE HARVESTING COSTS	0.00	292.51	203.87	547.92	322.53	1,088.19
SCH 2A CANE TRANSPORT COSTS						
Labour	0.00	3.69	54.22	17.67	0.00	421.70
Material	0.00	0.00	0.00	0.68	0.00	67.90
Machinery	0.00	59.72	164.83	47.58	235.98	101.86
Contract & Services	0.00	95.60	0.00	1.81	0.00	0.00
	0.00	159.01	219.05	67.74	235.98	591.46
SCH 2A FIELD OVERHEADS						
Labour	0.00	406.73	41.65	458.74	860.45	488.16
Other	0.00	333.88	7.66	146.42	483.44	76.56
	SCHEDULE 2					
	0.00	740.61	49.31	605.16	1,343.89	564.72

Appendix C

As one of the biggest suppliers to the Caribbean Islands, Venezuela has proposed creating "PetroCaribe," a state oil company representing all the Caribbean nations which would centralize refining, procurement and marketing. On the 29th of June 2005 at Puerto la Cruz in Venezuela, the energy cooperation agreement "PetroCaribe" was signed by Venezuela and 13 Caribbean States, including St. Kitts and Nevis[260].

The key element of the PetroCaribe agreement is that Venezuela will create a fund (ALBA Caribe) and initially subsidize this initiative with US$ 50 million that will be used for the development of common energy policies, financing socio-economic programs and energy projects. Further, the Petroleros de Venezuela (PDV Caribe) will handle the intermediation and distribution operations, that also includes creating logistical plans and where possible increasing refinery and storage capacity in the Caribbean region. The agreement entails Venezuela financing the price per barrel of crude and petroleum products with the following rates, see table C-1.

Table C-1. Financing scheme for Petroleum Delivered by "PetroCaribe"[260]

Price of Petroleum (US$/Barrel)	Percentage to finance (%)	Pay back time (Years)
15	5	15
20	10	15
22	15	15
24	20	15
30	25	15
40	30	25 (+ 1%)
50	40	25 (+ 1%)
100	50	25 (+ 1%)

The above means that at the average petroleum price of US$ 55.61 per barrel[261] (in 2005), approximately US$ 22.2 per barrel (40%) will be financed by Venezuela and thus the receiving Caribbean state pays US$ 33.4 per barrel. In the agreement, it is stated that the importing state will have to pay back Venezuela this 40% financed price (US$ 22.2 per barrel) in the period of 25 years with a 1% interest rate. The importing countries are given a two year grace period before beginning payments.

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[260] Ministry of Foreign Affairs of the Government of Venezuela, source: http://www.mre.gov.ve/PetroCaribe2005/acuerdo_final.htm

[261] Average crude oil price of WTI and Brent Crude Oil, source: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_a.htm

Appendix D

Table D-1 is the result of using the US Energy Information Administration (EIA, 2005) Spot Price projections[262] that are converted from [US$cents/gallon] to [US$/Barrel] and multiplying these data by the information provided in table D-1, where a list is showed with the fraction of Venezuelan finance to the fuel oil price depending on the international price of petroleum. Table D-1 shows the possible fuel oil #2 price developments over the period 2005 to 2008.

Table D-1. Fuel Oil #2 Price (US$/US barrel) Projections for Period 2005-2008[263]

Fuel Oil #2 price (US$/US Barrel)	2005	2006	2007	2008
Reference	76.56	71.06	67.03	64.51
Low Price	76.56	66.00	59.40	55.44
High Price	76.56	76.10	75.59	75.09
PetroCaribe price	76.56	53.29	50.27	48.38
PetroCaribe price + payback	76.56	53.29	51.39	50.57
PetroCaribe price + depreciated payback	76.56	53.29	51.28	50.19

With other words, the prices projected in table D-1 are the projected prices of the imported fuel oil to St. Kitts and Nevis for the period 2005 to 2008, with a differentiation between normal projections (“Reference”, “Low Price” and “High Price”) and prices influenced by the PetroCaribe treaty (“PetroCaribe”, “PetroCaribe + payback” and “PetroCaribe + depreciated payback”).

In order to estimate the total annual fuel costs per each scenario, the fuel consumption predictions are used. The fuel consumption in [US barrels/yr] from table D-2 are multiplied by the fuel price developments [US$/US barrels] provided in table D-1, to estimate the total annual fuel costs in [US$/yr] showed in table D-3.

Table D-2. Fuel Consumption Projections for SKED in Period 2005-2008

Year	Fuel consumption (IG)	Fuel consumption (US barrels)
2005	7,156,452	204,603
2006	7,745,463	221,443
2007	8,137,672	232,656
2008	8,529,881	243,869

Table D-3 shows the results of multiplying the fuel consumption data (Table D-2) by the Fuel Oil #2 price (Table D-1).

As can be seen in table D-3, the annual fuel costs could range between 11.8-16.9 MUS$ (2006), 11.9-17.6 MUS$ (2007) and 12.3-18.3 MUS$ (2008), thus with an increasing tendency in fuel costs.

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[262] Average crude oil price of WTI and Brent Crude Oil, source: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_a.htm

Table D-3. Fuel Oil #2 Cost (US$/yr) Projections for SKED in Period 2005-2008

Fuel Oil #2 costs (US$)	2005	2006	2007	2008
Reference	15,664,403	15,735,032	15,593,836	15,730,918
Low Price	15,664,403	14,615,224	13,819,769	13,520,114
High Price	15,664,403	16,850,991	17,587,033	18,311,772
PetroCaribe price	15,664,403	11,801,274	11,695,377	11,798,189
PetroCaribe price + payback	15,664,403	11,801,274	11,955,274	12,332,794
PetroCaribe price + depreciated payback	15,664,403	11,801,274	11,931,647	12,240,011

Appendix E

Table E-1. Overview of Commercially Available Biomass-to-energy Conversion Technologies and/or Facilities [264,265,266,267,268,269,270]

Conversion process	Company	Technology	Number of operating facilities	Active in:	Processing Capacity (TPD)	Output	Feedstock
Commercial (Mid-scale)							
Fermentation/ Ethanol	Masada Oxynol	CES Oxynol, acid hydrolysis	1	USA	~230,000 TPY	8.5 Mgallons	MSW
Gasification	Xylowatt[271]	Gasification/CHP	2	Belgium	N/A	0.3 – 5 MWe	Woodchips
Gasification/CHP	Babcock and Wilcox[272]	Several technologies	50>	EU, LAC, USA			MSW, Biomass, Coal
Gasification	ALSTOM Power[273]	Fluidized Bed gasifier	50	Japan	24 – 220	2 – 17 MWe	Tires, wood, agricultural waste, sludge
Gasification	Krupp Uhde[274]	Different Gasification systems	2	Germany, Spain	~150		Coal, MSW
Gasification	Nippon Steel[275],[276]	Fixed Bed Gasification	26	Japan	88 – 795	1.2 – 22 MWe	MSW-coal, landfill waste, plastic waste
Gasification	Foster Wheeler[277]	Atmospheric	6	Finland,	55 – N/A	6 – 42 MWe	RDF, wood,

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[264] Please note the content of this literature study has not been confirmed with the supplier. The content has been prepared and presented in good faith, and should be regarded as indicative. The supplier should be contacted directly for any clarification, confirmation of detailed technical data.

[265] Gasification Technologies Council website: http://www.gasification.org/resource/database/search.aspx

[266] Gasifier Inventory website: http://www.gasifiers.org/manufacturers

[267] Global Directory for Environmental Technology website: http://www.eco-web.com

[268] Comparison of Alternative Thermal Processes, Feasibility Study of Thermal Waste Treatment/Recovery Options in the Limerick/Clare/Kerry Region, page 45-51, website: www.managewaste.ie/docs/WMPNov2005/FeasabilityStudy/ComparisonAlternative.pdf

[269] California Energy Commission website: http://www.energy.ca.gov/development/biomass/index.html#Biomass

[270] Gupta, S., Plant Power: Biomass-to-Energy for Minnesota Communities, May 2004, pages 13-14.

[271] Xylowatt website: http://www.xylowatt.com/MainHomeEN.htm

[272] Babcock & Wilcox website: http://www.volund.dk/home

[273] ALSTOM Power website: http://www.power.alstom.com/home/index.EN.php?languageId=EN&dir=/home/

[274] Uhde GmbH website: http://www.uhde.biz/company/index.en.epl

[275] Info: http://www.japancorp.net/Article.Asp?Art_ID=6348

[276] Nippon Steel Corporation website: http://www0.nsc.co.jp/shinnihon_english/index.html

		Circulating Fluidized Bed (ACFB) gasifier, Bubbling Fluidized Bed gasifier		Sweden, Portugal			packaging material
Gasification	TPS[278]	Circulating Fluidized Bed gasifier, Bubbling Fluidized Bed gasifier	2	Italy, Sweden, Brazil	~100	30 MWe	RDF, agricultural and bio waste
Gasification	Primenergy[279]	Different Gasification systems	4	USA, Italy	100 – 500	1 – 15 MWe	Rice hulls, olive oil
Gasification	Ener.G[280]	Energon gasification	1	UK			
Gasification	Lurgi[281]	Circulating Fluidized Bed Gasification Process	1	NL, Germany	~500	85 MWth	Biomass/Waste
Pyrolysis/ Gasification	Noell (Babcock Borsing)	Pyrolysis/gasification	1	UK, Germany	~120	5 MWe	MSW, industrial waste, oil, coal
Pyrolysis/ Gasification	Hitachi Metals	Plasma Arc Gasification	1	Japan	165 – 300	4.3 – 7.0 MWe	MSW
Pyrolysis/ Gasification	Thermoselect[282]	Pyrolysis/gasification	4	EU, USA, LAC	140 – 792	1.2 - 12.5 MWe	MSW, Industrial waste
Pyrolysis/ Gasification	PKA	Pyrolysis/gasification	2	Germany	10 – 220		MSW, mixed waste
Several technologies	BTG Group[283]	Several technologies	50>	Global	Wide range		MSW, animal waste, etc.
Pyrolysis	Ensyn Group[284]	Rapid Thermal Processing	4	USA	~40	Bio-oil	Wood, bagasse
Pyrolysis	Siemens/Mitsui/Taku	Horizontal Pyrolysis	7	Japan	130 – 440		MSW

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[277] Foster Wheeler Power website: http://www.fwc.com/GlobalPowerGroup/index.cfm

[278] TPS Termiska website: http://www.tps.se/gasification/intro_gas_en.htm

[279] Primenergy website: http://www.primenergy.com/

[280] ENER.G website: http://www.energ.co.uk/?OBH=352

[281] Lurgi AG website: http://www.lurgi.com/website/index.php?L=1

[282] Thermoselect S.A. website: http://www.thermoselect.com/index.cfm?fuseaction=DasUnternehmen&m=0

[283] BTG Group website: http://www.btgworld.com/

[284] Ensyn Group website: http://www.ensyn.com/index.htm

	ma	Reactor					
Pyrolysis	WasteGen	Rotary Kiln Pyrolyzer	2	Germany	120	2.2 MWe	MSW, Mixed waste
Pyrolysis	Thide Environmental	Rotating Drum Pyrolysis	3	Japan, France	30 – 140		MSW, Industrial waste
New companies / Pilot stage technologies							
Fermentation/ Ethanol	*Arkenol/Blue Fire*	*Acid Hydrolysis*	*1*	*USA, Japan*	***Pilot scale***		
Fermentation/ Ethanol	Bio-energy International[285]		2 u.d. (under development)	USA		108 Mgpy	Corn, Milo
Fermentation/ Ethanol	Ethanex[286]		1 u.d.	USA		132 Mgpy	Corn
Fermentation/ Ethanol	Iogen[287]	Cellulosic Enzyme process	1 u.d.	Canada			
	US Envirofuels[288]		N/A	USA			
	Agri-Therm[289]		N/A	Canada			
	Earth Biofuels[290]		N/A	USA			

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[285] Bio-energy International website: http://www.bio-energyllc.com/index.htm
[286] Ethanex website: http://www.ethanexenergy.com/ethanex.htm
[287] Iogen website: http://www.iogen.ca/company/about/index.html
[288] US Envirofuels website: http://www.usenvirofuels.com/default.asp
[289] Agri-Therm website: http://www.agri-therm.com/index.html
[290] Earth Biofuels website: http://www.earthbiofuels.com

Appendix F

Direct combustion is a commercially widely used system that is traditionally used in sugar mills. There are newer combined heat and power generation system that can drastically increase the energy conversion efficiencies.[291] Also the main products produced are electricity and heat. Since the current electricity generation costs on St. Kitts (0.17 US$/kWh) is among the highest in the world, the production of excess electricity to sell to the national grid is an attractive alternative. This process has a large flexibility for the biomass feedstock quality (<60% m.c.) and can combust a wide range of biomass sources.

Gasification has similar to the direct combustion system a large flexibility for the fuel type and quality. The gasification system can reach high overall energy conversion efficiencies because the syngas is combusted in gas engines/turbines with higher electrical conversion efficiencies compared to steam turbines used generally in direct combustion systems.

Pyrolysis is an energy intensive process, as can be seen in table 6.1 the feedstock moisture content should be <10% m.c. for the pyrolysis process. Therefore large amounts of heat need to be extracted from the primary energy entering the pyrolysis process. And depending on the initial moisture content of the biomass feedstock and operating conditions the energy balance of the system can result in a net consumer of energy. The main biomass feedstock on St. Kitts is the sugarcane, this biomass source has a high sucrose content that makes it a more valuable feedstock for ethanol production than for liquid bio-diesel that is the main output of the pyrolysis process.

Anaerobic digestion is a biomass conversion system more adequate to treat wet or liquid biomass sources as manure and waste water sludge that have very high moisture contents. Also the overall energy conversion efficiency of the anaerobic digestion system (10-16%) is the lowest among the biomass-to-energy conversion systems. This process has traditionally been used for waste water sludge treatment that is a waste product of a waste water treatment plant (wwtp) and is under these conditions a very attractive process. But when dealing with sugarcane, first of all the moisture content of this biomass is too low, and secondly as in the case of the pyrolysis system, the output product, for digestion being biogas, has a lower energy content value compared to electricity and/or ethanol production.

Fermentation-Distillation is a bio-chemical conversion process that uses the sucrose content in the biomass source to convert into ethanol. The sugarcane is therefore an adequate biomass feedstock. The small range of moisture content requirements (65-75% m.c.) are for the fermentation process, the sugarcane type on St. Kitts has m.c. values over a wider range. Therefore one to has to take in account the water consumption requirement for the ethanol process. This could form a problem when water has to be

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[291] OPET, Micro and Small-scale CHP from Biomass (<300kWe), Technology Paper 2, NNE5/3/2002

extracted from aquifers that are primarily used for potable water extraction or contribute to the hydrology system where the sugarcane plantations depend on.

Appendix G

Energy balance of ethanol process

The ethanol production process is a net energy producing process, this means that more energy is produced then consumed in the process. Some sources in the literature indicate that the overall energy requirement of the milling-fermentation process is between 0.05 – 0.06 (GJ/GJ HHV fuel) and heat requirement is between 0.20 – 0.24 (GJ/GJ HHV fuel).[292] In case of corn-based ethanol production the internal energy (heat and electricity) consumption ranges between 56.0 – 79.1 MJ/gallon of dehydrated ethanol.[293],[294] For ethanol plants with capacities between 15 to 50 Mgallon per year, the energy requirement ranges by 0.9 – 2.0 kWh/gallon of ethanol.[295] The higher end of this range, 2.0 kWh/gallon of ethanol, is used for the analysis and kept as constant. The sensitivity analysis will demonstrate the effects of changes in internal energy consumption on the potential to export and sell excess electricity to the grid, based on their effect on cost.

To be able to assess the difference in energy demand for the production of hydrated (without distillation unit) and de-hydrated (including distillation unit) ethanol, an energy balance is needed. Table G-1 shows an energy balance for a corn-ethanol process.

Table G-1. Energy Consumption in a Distillery Producing Ethanol from Corn

Process step	1000x BTU / gallon of ethanol	MJ/gallon of ethanol
Receiving, storage and milling	0.8	0.8
Conversion to sugar (including enzyme production)	16	16.9
Fermentation	0.6	0.6
Distillation	24.8	26.2
Distillers grain recovery	6.2	6.5
Miscellaneous	6.6	7
Total	**55**	**58**

The most energy intensive step in the ethanol production process is the distillation process. Here it is 45% of the total energy (primarily heat) consumption of 58 MJ/gallon of dehydrated ethanol. Other sources indicate levels of 70% of the overall thermal-energy

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[292] Hamelinck, C.N., Outlook for advances biofuels – thesis, Copernicus Institute, Utrecht University, website: igitur-archive.library.uu.nl/dissertations/2005-0209-113022/c4.pdf.

[293] Hedman, B., presentation: CHP in the ethanol industry: the Business Case, Combined Heat and Power Partnership (CHP), Energy and Environmental Analysis Inc., 2004, Environmental Protection Agency (EPA), website: www.epa.gov/chp/pdf/Iowa%20**Ethanol**%20Workshop_B.pdf.

[294] Shapouri et al., *Estimating the Net Energy Balance of Corn Ethanol*, U.S. Department of Agriculture, 1995, website: http://www.ethanol-gec.org/corn_eth.htm.

[295] Hedman, B., presentation: CHP in the ethanol industry: the Business Case, Combined Heat and Power Partnership (CHP), Energy and Environmental Analysis Inc., 2004, Environmental Protection Agency (EPA), website: www.epa.gov/chp/pdf/Iowa%20**Ethanol**%20Workshop_B.pdf.

requirement of the ethanol production process.[296] Therefore when excluding the distillation process from the ethanol production system a reduction of 45-70% in internal energy consumption can be achieved. In the early 1980s, in order to dry alcohol to 99.9 percent, isotropic distillation was used to remove the water. Benzene and cyclohexane (both carcinogenic) were used to remove the water. Today, molecular sieves are used for dehydrating ethanol. Replacing isotropic distillation with molecular sieves eliminates the use of carcinogenic material, eliminates one distillation process, saves as much as $25,000 per installation, and reduces energy costs by up to 20 percent.[297] A distillation could range between 25,000 to 26,200 US$ per system[298]

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[296] Brown, D., The conversion of Biomass to Ethanol using Geothermal Energy derived from Hot Dry Rock to supply both the thermal and electrical power requirements, Los Alamos National Laboratory, Earth and Environmental Sciences Division, USA, 1997.

[297] Shapouri et al., *The economic feasibility of ethanol production from sugar in the United States,* U.S. Department of Agriculture, July 2006.

[298] www.epa.gov/opptintr/dfe/pubs/iems/iems_guide/appf.pdf

Appendix H

Scaling method

To resolve the problem of variation in capital investment due to the scale an exponential scaling equation is used to down scale and assess the possible capital investment cost of smaller ethanol or power plants. The results of this method have to be treated with care, in some cases the size of equipments have a linear relation with the input flow (this could be heat, materials, etc). Other equipments have maximal capacity size ranges, whereby the costing aspects of it may differ considerably when redesigned on a different scale. Nevertheless using a scaling exponent and this equation a relative representative costing data can be provided. This method is widely used by companies and universities.

$$New\_Cost = Original\_Cost * \left(\frac{New\_Size}{Original\_Size} \right)^{\exp} \qquad \text{(H-1)}^{299}$$

The scaling exponent was assessed over a large amount of equipments necessary for the ethanol production process, the scaling exponent ranged between 0.30 – 1.0.[300] For this analysis the scaling factor is found by modifying equation H-1 and inserting the collected investment data attached to varying capacities.

$$\exp = \frac{LOG(New\_Cost / Original\_Cost)}{LOG(New\_Size / Original\_Size)} \qquad \text{(H-2)}$$

As a result of applying this method, the scaling factor for the **Ethanol Plant** Capital Investment is calculated to be 0.525.

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[299] Wooley et al., Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dillute Acid Prehydrolysis and Enzymatic Hydrolysis Current and Futuristic Scenarios, Technical Report, National Renewable Energy Laboratory (NREL), Golden, USA, 1999, page 3.

[300] Wooley et al., Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dillute Acid Prehydrolysis and Enzymatic Hydrolysis Current and Futuristic Scenarios, Technical Report, National Renewable Energy Laboratory (NREL), Golden, USA, 1999, Annex B pages 1-9.

Appendix I

Gasification costing data

Gasification systems have higher overall energy conversion efficiency ranging between 22-40%[301],[302] compared to Direct Combustion systems. However, the use of sugarcane for gasification is relatively unproven and would require considerable innovation for deployment in St. Kitts. In general there are different gasification configurations possible depending on the gasifier type, gas cleaning process, and the end application wanted (syngas or electricity). During the 1980s, a number of biomass gasification projects sprouted in France, Sweden, and Finland, which mostly produced methanol from wood and wood wastes, but lower petroleum prices and cheaper methanol eventually undercut these operations. [303] The conditions on St. Kitts are based on the global price increase of fossil fuels and inefficiencies in the conventional power production system, create a much more favorable condition for the application of a gasification system.

Depending on the scale of the system (the installed capacity, based on feedstock availability) a gasification system may be more or less expensive than a combustion service. Scale will be an important factor when deciding on the technology used and is vendor specific.

The investment cost ranges for gasification units are provided in table I-1. The costs of the gasification units are rated to the fuel processing capacity.

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[301] American Council for an Energy Efficient Economy, Small Scale Cogeneration (CADDET 1), November 1995, website: http://www.aceee.org/store/proddetail.cfm?CFID=6190&CFTOKEN=44729708&ItemID=65&CategoryID=10.

[302] OPET-RES, Micro and Small –scale CHP from Biomass (<300 kWe), Technology Paper 2, 2002, website: websrv2.tekes.fi/.../Viestinta_ja_aktivointi/Julkaisut/OPET-RES/TechnologyPaper2_chp_70404.pdf.

[303] Andre Faaij, “Bio-energy in Europe: Changing Technology Choices,” *Energy Policy*, 5 December 2003; M. Kaltschmitt, C. Rosch, and L Dinkelbach, eds., “Biomass Gasification in Europe,” prepared for the European Commission (Stuttgart: Institute of Energy Economics and the Rational Use of Energy (IER), University of Stuttgart, October 1998).

Table I-1. Investment Cost of Gasifiers with Varying Capacities

Technology	Investment cost[304] (MUS$$_{2006}$)	Capacity	Unit
Gasifier (including gas clean-up)[305],[306]	18.0	2000	TPD[307]
Gasifier (including gas clean-up)[308]	27.0	2000	TPD
Gasifier (including gas clean-up)[309]	12.0 – 13.0	2000	TPD
Gasifier (including gas clean-up)[310]	11.0	2000	TPD

The investment costs for the gasification systems range between 11.0 – 27.0 MUS$ for 2,000 TPD capacities. On St. Kitts there is 147,000 tons of sugarcane available, with a harvesting season of 100 – 140 days per year, the feedstock supply will be on average 1,225 TPD over a period of 4 months. When considering these conditions and applying the scaling factor of 0.65, the investment cost could range between 8.0 – 19.6 MUS$.

Using the higher end of this range, 19.6 MUS$ for a 2000 TPD Gasifier, and the scale factor of -0.65 the investment cost for varying TPD capacities can be estimated.

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[304] Inflation correction: X US$*$(1+i)^{yr}$, with inflation rate of 3% per annum.

[305] Breault, R.; Morgan, D. (1992). *Design and Economics of Electricity Production Form An Indirectly-heated Biomass Gasifier.* Report TR4533-049-92. Columbus, Ohio: Battelle Columbus Laboratory.

[306] Dravo Engineering Companies. (1987). Gasification Capital Cost Estimation. Obtained from Mark Paisley, August, 1994. Battelle Columbus Laboratory.

[307] Ton per day

[308] Weyerhaeuser, Nexant, and Stone & Webster. (2000). *Biomass Gasification Combined Cycle*. Weyerhaeuser Company, Tacoma, WA . DOE DE-FC36-96GO10173.

[309] Wan, E. I. and Malcolm D. F. (1990). "Economic Assessment of Advanced Biomass Gasification Systems," in *Energy from Biomass and Wastes XIII*, Donald L. Klass ed. Chicago: Institute of Gas Technology, pp.791-827.

[310] Weyerhaeuser. (1992). Gasification Capital Cost Estimation. Obtained from Mark Paisley, August, 1994. Battelle Columbus Laboratory.