Cellulosic Ethanol Technology as Waste Management tool – the Belize Potential

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Abstract
Waste is an indigenous energy rich source that can be converted into power or transport fuels critically important to build resilience in an age of global energy crises and volatile energy supply and costs. Furthermore, the proper use and conversion of waste to generate energy is a suitable alternative to its dumping at saturated landfills, mitigating climate change, create new jobs, and addressing land use management challenges, especially in the agricultural and forestry sectors. Therefore, finding an optimal solution for waste collection, treatment and disposal in small developing states is increasingly an important paradigm in sustainability. This applied research concludes that production of cellulosic ethanol (CE) derived from agricultural and forestry residues and municipal solid waste (MSW) in the near future will become a suitable waste management tool and transport fuel production alternative to supply the domestic market in Belize with potential use as an export commodity.

1. Introduction
Cellulosic ethanol is increasingly being recognized by the global community as one of the great promises and alternatives for the sustainable production of ethanol as alternative transport fuel. Cellulosic ethanol can be used to reduce a nation's dependency on volatile imported fossil fuels and bring about socio-economic development with reduced negative impact to the environment and reduced contribution to climate change, while addressing inherent challenges of disposal and management of waste.

1.1 Beyond current biofuels
The critical difference of this technology to the currently established biomass-to-liquid fuel systems, as for instance the corn- and sugarcane-based ethanol production, is that cellulosic ethanol can be produced from a wide variety of biomass waste feedstocks. These include agricultural plant wastes (e.g. corn stover, cereal straws, and sugarcane bagasse), forest industry wastes, organic wastes from industrial processes (e.g. sawdust and paper pulp), the organic fraction of municipal solid waste, liquid waste originating from sewers and septic tanks and a wider range of alternative energy crops (non-food crops) grown specifically for fuel production, such as switchgrass. In other words CE does not compete with food products and brings added-value to waste generated in multiple sectors of the economy.

1.2 Cellulosic ethanol potential
A key objective of this study was to identify and characterize feedstock to assess the potential for cellulosic ethanol production in Belize. The study explores state-of-the-art technologies, their costs and availability. It also describes a number of likely obstacles that may affect the potential development of CE production in Belize. Moreover, it addresses possible strategies to overcome these challenges through public policy initiatives and market development tools ensuring that cellulosic ethanol is produced in a sustainable manner in the long-term.

2. Methodology
The assessment of cellulosic ethanol production potential in Belize – including volume and cost competitiveness - was narrowed down by focusing in particular on assessing the feedstock availability,

its transportation and conversion into cellulosic ethanol by evaluating a variety of technologies. Via a simplistic biomass-to-ethanol conversion rate, the gross potential volume of ethanol is calculated to provide an initial picture of the scale of yield potential.

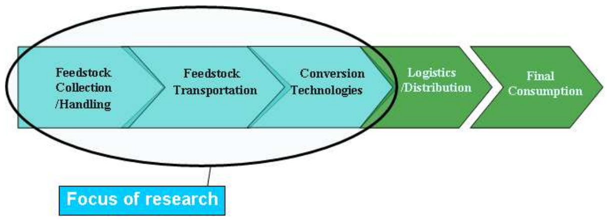

Figure 1 Life-cycle of cellulosic ethanol

Taking into account that most cellulosic ethanol conversion technologies are in a pilot and pre-commercial scale this study analyzed the technological development and prospects for the time frame of 2008 to 2012. Furthermore the long-term feedstock supply and cellulosic ethanol production is assessed using the "5E" assessment method[1] that includes the qualitative review of the following components to be taken in account during project preparation i.e.: technology evaluation (E1); energy efficiency (E2); environmental impacts (E3); economic viability (E4); and socio-political and human resource effectiveness (E5). Results of the 5E assessment are provided generically for bio- and thermo-chemical conversion technology categories where suitable data was found to perform such an assessment.

2.1 Feedstock identification and supply

The available feedstock for potential conversion into cellulosic ethanol was assessed by looking at the current amounts of organic waste, forest and crops residues available in related sub-sectors of the economy in Belize. Due to the varying characteristics of these sectors, different methodologies were applied to each to identify and quantify waste materials or residues. During a technical mission to Belize in August of 2008 additional data was gathered and verified with local experts.

2.1.1 Potential sustainable harvestable Agricultural-Residues

A selection of the most important agricultural commodities was made. This was done by deriving information from the national crop statistics database published by the United Nations Food and Agricultural Organization (FAO) in their Production Year Book and their Agro-MAPS Global Spatial Database of Agricultural Land-use Statistics.[2, 3] The information from these sources was combined with data gathered in Belize from interviews with several authorities and stakeholders related to the agricultural sector. This was followed by determining the gross quantities of dry matter of various residues by crop type within the agricultural sector in Belize. The following steps were taken:

(1) The total agricultural production per year was assessed from data revealing production levels for the years 2004 and 2005. The amount of production was derived from the annual report of the Ministry of Agriculture & Fisheries 2005 (acquired during an in-country assessment mission in Belize, August

[1] Dennis Schuetzle, Gregory Tamblyn and Frederick Tornatore, TSS Consultants, 2007. Alcohol Fuels from Biomass – Assessment of Production Technologies, www.westgov.org/wga/initiatives/biomass/ASSESSMENT-BIOALCOHOL-tech.pdf
[2] United Nations Food and Agricultural Organization, FAO Agro-Maps; http://www.fao.org/landandwater/agll/agromaps/interactive/page.jspx
[3] United Nations Food and Agricultural Organization (FAO), website: http://www.fao.org/countryprofiles/index.asp?lang=en&iso3=BLZ&subj=4

2008); (2) The cultivation activities per crop by district were determined based on the areas' locations and sizes described in the FAO Agro-maps v.2.5; (3) Furthermore a Residue to Product Ratio (RPR)[4] was used to determine the yield of crop residue from the agricultural products, as well as composition, lower moisture content and ash content. The total amount of residues per crop (R_{fpc}) was derived via the following equation 1:

$$R_{fpc} = \left(\frac{A_{c2004} + A_{c2005}}{2} \right) \times C_{fr} \qquad \text{(Eq. 1)}$$

Where A_c is the amount of total crops production (ton) and C_{fr} is the residue factor per crop or Residue to Product Ratio (a-dimensional).

(4) Factors for calculating realistic and sustainable amounts of extractable residues from farm lands to produce CE are numerous and beyond the scope of this study. However, until better data is available, a conservative rate of 60% is used for the total amount of residues sustainably extracted from the agricultural lands.[5] (5) As part of a 10-year strategic plan, Belize Sugar Industry is considering constructing a distillery for the production of dehydrated ethanol using its molasses. Within this context, bagasse and molasses may not be available sources to produce ethanol in Belize. (6) Finally, accounting for these limiting factors a more realistic and sustainable amount of potential harvestable residues originating from the agricultural sector for CE production is determined.

2.1.2 Potential sustainable harvestable Forestry-Residues

To determine the harvestable forestry residues the sector's structure was investigated looking at the main lumber industries and their waste production levels in particular logging and saw-milling residues. Since thinning depends on a wide range of factors, as among others planting density, species, age and location that vary considerably per region it is difficult to assess the residues volumes. However, the national forestry statistics published in the FAO Production Year Book in combination with the information gathered from interviews at the Forestry Department were used to estimate the current amount of forestry residues available for cellulosic ethanol production. A focus was set at *Logging Residues Recovery rates (LRR)* and *saw-milling residues*.

LRR rates are logging residues consisting of branches, leaves, lops, tops, damaged or unwanted stem wood, such residues are often left in the forests. A conservative LRR recovery rate of 40% was used in this study. Saw-milling residues availability depends on the milling process, the local practices as well as wood species. After a detailed analysis of the various milling stages that generate several by- or waste products as bark, slabs, edgings, trimmings, sawdust and planer shavings a milling residue yield factor of 50% is used, composed of 38% solid wood and 12% sawdust. To calculate the potential amount of harvestable forestry residues in tons, the following steps were taken:

(1) The total amount of 'round wood' composed of the sum of logged 'Fuel wood' and 'Industrial round wood' was estimated via a balance of volume of production by species.[6] See Figure 2 for a schematic overview of the balance of volume.[7]

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[4] Contreras, R. and De Cuba, K., Feasibility Study on the Cellulosic Ethanol Market Potential in Belize, Annex 11.5, page 96-98, Department of Sustainable Development, Organization of American States (OAS), March 2009, Washington, D.C., USA. http://www.sepa-americas.net/estadisticas_detalle.php?ID=11

5 According with the U.S. National Resource Conservation Service, a minimum of 30% cover by residues on the field is required for sustainable agricultural practice.

[6] Conversion factor, sources; http://www.simetric.co.uk/si_wood.htm

[7] Latin American Forestry Sector Outlook Study, Working Paper, National Report Belize, 2004. http://www.fao.org/docrep/007/j4051b/j4051b00.htm

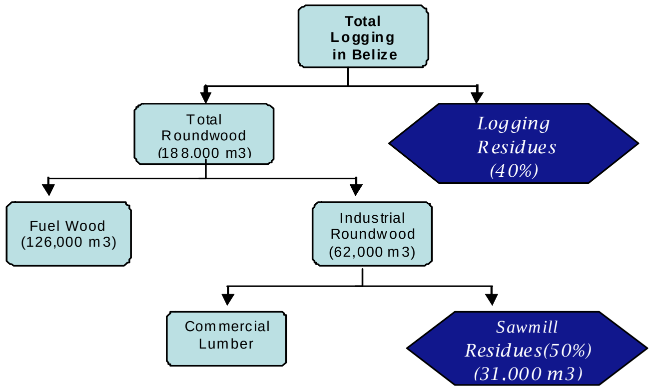

Figure 2 Volumes of logged wood in Belize

The total volume of 'round wood', identified for the year 2004[8] was the sum of 62,000 cubic meters of 'Industrial round wood'[9] and 126,000 cubic meters as 'Fuel wood'. During the milling process about 50 percent of the 'Industrial round wood' remains as a residue. This sawmill residue matches a total volume of 31,000 cubic meters. (2) Once the relative residues from general logging activities were determined, the relative contribution to the overall wood production by species was assessed. (3) Furthermore the volume of wood was converted into mass expressed in dry tons by using the density (kg/m^3) per species logged in Belize. (4) The National Forestry Report of Belize[10] notes that a sustainable rate of industrial round wood is approximately 10,000 to 12,000 cubic meters per year. Based on these conditions, the amount of residues generated by logging activities is about 92,000 cubic meters. According to these amounts, considered sustainable, the sustainable potential CE yield was calculated.

2.1.3 Potential organic waste from MSW

The total amount of organic waste as feedstock for the cellulosic ethanol system is difficult to measure in the Belizean context. This is because there has been limited monitoring of generated Municipal Solid Waste (MSW) in cities and other urban settings. To estimate the available amount of solid organic waste, an attempt was made to determine the waste quantity and composition. As an ad-hoc solution to the limited information available, the following method was used:

(1) Waste statistics data were collected from reports provided by the National Solid Waste Management Project and the Central Statistical Office of Belize (CSO)[11] for the year 1999. One report highlighted that the average production of waste was around 1.69 kg/person/day. Current research[12] verified this average amount of waste per capita/day. (2) Interviews were held with officials from the Ministry of Natural Resources and Environment that include Waste Management as one of their mandates. According to information provided by the Ministry, it is estimated that Belize in 2006 produced over 200,000 tons of solid waste annually from domestic households and commercial

[8] This was the only available reported data.
[9] Industrial round wood, as defined in FAO Forest Products Yearbook, includes all industrial wood in the rough (saw logs and veneer logs, pulpwood and other industrial round wood).
[10] Latin American Forestry Sector Outlook Study, National Report Belize, Prepared by the Belize Forest Department (2004); http://www.fao.org/docrep/007/j4051b/j4051b00.htm#TopOfPage
[11] National Solid Waste Management Project, 199 and the Central Statistical Office of Belize (CSO) in 2002; source: NATIONAL ASSESSMENT REPORT for Barbados +10, Government of Belize September 2003. visited 09 June 2008
[12] Lewis, G. (2008), Analyzing the potential of utilizing the Methane emissions from the Western Corridor Waste Landfill sites for electrical energy generation; http://www.hydromet.gov.bz/Microsoft%20Word%20-%20LEWIS%20Methane%20Abatement%20PROGRESS-Report%20.pdf

establishments.[13] (3) Since no updated information exists concerning the composition of the waste, the waste composition data dated from 1997 was used. The composition of the solid waste was dominated by paper (20%) and organic waste (60%) thus representing an organic waste fraction of 80%. Those are data consistent with economies with high dependency on the agricultural sector. (4) The agricultural sector is currently the second most import sector in the Belizean economy and the amount of plastic has probably increased in the last decade, due to changes in imported products and in consumption patterns triggered by economic development. A regional study performed in 2003 confirmed that organic waste remains high in the region and accounts for 30 to 60 percent of the MSW in most Caribbean and Latin American countries.[14] In the Belizean context, it was decided to use an organic waste fraction of 80%. (5) Due to feedstock requirements, only the thermo-chemical process is capable of converting organic MSW into cellulosic ethanol. (6) To explore the potential MSW generation in the near future (2010-2015) a linear regression analysis was developed. The data consisted of per capita daily waste generation rate for Belize (1.7 Kg/person/day) and population growth estimates from the Statistical Institute of Belize (the medium variant projection was used).[15]

2.1.4 Feedstock supply and costs

In the Belize context, the classic econometric tools are not useful for estimating the supply cost of residues because currently there is no existing formal market for the residues materials or products and therefore price data is not available. Nevertheless data from the Ministry of Agriculture & Fisheries and FAO 2004 are used as a baseline. In this study, an attempt is made to estimate the cost of potential harvestable residues from the fields and from industrial processing. Of which the costs of the former are influenced by; first, the cost of harvesting residue and second, the transport rate and density of available residues to be delivered to the processing plant. Using the maps developed by the Food and Agriculture Organization of the United Nations (FAO) [16] and a map of the principal roads of Belize, it was possible to estimate the distance between the principal roads and location of permanent crops.[17]

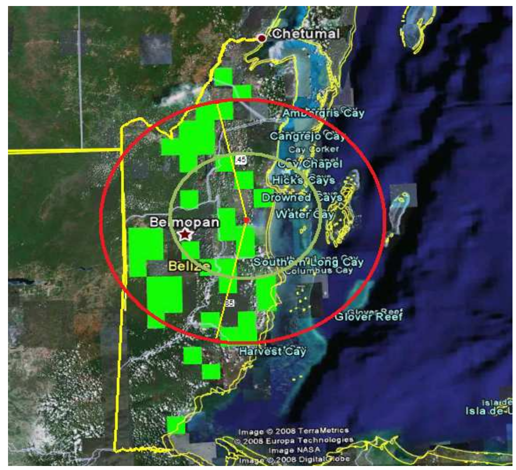

Figure 3 Map of Agro-activities in Belize

In order to assess the potential total cost of residues, the next methodology was used:

(1) Assessing the *Critical Distance* - The transportation costs of the feedstock increases with factory capacity because greater distances are to be traveled to guarantee supplies. Based on this assumption, the relationship between distance from a cellulosic ethanol plant (d) and available residues supplies (S_{ra}) of one crop can be defined by:

$$S_{ra} = (\pi d^2) R_y C_d \quad \text{(Eq. 2)}$$

(Eq. represents the product of the area of a circle of radius d, and the density of residue by the product of $R_y \times C_d$. Residue density is the product of the residue yield (R_y) and the density of planted crops in

[13] Albert Roches, 2007. Solid Waste Management Present State in Belize. http://www.epa.gov/landfill/conf/ca_workshop/SolidWasteBelize.pdf
[14] International Development Research Centre, 2003, Recycling Organic. Wastes. http://www.idrc.ca/uploads/user-S/10530123150E5.pdf
[15] Statistical Institute of Belize (2007), http://www.statisticsbelize.org.bz/dms20uc/dm_browse.asp?pid=6
[16] FAO Country Profiles and Mapping Information System; http://www.fao.org/countryprofiles/maps.asp?iso3=BLZ&lang=en, visited 12 June 2008
[17] This is necessary because it is generally less expensive to produce ethanol close to the feedstock supply.

the total area (C_d). For example, in a region that produces rice, the amount of planted hectares per km^2 is C_d = 130 Ha of crop per km^2. Based in the RPR, it is possible to know the amount of residue per Ha of crop, where in this example it is, R_y = 4 tons of residue per Ha, then the product of R_y and C_d give the density of residue, i.e. $R_y C_d$=520 tons/km^2. The density of residue is calculated only for the feedstock that is generated in the field or is deposed in a land/field.

(2) If $\tilde{S}_a$ is established as the potential capacity of a processing plant, the maximum distance between feedstock and plant required can be obtained by re-arranging (Eq. 3) as follows:

$$d_{\max} = \sqrt{\tilde{S}_{ra}/(\pi R_y C_d)} \qquad \text{(Eq. 3)}$$

The relationship between the cost of feedstock transportation and distance from the processing plant to the feedstock is defined by the radius of the circle; this radius represents the distance between the crop and the plant. Also, the production capacity of the plant depends on the density of residues. For this study, the transport cost estimates are specified using plausible biomass plant capacities ($\tilde{S}_{ra}$=600.000 tons of residue per year (which could be considered a medium size CE plant)) and the density conditions for all available feedstock ($(R_y C_d)_i$, where *i* refers to different types of crop residues in Belize).

(3) Assessing the *Harvesting Cost* - Assuming that the harvesting of the residue is done manually (highly true in Belize's case), the harvesting cost of residues (H_c) is estimated by dividing the daily remuneration rate of labor *(R)* (expressed in US $ per day), by the harvesting capacity (H_{cap}) (in tons per day). In this research, the harvesting cost has been calculated for maize stalks, husk and cob only, because the other residues do not require a separate harvesting. The expression is:

$$H_c = \frac{R}{H_{cap}} \qquad \text{(Eq. 4)}$$

(4) Assessing the *Collection Cost* - The residues are required to be collected from different points on the farm before transportation. The cost of collection is related with the wage rate and time used in the collection. The Collection Cost (C_c) could be calculated by dividing the daily wage cost or remuneration (*R*) by the carrying capacity in tons per trip ($C_{cap.}$) and the numbers of trips made by a person per day (*n*).

$$C_c = \frac{R}{(C_{cap} \times n)} \qquad \text{(Eq. 5)}$$

(5) Assessing the *Transportation Cost* - The main factors influencing the distribution between farm costs and delivered plant costs are the density of residue, the capacity of processing plants, and local truck-hauling rates. It is important to account for local variation of transport costs. The transportation cost (T_c) was estimated, based on the fuel consumption (*Fcons*) of the truck per hour of operation, the cost of fuel (*Cfuel*), the driver's remuneration per hour (R_d), the distance of transportation (d), the

carrying capacity of the tractor (Tr_{cap}) and the transportation speed in km/h (S_t). In this research, the assumptions are made for a standard dump truck.

$$T_c = d_{\max} \frac{(F_{cons} \times C_{fuel} + R_d)}{(Tr_{cap} \times S_t)} \qquad \text{(Eq. 6)}$$

(6) Assessing the Total Cost - The total cost of the agricultural residues ($TT_{\cos t}$) is the sum of the equations described above:

$$TT_{\cos t} = H_c + C_c + T_c \qquad \text{(Eq. 7)}$$

The storage cost could be considered as part of the first capital invested, to prevent cost generated by a rental of a space or cost to cover the feedstock to protect from rain. In this preliminary analysis, the contribution of storage cost to the total cost could be assumed negligible[18].

2.2 Cellulosic Ethanol Yield and Costs

The cellulosic ethanol yield potential and the production costs are determined based on the available feedstock and its sustainable harvesting, taking in mind the "5E' evaluation tool, in Belize. The yield potential is derived from literature and research studies[19, 20]. The CE production cost is determined by a detailed analysis of the cost of feedstock supply under Belizean conditions as critical input next to the theoretical conversion costs found in literature.

2.2.1 Potential Sustainable Cellulosic Ethanol yield

After determining the availability and characteristics of feedstock originating from agricultural and forestry residues and organic waste from MSW, the cellulosic ethanol yield is estimated based on theoretical conversion efficiency range based on literature review. The range of CE yield mainly varies by technology and feedstock. The following steps were taken to determine the potential cellulosic ethanol yield range per sub-technology (thermo-chemical and biochemical).

(1) First the theoretical yield (gallons/dry ton) per feedstock type is collected ranging from forest residues to paper mill sludge. (2) In order to assess the cellulosic ethanol yield potential (in gallons per year) two scenarios are composed describing a conservative, lower-end current and future (2012) scenario, and an optimal current and future (2012) projection in ethanol yield per sub-technology. The results are found in table 1 below.

Table 1 Theoretical ethanol yields for the Conservative and Optimal Scenarios[21]

Conversion Technology	**2008 Technology Ethanol Yield (gal/dry metric ton)**	**2012 Technology a. Theoretical *Conservative* Ethanol Yield Scenario (gal/dry metric ton)**	**2012 Technology b. Theoretical *Optimal* Ethanol Yield Scenario (gal/dry metric ton)**
Biochemical Conversion	70.0	90.0	105.3
Thermo-chemical Conversion	65.0	75.0	100.6

[18] Contreras, R., de Cuba, K. (2009), Feasibility Study on the Cellulosic Ethanol Market Potential in Belize, Organization of American States, Washington, DC. p. 45 - 46.
[19] United States National Renewable Energy Laboratory, see for more information: www.nrel.gov David D. Hsu, July 1, 2008
[20] Oregon Cellulose Ethanol Study: www.oregon.gov/energy/renew/biomass/study.shtml
[21] Ibid. 19 and 19

2.2.2 Potential Sustainable Cellulosic Ethanol Costs

The estimation is made of the production cost per sub-technology based on literature review of CE conversion technologies[22].

3. Results

Results from the resource assessment indicate that more than 1.3 million tons of cellulose feedstock could be produced based on 2004 and 2005 feedstock amounts. If all the available materials are collected, Belize has the potential to produce in the range of 85.6 – 89.6 million gallons of ethanol per year from cellulosic biomass feedstock when considering the application of thermo-chemical and biochemical conversion processes. This potential was scoped down when applying the "5E' method with the objective of achieving sustainable harvesting and collection rates[23].

3.1 Cellulosic Ethanol Production volume

The cellulosic biomass feedstock was assessed for the agricultural, forestry and MSW sectors where agricultural residues were sub-categorized in feedstock originating from the fields and from industrial processing. A total amount of approximately 557,469 – 717,469 MT can be sustainably harvested or collected originating from both the lands and at the processing plants, this can lead to 50.2 – 58.7 Mgal/y (biochemical) and 53.8 – 93.4 Mgal/y[24] (thermo-chemical) in 2012; see Figure 4 for results.

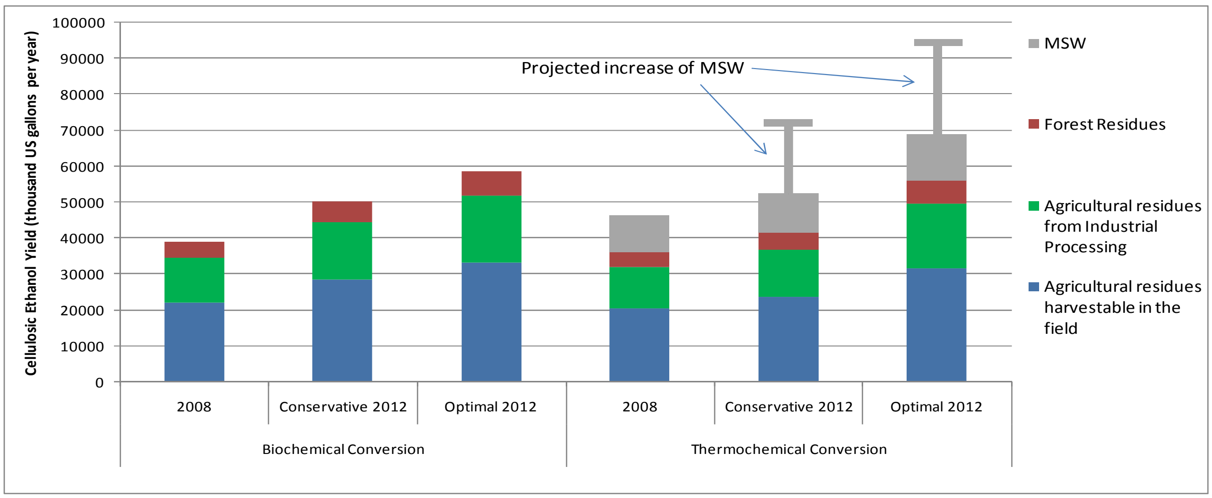

Figure 4 Cellulosic ethanol yields through Biochemical and Thermo-chemical conversions in 2008 and 2012 (conservative and optimal scenarios) by type of feedstock including projected increase of MSW

3.2 Cellulosic Ethanol Production costs

Figure 5 shows the production cost by technology, where CE production cost in Belize will range between US$ 1.64 – 2.89 per gallon. The CE production cost via the thermo-chemical process has a range of US$ 1.64 – 2.17 per gallon under Belizean conditions and is the cheapest among the two conversion processes. Note, that the capital and operational costs are kept static in this study, where only the feedstock cost has been adapted to Belizean conditions. The technology development (learning curve via R&D activities) will determine the rate of increased efficiency, available unit capacity, and potential capital investment cost reductions.

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[22] Contreras, R., de Cuba, K. (2009), Feasibility Study on the Cellulosic Ethanol Market Potential in Belize, Organization of American States, Washington, DC. p. 53.

[23] Ibid.22, p.58

[24] This higher end range is due to use of projected increase of MSW in Belize.

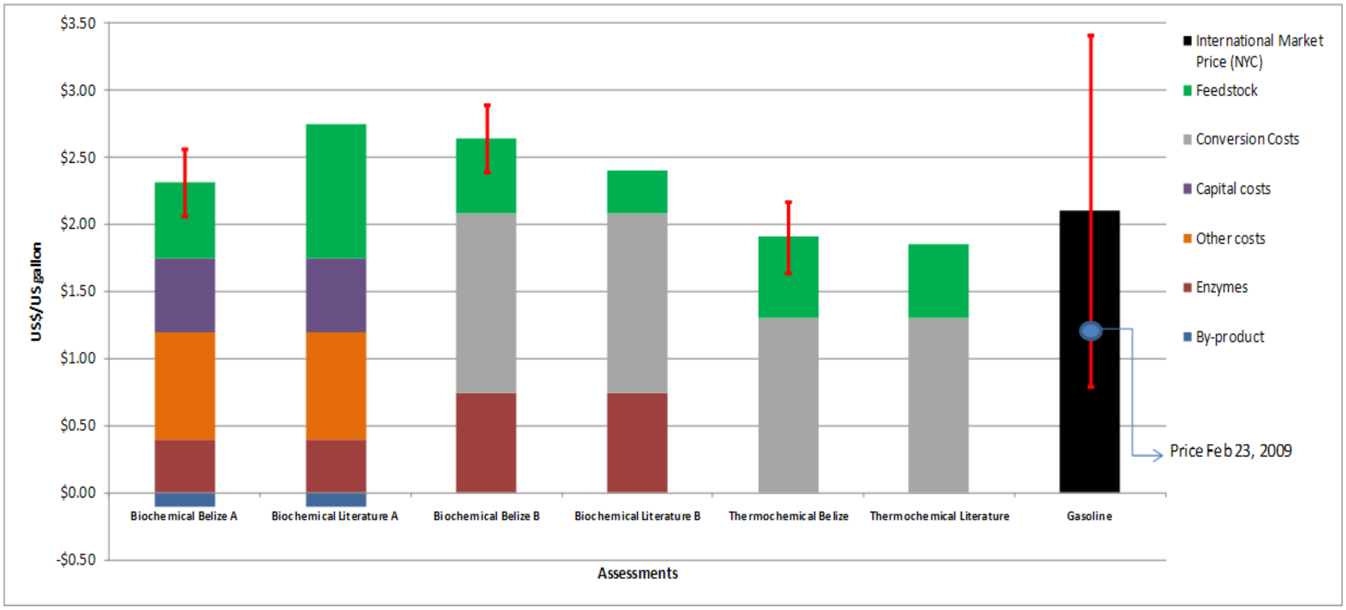

Figure 5 Cost breakdown comparison between Belize (error bars for uncertainty in feedstock costs) and literature reported CE production costs vs. Gasoline NYC international spot prices (average value from 2004-2009; uncertainty range represents the lowest and highest values in the market in the last 5 years)

4. Discussion

Feedstock availability

It is important to distinguish between residues generated in the field and those generated during the processing phase. The reason for this is that it may be assumed that in the latter case, residues are more easily concentrated, which will make it easier for disposal or collection. On the other hand, residues spread over large areas, in such cases as straw, stalks and leaves are concentrated generally in smaller quantities. It must be noted that, agricultural production has been changing with time. This is due to usage of different farming techniques and the lasting impacts of natural disasters. In this research the latest information available corresponds to the agricultural average production data from years 2004 and 2005. This highlights the need for further assessment and data collection.

Cellulosic ethanol production cost projections

These estimates for the CE production costs for 2012 should be considered very preliminary as it is extremely difficult to predict the costs for an emerging technology. These figures are offered to give an idea of the possible range of costs for production assuming that the technology development process occurs as predicted.

Table 3 Cost comparison of Sustainable CE production cost in Belize and current CE production costs according to different assessments (Conservative and Optimal Scenarios)

	CE Biochemical in Belize Scenario (2012)	CE Biochemical in Belize Scenario (2012)	CE Thermo-chemical in Belize Scenario (2012)
Conservative	**US$ 1.014 – 1.40**	**US$ 0.884 – 1.27**	**US$ 1.069 – 1.493**
Optimal	**US$ 1.003 – 1.372**[25]	**US$ 0.873 – 1.242**[26]	**US$ 1.029 – 1.390**[27]

[25] Keith Collins, Chief Economist, USDA, The New World of Biofuels: Implications for Agriculture and Energy, EIA Energy Outlook, Modeling, and Data Conference, March 28, 2007.
[26] Gil Jackson (2007), Office of the Biomass Program. Retrieved September 20, 2008 from; www.sener.gob.mx/webSener/res/345/3.%20DOE%20**Gil**%20**JACKSON**.pdf

According to sources used in this study, the cost for cellulosic ethanol production is expected to fall between 2008 and 2012 by 53% for the biochemical approach and by 35% for the thermo-chemical approach.

5. Conclusions

Thermo-chemical conversion technology has the best potential for cellulosic ethanol production in Belize. This conclusion is based on the type and quantity of feedstock found in Belize and the current cost of this technology, expecting in the near future (2012) further reductions in cost.

In reviewing the likely conversion technologies, the study indicates that biochemical conversion processes that utilize enzymatic hydrolysis of lignocelluloses, followed by fermentation of the simple sugars, would currently have the potential for producing ethanol in Belize at approximately US$1.96 - $2.89 per gallon. In the case of such an approach, the amount of feedstock for a typical plant exceeds the current amount of feedstock available in Belize (over 2000 dry tons/day). Based on this information, a biochemical approach appears most applicable where large volumes of a biomass feedstock of consistent quality are available. Examples include current corn and sugarcane ethanol and where conventional ethanol facilities already exist and using biochemical technologies. However, the assessment indicates that current state-of-the-art thermo-chemical technology will be capable of producing ethanol from the cellulosic biomass of Belize using 1,400-1,700 dry tons (DT) per day of biomass at a production cost of about US$0.34 – 0.87 per gallon and the ethanol cost based on cellulosic feedstock is approximately US$1.64 – $2.17 per gallon in the near term with further cost reductions of US$0.15 – 1.14 per gallon expected as the technology matures by 2012 and beyond. It is estimated that approximately 46 million gallons of ethanol could be produced annually given the state of the technology today. With expected technological improvements, that number may increase to 93 million gallons per year.

Belize currently consumes about 12.5 million gallons of gasoline per year for transportation. Thus, if one assumes that ethanol is blended with gasoline at 10%, approximately 1.2 million gallons would be required per year. Even if flex fuel vehicles replaced the entire vehicle fleet, no more than 12 million gallons of ethanol would be required locally. Therefore, it is clear that Belize has the potential to meet all of its domestic demand for ethanol and export considerably more than this amount, based on its available feedstock for cellulosic ethanol production. The competitiveness of such development will depend on the continued improvements in production technology and the prevailing price of gasoline. Even as today's relatively low cost of gasoline (US$1.80 to 1.95/gallon)[28] and the immature status of the technology (producing ethanol at US$1.64 to 2.17/gallon) cellulosic ethanol offers great promise for production in Belize. At this stage it is recommended to articulate National Energy Priorities via a National Energy Policy and/or Sustainable Energy Plan, create appropriate Energy Sector Governance Mechanisms, establish environmental and sustainability guidelines for biofuels, establish environmental and socio-economic evaluation criteria to guarantee development of a sustainable CE market.

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[27] Thermo-chemical Conversion Roadmap Workshop, January 9 - 10, 2007 Marriott at Metro Center. Retrieved October 13, 2008 from; http://www.thermochem.biomass.govtools.us/documents/TC_R&D_Plan.pdf

[28] 2009 values